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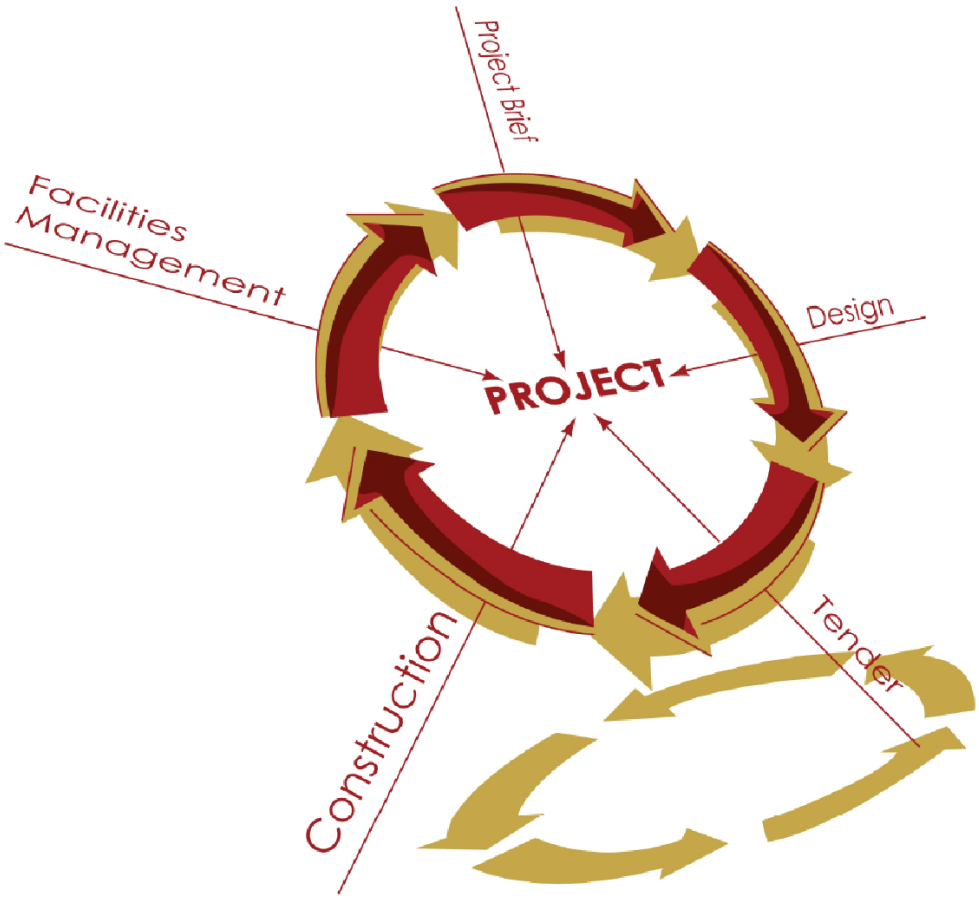
10TH ASIA PACIFIC STRUCTURAL ENGINEERING AND CONSTRUCTION CONFERENCE 2018



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Contents

Introduction

Welcome to the Special Issue of Malaysian Construction Research Journal (MCRJ) in conjunction with the 10th Asia Pacific Structural Engineering and Construction Conference (APSEC) 2018.

This Special Issue of MCRJ for the APSEC 2018 consists of 20 selected papers by conference committees and expert reviewers. The selected theme of APSEC 2018, which is 'Sustaining the World with Better Structures and Construction Practices' is indeed consistent with the national agendas in gearing up the sustainability development towards economy, social and environment for Malaysia. Besides, sustainable in construction, material and structural building are important keys to reduce direct impact on the environment.

Hence, it is believe that this special issue will help and contribute to promote sustainable structures and construction practices in Malaysia. We are well concerned of the importance in incorporating the sustainable elements in the construction practices and keep on the exploration in this direction especially in research and development. This Special Issue volume is one of initiatives that shows we are ready to be the leader in this area. Therefore, we hope that this special issue can promote new knowledge and technology towards a sustainable future.

Editorial Advisory Board

Secretariat Special Issue

Editorial

Welcome from the Editors

Before venturing into this special issue in Malaysian Construction Research Journal (MCRJ) for 10th Asia Pacific Structural Engineering and Construction Conference 2018, we would like to invite you to rethink about sustainable construction and engineering in the world. Is the existing construction industry can be considered as sustainable?

Welcome to this special issue in Malaysian Construction Research Journal (MCRJ) for the 10th Asia Pacific Structural Engineering and Construction Conference (APSEC) 2018. We would like to express our sincere gratitude to our contributing authors, reviewers, organizers and readers.

This special issue in MCRJ for APSEC contains twenty (20) interesting papers covering the theme of "Sustaining the world with better structures and construction practices". It is hoped that the readers would greatly benefit from the scientific content and quality of papers published in this issue:

Brief introduction of each article is given as hereunder:

Harianto Hardjasaputra et al., have presented on the technology of producing high strength geopolymer concrete treated with two curing methods and reported as influence of steam curing time to the concrete strength. The steam curing method is an effective way to produce high strength geopolymer concrete. Through heating with steam for four hours increasing in compressive strength up to 20% is expected, compared to room temperature curing.

Zuraida Zaini Rijal et al., have presented on the ability of steel fibres in resisting the widening cracks and structural ductility. It was demonstrated that 1.25% volume fraction of steel fibre generated optimum performance in terms of maximum bond stress and splitting tensile strength. The significance of optimising steel fibre volume fraction is that it offers optimum performance to ascertain maximum efficiency of steel fibres in the structural system.

Nor Fazlin Zamri at al., have presented on the experimental study considering the effects of hooked-end steel fibre on the flexural properties of the self compacting concrete. The inclusion of steel fibre increased the stiffness of the concrete, where the specimens of steel fibre self compacting concrete can sustain a larger load with small deflection as compared with plain concrete, resulting in the enhancement of ductility behavior of the concrete.

Wan Nur Firdaus Wan Hassan et al., have presented on the fresh and hardened properties of high-performance blended concrete (HPBC) containing 10% of micro palm oil fuel ash with an enhancement of 1–3% of nano palm oil fuel ash. The effect of micro and nano form of agricultural waste investigated for the fresh and hardened properties of HPBC. The utilisation of the micro and nano POFA in the high-performance concrete showed significant improvement in the workability and compressive strength at the early and later ages, as well as a reduction in initial absorption and sorptivity.

Abdul Rahman Mohd. Sam et al., have presented on the effect of industrial ceramic waste powder (CWP) as a cement replacement material in mortar. The characterization of the CWP and tests on fresh and hardened properties of mortar containing CWP were conducted. The experimental results revealed that when compared with control mortar, mortar containing 20% CWP recorded better performance in terms of flowability, compressive strength, density, strength activity index, ultrasonic pulse velocity, and water absorption. The results indicate that the ceramic waste powder can be used as partial cement replacement and improve the properties of mortar.

Mohammad Ismail et al., have presented on the investigation on the effects of polymer vinyl acetate effluents on normal strength concrete. The incorporation of the effluents by weight of cement were 0%, 2.5%, 5%, 10%, 15% and 20%, and tested at 28, 56 and 84 days. The tests performed were compressive strength, leaching test and microstructure characterization of the specimen using FESEM and XRD. The results indicate that incorporation of polymer vinyl acetate waste in the range of 2.5% - 15% gave compressive strength of concrete comparable to that of the control specimen. The FESEM of polymer modified concrete incorporating 5% effluents showed a well-dispersed morphology of the polymer.

Tuti Haryati Jasimin and Rohayah Che Amat have presented on the importance of economic recognition of green commercial office buildings by establishing linkages between IEQ's attributes towards the economic aspect of sustainability from the Malaysian context. The results show that there is a significant relationship between IEQ towards the economic aspect of sustainability. The IEQ through the attributes such as indoor air quality, air change effectiveness, less pollution, thermal comfort, noise level, access to sufficient fresh air and glare reduction contribute to the reduction of risk, greater marketability, faster sales and rents and also resulting to higher net operating income (NOI) and return on investment (ROI).

Noor'Ain Zainal Abidin and Mohamad Syazli Fathi have presented on the empirical study that probes the training concept of using game and virtual reality (VR) technology as a learning approach for construction project managers. A survey is conducted with project management professionals attached to the government sector. This training concept is reviewed by selected experienced Project Managers who are in agreement that the training concept has the potential to increase the knowledge and skills of project managers. To be recommended as a complement to existing project manager classroom training, some aspects of the game need to be improved. The virtual reality input will enhance the visualization of a real project site.

Mohd Ashraf Mohd Fateh and Naziz Nashriq Nijar have presented on the statistical evidence on the issue of the low adoption of IBS in Malaysia. The findings from the analysis provide overall perception from the IBS players and identify mean differences between two or more groups. The outcome will be the basis for drawing the general conclusion about the groups on the issues. The study also revealed a useful statistical evidence related to the contractual aspect in the IBS construction approach to enhance the local standard form of contract to suit the IBS construction approach.

Nur Arzwin Mohamed Aris et al., have presented on the effectiveness of prefabricated components used for better improvement in the future housing project. This paper scrutinizes the perspective on the effectiveness of utilizing the prefabricated components among the owners of housing projects through in depth interviews. The findings show that the use of IBS resulted in faster completion; however, the quality of the workmanship among the contractor-suppliers of the prefabricated components can always be disputed. In rural areas, the logistics cost of using IBS has been found to rise due to the spatial geographical location.

Noor Nabilah Sarbini et al., have presented on the utilization of steel fibre reinforced concrete (SFRC) in concrete topping of composite slab to replace steel fabric (SFA) as a secondary reinforcement. The investigation is carried out for the shear strength of the composite slab component. It was found that steel fibre with smaller aspect ratio in the concrete topping can sustain higher ultimate shear capacity as compared to the larger aspect ratio. To that, this research proved the benefits of SFRC in concrete topping in which it can reduce the problems associated with the use of SFA.

Sunder Narayan and Hai Chen Tan have presented on the concept of forecasting in various industries including construction, new challenges faced in forecasting, and the concept of Big Data. It tries to bridge the gap between the three aspects namely project success criteria, forecasting and tool required for the same. It then delves into Big Data in various industries and its potential to facilitate accurate forecast of the success of construction project, which has hitherto not been sufficiently addressed. The paper concludes by suggesting further research in bridging of the gap in forecasting the project success and its benefits and suggests looking at Big Data as tool.

Lee Huan Boon et al., have presented on the identification of the principles of Integrated Project Delivery (IPD) in Malaysia followed by examining the implementation level of IPD in Malaysian construction industry as well as evaluation of the BIM integration in Integration Project Delivery. Three (3) phases of research methodology had been adopted: initial discussion and literature Review; data collection and analysis and conclusion. Overall IPD improveD the delivery for overall construction projects in Malaysia besides improving the Gross Domestic Product (GDP) of national economic in directly.

Ahmad Farhan Roslan et al., have presented on the assessment on the status of Building Information Modelling (BIM) adoption in Malaysia. The purpose is to ensure that the development of strategy can be used as an overarching framework for the implementation scheme. Survey was conducted in 2016 among construction industry players in Malaysia and generated a sample of 570 responses. The findings revealed that the percentage of BIM adopters (17%) is extremely low due to several challenges that hinder the adoption of BIM in Malaysia.

Saidah An'nisaa Salam et al., have presented on the housing types factor that may influenced reason of housing abandonment in Malaysia, specifically in Peninsular Malaysia. This paper also reviewed other factors such as improper market study, mismanagement, financial problem, land and legal disputes, lack of project risk assessment, inapplicable government policy, incompetent workers, lack of enforcement and inconsistent monitoring by the authorities. Together, the economic analysis was presented to analyse the impact of housing project abandonment to the economy of the country.

Maulana Derry Imansyah et al., have presented on the influence of high-strength reinforcing bars on the behavior of structural elements, and the effect of fibrous concrete to compensate the negative effect of high-strength reinforcing bars. Loading protocol of all test specimens is defined according to ACI 374.2-13. The structural behaviors, such as dissipated energy, bond between reinforcing bars and surrounding concrete, and stiffness degradation of the five specimens were evaluated.

Chin Siew Choo et al., have presented on the application of bamboo fibre vinyl-ester composite plate (BFVCP) for the strengthening of reinforced concrete (RC) beams. The structural behaviour of RC beams was tested to failure using a four-point bending. BFVCP were applied externally in the beam's mid-span of the bottom soffit to study the structural strengthening in flexure. Strengthening of RC beam using BFVCP successfully re-gained about 2% of the original beam structural capacity, when applied to the weakened beam in flexure along the tension zone. Strengthening by BFVCP has diverted the vertical cracks at the mid-span to the edge of the plate. Result from this study shows that BFVCP may be used for weakened beam external strengthening.

Chiew Shing Mei et al., have presented on the investigation of the biaxial tensile behaviour by using different testing techniques under an equal stress ratio. For steel fibre reinforced concrete, hooked-end type steel fibre with fibre volumetric fractions 0%, 0.5%, 1.0% and 1.5% are used. Uniaxial tensile strength of plain concrete is greater than biaxial tensile strength in SFRC. For plain concrete, the opposite result is obtained. The biaxial tensile strength is insignificantly affected by the increment of fibre volumetric fraction but the post-cracking behaviour of concrete is enhanced with the inclusion of steel fibre, which is in agreement with previous findings.

Chin-Boon Ong et al., have presented on the review of experimental studies on different innovative techniques used to confine beam-column joint. Different behaviour and confinement schemes of concrete jacketing, steel jacketing and FRP confined beam-column joint are described. The effectiveness of confinement techniques is based on the behaviour of confined beam-column joint in terms of strength, stiffness, energy dissipation, and ductility as compared to unconfined beam-column joint.

Mohammed Ali Mohammed Al-Bared et al., have presented a review on the types of slopes failure, factors of instability, degradation of engineering structures and degradation of rock to the rock slope stability. It can be observed from the reviewed studies that the main factors influencing the degradation of rock slope include the history of rock, weathering, surrounding environment and the disturbance caused during the construction stage of projects through or besides the slopes. Degradation in the form of drying and wetting also plays an important role in deteriorating the rock masses resulting in various types of failure.

EVALUTION OF HIGH STRENGTH FLY ASH BASED GEOPLYMER CONCRETE TECHNOLOGY WITH STEAM CURING

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Abstract
Concrete is one of the most important material in construction, especially for structure. Until now, concrete still made up of cement as basic component. In the production line, cement consumes a lot of energy that produce high emission of carbon dioxide (CO_2), and this has resulted in increasing the temperature of the earth or Global Warming. Nowadays, geopolymer concrete is being developed to replace cement for making structural concrete. Fly ash is the appropriate materials to develop geopolymer concrete. It will have the positive impact in reducing the cement production and also to create sustainable construction materials, because fly ash is actually hazardous waste of electric steam power, which is produced by coals burning. This research is part of geopolymer concrete mix design with fly ash as the basic component. The fly ash which used in this research is produced from Suralaya Electric Steam Power Plant, Indonesia. This study focuses on developing the technology of producing High Strength Geopolymer Concrete treated with two curing methods and reported as influence of steam curing time to the concrete strength. Geopolymer concrete with room temperature method has been made also as the comparison. As the result, the compressive strength of geopolymer concrete as high as 66.82 MPa can be achieved with steam curing, which is much higher by 8 – 23% than geopolymer concrete with room temperature curing.

Keywords: *High strength geopolymer concrete; Fly ash; Steam curing*

INTRODUCTION

Cement industry is one of the major contributors to the global warning and climate changing. The climate change is caused by the emissions of greenhouses gasses like carbon dioxide to the atmosphere by huge industries, the cement industry is held responsible for carbon dioxide emissions, because the production of cement need huge temperature up to 1500°C. In this case, the geopolymer concrete technology can be as an alternative binder to the cement. It could significantly reduce carbon dioxide emission to the atmosphere because the geopolymer concrete made based on the fly ash.

In fact, coal based Electric Steam Power Plants in Indonesia contribute 55% of the electric power. Meanwhile the ash content of coal used by thermal power plants in Indonesia varies between 25% and 30%. As a consequence, a huge amount of fly ash is generated in thermal power plants, causing several disposal-related problems. Disposal of fly ash has been declared as Hazardous toxic materials, it should be deposit without polluting the environment (Yewale et al., 2016).

In spite of initiatives taken by the government, research and development institutions, the total utilization of fly ash Indonesia is only very limited, about 5% until 10%. Disposal of fly ash is a growing problem as only 7% of fly ash is currently used for high value addition applications like Portland Cement Composite (PCC) and the remainder being used for only land filling. Fly ash has been successfully used as a mineral admixture component of Portland cement composite for nearly 10 years.

Geopolymer concretes are Inorganic polymer composites, which are made based on 100% fly ash without any Portland cement inside. Geopolymer Concrete can be included as prospective concretes with the potential to form a substantial element of an environmentally sustainable construction by replacing the conventional concretes (Davidovits, 2002).

On the other hand, the climate change due to global warming has become a major concern. The cement industry is responsible for their contribution of the CO_2 emissions (Madeleine, 2012). The use of geopolymer concrete as a structural concrete will reduce the use of Portland cement, thereby impacting on the reduction of CO_2 emissions significantly. In addition, the use of fly ash, which is a hazardous waste from Electric Steam Power Plant as concrete material, will have a high economic value.

Same as the Portland Cement based concrete, there are 3 main conditions needed on the results of the manufacture of fly ash based geopolymer concrete for industry, namely strength, work-ability and durability (Shayan, 2016).

This study focuses on developing the technology of producing High Strength Geopolymer Concrete treated with two curing methods, steam curing and room temperature curing.

RESEARCH REVIEW

Geopolymer

For the first time Davidovits (1988) proposed that an alkaline activator could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by product materials such as fly ash. The term of geopolymer is used to represent that the chemical reactions that take place is a polymerization process. The reaction of alkali-aluminosilicate will result strong structural binders, potentially to be used as structural and non-structural concrete. There are two main constituents of geo-polymer concrete, which are the source of fly ash and the alkaline solution (Davidovits, 2002; Davidovits, 1991).

The choice of fly ash must be rich in silica (Si) and alumina (Al). The selection of fly ash depends on factors such as availability, cost, application type, and user demand. Fly ash used in this research comes from one Electric Steam Power in Suralaya, Banten Province.

Alkaline Solution

The alkaline solution is usually based on sodium and potassium. The most commonly used alkaline in geopolymerization is a combination of sodium hydroxide (NaOH) and sodium silica (Na_2SiO_3). The silica (Si) and alumina (Al) elements in the fly ash when mixed with an alkaline solution will produce geopolymer paste as strong binder.

Alkaline solution as activator of the polymerization reaction has important influence either on the fresh concrete or hardened concrete. This alkaline solution can be likened to the role of water in the hydration reaction in Portland Cement based concrete. Some studies have found that the higher molarity of NaOH concentration in Geo-polymer concrete mixtures will produce higher compressive strength of concrete (Topark-Ngam et al., 2015).

In addition to the role of the molarity of NaOH solution concentration on concrete compressive strength, it should be noted the comparison of Sodium Silicate (Na_2SiO_3) with NaOH solution. Increasing the ratio of Sodium Silicate (Na_2SiO_3) and NaOH solution will slow polymerization process and produce less heat (Kumar et al., 2016). In the previous research the author used the ratio of Sodium Silicate (Na_2SiO_3) and NaOH solution as 2 to 1 (Hardjasaputra and Esteriana, 2018), while in this study the ratio of Sodium silicate (Na_2SiO_3) and NaOH solution was 3 to 1.

Fly Ash

Based on the chemical composition, fly ash can be classified as either class C or class F (ASTM C618). According to some research results in geopolymer concrete, there are several factors that may affect the fresh and hardened geopolymer concrete.

High calcium fly ash (HCFA) may produce fresh geopolymer concrete with faster setting time due to the presence of calcium and presence of calcium and the formation of calcium silicate hydrate (Hanjitsuwan et al., 2014). But according to the previous researches, the hardened high calcium fly ash based geopolymer concrete will have good strength and durability (Topark-Ngam et al., 2015). In this research, source of fly ash comes from electric steam power plant Suralaya in Banten Province, Indonesia. Approximately 2 million tons of fly ash per year is generated from this plant. The results of the XRF shows that the content of calcium (CaO) of fly ash is relatively high around 12.20 % (see Table 1).

Curing Method

Like in normal concrete, the room temperature will affect the hydration reaction process of cement and water. Likewise, at room temperature reaction fly ash with alkaline activator will run slowly. This polymerization reaction can be accelerated by increasing the temperature. Steam curing is one of the most feasible and practicable curing methods. Research Yewale et al. (2016) found that the strength of geopolymer concrete would be optimal at 80°C temperature. Similar was observed by Rangan (2008) that geopolymer concrete strength will increase with curing temperature increment. The concrete strength would be optimal if they are heated in the oven at 90°C.

The purpose of this research is to produce geopolymer concrete with compressive strength above 50 MPa, so that geopolymer concrete can be categorized as high strength structural concrete. To achieve this goal the authors choose steam curing method, by heating the concrete cylinders in the steam derived from boiled water for several hours.

EXPERIMENTAL PROCEDURE

Material Preparation

Aggregate

The available crushed lime stone with maximum size 10 mm and specific gravity 2.57 in saturated surface dry (SSD) was used as coarse aggregate. For fine aggregate, sand from Bangka Island with maximum size 600 μm (sieve no. 30), and specific gravity 2.55 also in saturated surface dry (see Figure 1).

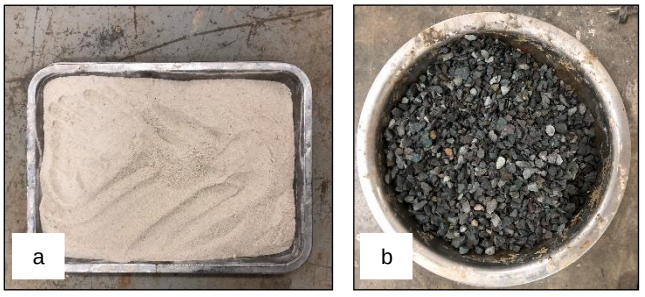


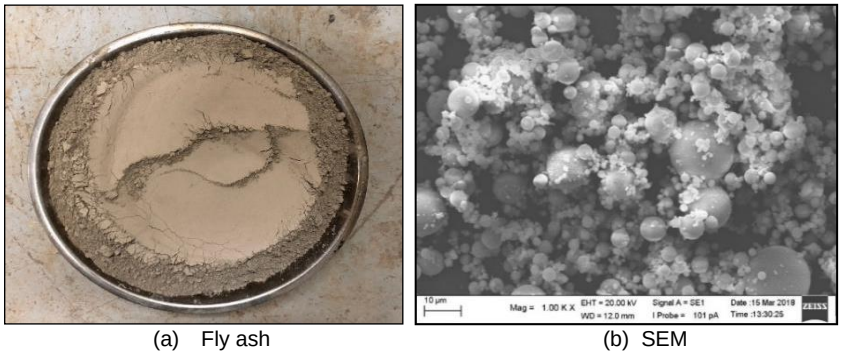
Figure 1. a) Fine Aggregate b) Coarse Aggregate with max size 10 mm

Table 1. Result of Suralaya Fly ash XRF Analysis

Composition	Percentage	Composition	Percentage
SiO_2	38.79	ZrO_2	0.13
Fe_2O_3	21.84	Nd_2O_3	0.10
Al_2O_3	18.51	ZnO	0.07
CaO	12.23	BaO	0.05
SO_3	2.41	SnO_2	0.03
TiO_2	1.76	NiO	0.02
K_2O	1.66	Y_2O_3	0.02
P_2O_5	0.93	Rb_2O	0.02
Cl	0.67	CuO	0.02
MnO	0.35	Ga_2O_3	0.01
SrO	0.31	PbO	0.01

Fly Ash

Fly ash used in this research was actually as industrial waste from Electric Steam Power Plant in Suralaya, Banten province. Until now they are forced to treat the fly ash as hazardous waste. The result of SEM shows that the fly ash particle is spherical in size smaller than 30 μm, as seen in the Figure 2. The X-Ray Fluorescence (XRF) results showed the chemical composition of fly ash which is rich in SiO_2 (38.79%) and Al_2O_3 (18.53%) and can be included as F classification (ASTM C 618-03). While calcium content (CaO) of the fly ash is relatively high enough that is 12.23%.



(a) Fly ash (b) SEM

Figure 2. Fly ash and its SEM image

Alkaline Solution

Alkali solution serves as activator for polymerization reaction between fly ash and alkaline solution to form geopolymer paste binder. The alkali solution used in this study was

the mixture sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution. For making NaOH solution, NaOH chips with 98% NaOH content were dissolved in clean water according to the desired molarity concentration. This study used 3 different concentrations of NaOH solution i.e. 8M, 12M and 16M. NaOH solution was then left 24 hours before use. The mixture NaOH solution and sodium silicate gel were made few hours before materials mixing.

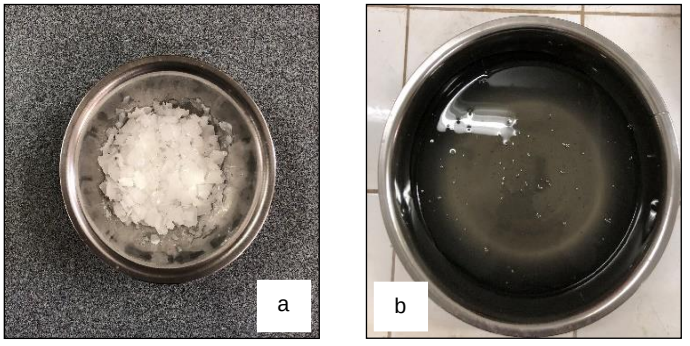


Figure 3. a) NaOH chips b) Na_2SiO_3 gel

Mix Proportions

Refer to the mix design standard of Portland Cement based concrete, the materials of geopolymer concrete consisted of coarse and fine aggregates, alkaline solution and fly ash. It can be determined that the coarse and fine aggregate was taken 73% of total weight. The ratio of coarse aggregate to fine aggregate was 65 % to 35 %.

For the alkaline activator it was determined that the weight ratio of Na_2SiO_3 and NaOH was as 3:1. The concentration of NaOH solution was varied 8M, 12M and 16M. In this research the ratio of fly ash to alkaline solution was 2 to 1. The material proportion can be seen in Table 2.

Table 2. Mix proportion of fly Ash based Geopolymer Concrete

Mix Design for 1 m3 concrete					
			Amount (kg/m3)		
No.	**Material**		**CG1-8M 8 Mol**	**CG2-12M 12 Mol**	**CG3-16M 16 Mol**
1	Coarse Aggregate		1128,7	1131,88	1134,76
2	Fine Aggregate		608,32	610,03	611,58
3	Fly Ash		428,31	429,51	430,61
4	Na_2SiO_3		160,61	161,07	161,48
5	NaOH solution	NaOH	13,65	19,01	23,84
		Water	39,89	34,68	29,98

Test Specimens

All of test specimens consist of two types, cylinder specimen with 100 mm diameter and 200 mm high, for compressive strength test and small beam with 300 mm length and 60 × 60 mm^2 cross section, for flexural tension test. The test plans and the number of specimens, which has been made, can be seen in Table 3.

Table 3. Test specimen's number

Mix Design	Curing Method	Number of Specimen			
		Compressive Strength		Flexural Strength	
		7 Days	28 Days	7 Days	28 Days
GC 1 - 8 M	Room Temperature Curing (RTC)	2	2	2	2
GC 2 - 12 M		2	2	2	2
GC 3 - 16 M		2	2	2	2
GC 1 - 8 M	Steam Curing (SC)	2	2	2	2
GC 2 - 12 M		2	2	2	2
GC 3 - 16 M		2	2	2	2
Total		**24**		**24**	

Mixing Procedures

The procedure of making fly ash geopolymer concrete is actually taken from the standard production of Portland Cement based concrete. Here are some highlights to be considere in making fly ash based geopolymer concrete:

- Coarse and fine aggregates were prepared under SSD conditions.
- NaOH solution was made by dissolving NaOH chips in clean water according to desired concentration (see Table 4), minimum 24 hours before mixing work.
- Furthermore, NaOH solution and Na_2SiO_3 gel were mixed in accordance with the proportions specified. In this study, the ratio of NaOH solution and Na_2SiO_3 gel was 1 to 3.
- First Fly ash and alkaline solution would be well stirred to 5 minutes in the mixer. After the fly ash and the alkaline solution were well blended, fine and coarse aggregate could be poured into the mixer and mixed for 7-10 minutes.
- After mixing for 15 minutes, fresh geopolymer concrete was ready to be tested slump and casted into the specimen mould.

Table 4. Concentration of NaOH Solution [11]

Molarity, M mole/l	For preparation of 1 kg of SHS		
	NaOH chips (g)	Water (g)	NaOH solution (g)
8	255	745	1000
12	354	646	1000
16	443	557	1000

Curing Methods

In this research two curing methods were applied. 24 specimens were treated with room temperature curing and the others 24 specimens were treated with steam curing. Curing method was done by putting the one day old concrete specimens into the steamed pan that has been filled with water up to 1/3 of the volume of the pan which then heated for 4 hours continuously at atmospheric pressure. The steam temperature could be kept constant at 85^{o}C-87^{o}C (see Figure 4).

Figure 4. Pan for steam curing

Compressive Strength and Flexural Tensile Strength

In this research, there were 2 types of testing. 24 concrete cylinders were tested for compressive strength at 7 days and 28 days age with 2500 kN concrete compression machine. The other 24 small concrete beams were tested flexural tensile strength at 7 days and 28 days age with Universal Testing Machine with 50 kN capacity. The reported test results were the average value of two specimens.

RESULT AND DISCUSSIONS

Compressive Strength

Table 5 show compression test results of 24 cylinders concrete from GC1-8M, GC2-12M and GC3-16 M mix designs, which have ratio Sodium hydroxide to Sodium Silicate 1 to 3. All the specimens, which have 8M, 12M and 16M NaOH concentrations and 28 days age have compressive strength greater than 50 MPa. It showed that NaOH concentration has an important role in influencing the concrete strength. Figure 5 and 6 shows the rate of concrete compressive strength to the increasing of NaOH concentration from 8M up to 16 M, either at room temperature or steam curing. The GC3-16 M concrete with the highest NaOH concentration achieved the highest compressive strength, which was 66.82 MPa. The results of this compression test show that High Strength Fly Ash based geopolymer Concrete can be achieved with mix design GC1-8M, which had the lowest NaOH concentration or 8M.

Steam Curing

The influence of steam curing on the strength of geopolymer concrete at 28 days age can be seen in the Figure 5. The increased strength of CG-8M geopolymer concrete at high temperatures were much larger than CG-16 M geopolymer, which is 12 MPa for CG-8M and 5 MPa for CG-16M.

Table 5. Results of compressive strength test (average values)

No.	Specimen	Curing Method	Test Date	Compressive Strength (MPa)
NaOH Concentration 8 Mol				
1	GC1-8M	RTC	7	36.27
2			28	51.23
3	GC1-8M	SC	7	41.68
4			28	63.00
NaOH Concentration 12 Mol				
1	GC2-12M	RTC	7	37.55
2			28	55.05
3	GC2-12M	SC	7	56.00
4			28	64.91
NaOH Concentration 16 Mol				
1	GC3-16M	RTC	7	43.59
2			28	61.73
3	GC3-16M	SC	7	61.41
4			28	66.82

Steam curing of geopolymer concrete at atmospheric pressures has the advantage of accelerating the polymerization reactions of fly ash and alkaline solution. Consequently, the material develops compressive strength and reduces its permeability in a shorter time compared with standard curing under room temperature condition. It means steam curing can accelerate the strength gain of geopolymer concrete at early ages, as can be seen in the Figure 6. At seven days age the strength of accelerated geopolymer concrete can gain almost 85% of 28 days age strength.

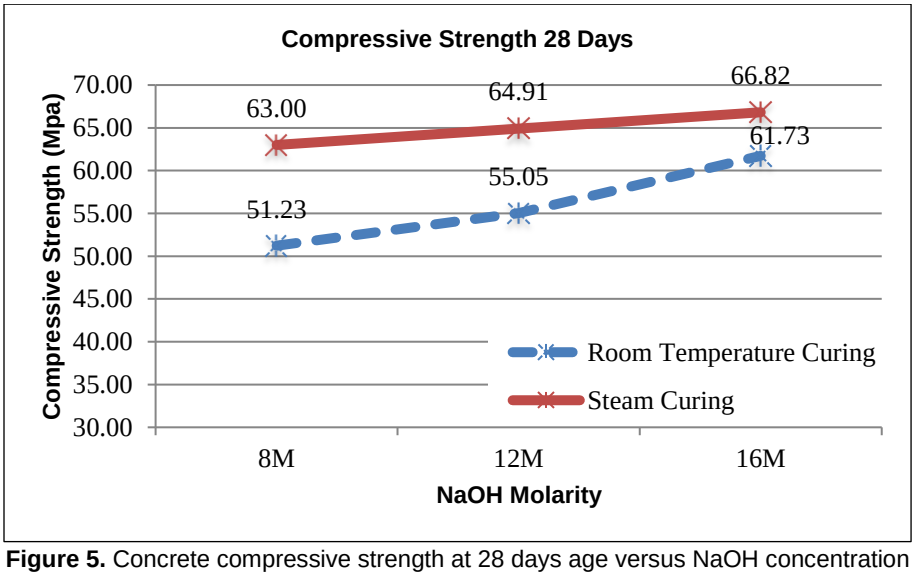


Figure 5. Concrete compressive strength at 28 days age versus NaOH concentration

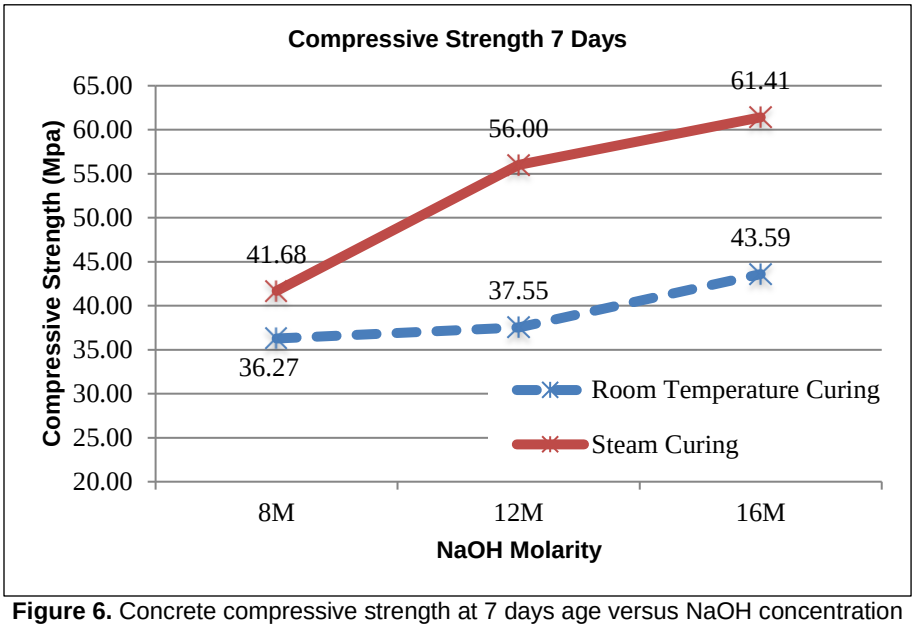


Figure 6. Concrete compressive strength at 7 days age versus NaOH concentration

Flexural Tensile Strength

The flexural tensile strength test results are presented in the Figure 7. The flexural tensile strength of CG1 = 8M, CG2-12M and CG3-16M at 28 days with steam curing were 9.76 MPa, 10.87 MPa and 10.35 MPa. The percentage of flexural tensile strength to compressive strength reached an average of 18%. This value indicates that the tensile strength of the geopolymer concrete is greater than the Portland cement concrete.

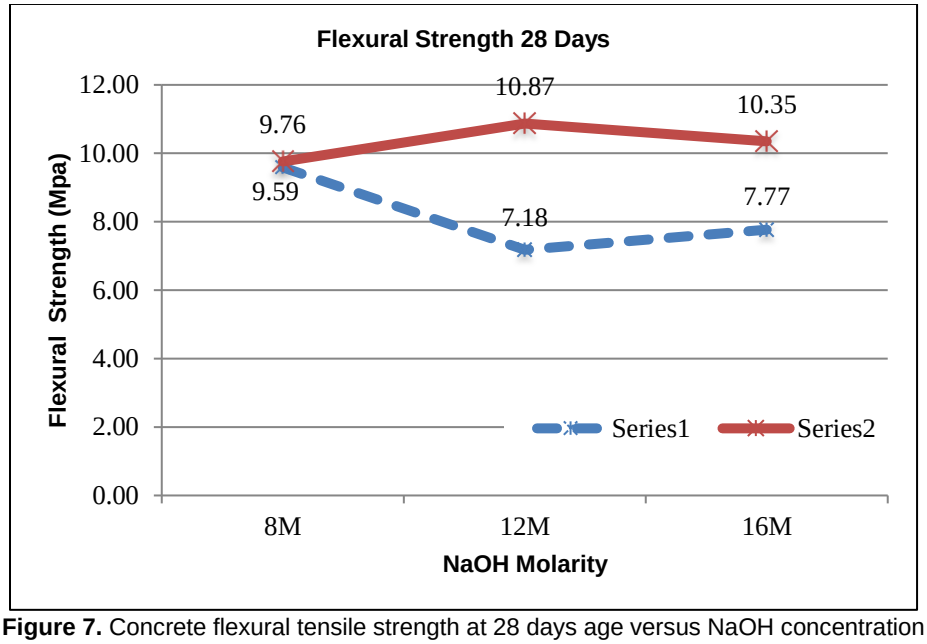


Figure 7. Concrete flexural tensile strength at 28 days age versus NaOH concentration

Slump

The result of fresh concrete slump test with different mix design is presented in Table 6. The values of slump tests were between 50 mm and 27 mm. The fresh concrete was quiet stiff, but it was still workable to be casted. This indicates that the workability of the geopolymer concrete was low. The slump value decreased with the increase of the NaOH solution concentration.

Table 6. Slump test result

No.	Mix Design	Slump Test (mm)
1	CG1-8 M	50
2	CG2-12 M	42
3	CG3-16 M	27

Figure 8. Slump test

SEM of Concrete

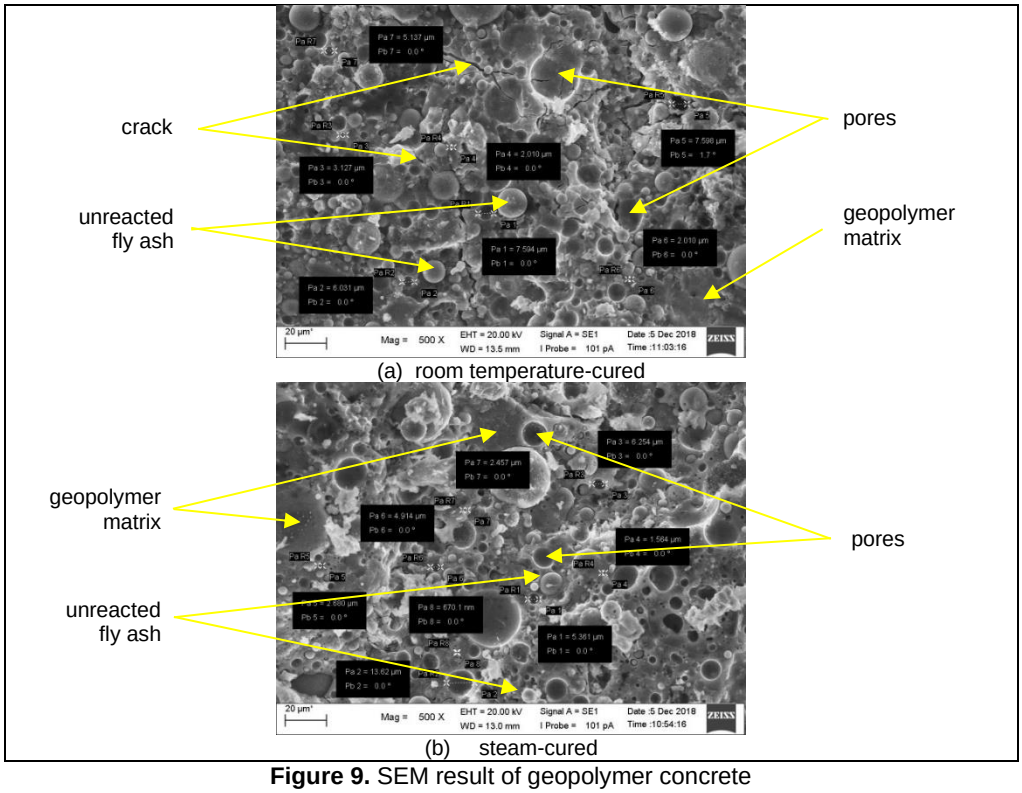


Figure 9. SEM result of geopolymer concrete

SEM results for geopolymer concrete cured at room and steam can be seen in Figure 9. Geopolymer concrete with room temperature (Figure 9(a)) have macro or micro cracks with size 1-5 μm, and there are unreacted fly ash particles with alkaline solution and have pore in the geopolymer matrix. In Figure 9(b) the results of SEM testing for geopolymer concrete with steam-cured denser compared with room temperature, which smaller pore sizes and less fly ash that does not react with alkaline solutions.

CONCLUSIONS

Based on the test results in this research, the following conclusions can be written.

- All type of mix designs in this study could produce high compressive strength of geopolymer concrete, which is greater than 50 MPa at 28 days age, cured in room temperature. The compressive strength of the geopolymer concrete increased by 20% when steam curing was applied for 4 hours.
- The compressive strength of the concrete increased with the increase of NaOH concentration. At high NaOH concentration the geopolymerization process was enhanced to bind alumina and silica from fly ash. For making of high strength geopolymer concrete with the strength above 50 MPa can be used enough with 8M NaOH concentration.
- To be noted that increasing the concentration of NaOH will decrease the value of fresh concrete slump, which means lower workability, for the higher the NaOH concentration means the water volume decreases.
- The steam curing method is an effective way to produce high strength geopolymer concrete. Through heating with steam for 4 hours can be achieved increasing in compressive strength up to 20%, compared to room temperature curing.
- The flexural tensile test results showed that the geopolymer concrete had a relatively higher tensile strength compared to normal concrete. From this study, the flexural tensile strength of geopolymer concrete reached 20% of its compressive strength value.

ACKNOWLEDGEMENT

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OPTIMISATION OF STEEL FIBRE VOLUME FRACTION IN STEEL FIBRE REINFORCED CONCRETE

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Abstract
The ability of steel fibres in resisting the widening cracks and in enhancing the structural ductility with increased toughness is indeed well renowned. Nevertheless, the addition of certain percentage of fibre to concrete leads to low workability in the concrete mix primarily due to balling-up or clumping issues. As such, this paper presents the optimum steel fibre volume fraction in steel fibre reinforced concrete (SFRC) mixes in fresh state. The mechanical behaviour of the hardened state was also assessed. The optimisation weighed in bond strength between deformed steel bar and concrete to comprehend the related mechanism. Workability, splitting tensile, and pullout tests were conducted by using concrete grade 40 with a range of steel fibre volume fractions (0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, 1.5%, and 1.75%). The cylinder specimens with a fixed length of embedded deformed steel bar were prepared for pullout test, which was performed under monotonic loading. The test outcomes showed that the fibre addition enhanced the ascending branch of bond stress and tensile strength, while decreasing the aspect of workability. This determined the correlation between the retrieved study outcomes. It was demonstrated that 1.25% volume fraction of steel fibre generated optimum performance in terms of maximum bond stress and splitting tensile strength. The significance of optimising steel fibre volume fraction is that it offers optimum performance to ascertain maximum efficiency of steel fibres in the structural system.

Keywords: *Workability; Tensile strength; Bond strength; Optimum volume fraction*

INTRODUCTION

In these recent years, fibre reinforced concrete (FRC) has been studied in terms of its ability to enhance the failure mode of concrete and to increase its resistance towards loading. In fact, FRC has been widely applied due to its improved mechanical properties for fracture toughness, ductility, and crack-width control (Bakhshi, Barsby, & Mobasher, 2014). Prior studies have reported that mixing plain concrete with FRC enhances the bond between concrete and reinforced bars (Dancygier & Berkover, 2012; Hameed et al., 2013).

Previous studies concerning steel fibre that emphasised on the bond between concrete and reinforced steel bars in normal- and high-strength concretes displayed that ductility can be described based on the post-peak behaviour of a load-slip relationship (Ezeldin; & Balaguru, 1989). The stability of post-peak behaviour and the area under load-slip curve have functioned as measurements to assess ductility. It was identified that ductility increased with inclusion of steel fibres, while the slip value of maximum pullout load was reliably augmented with increasing fibre content (FC) (Rostasy & Hartwich, 1988; Taengua, 2013).

Fibres have been applied to improve the characteristics of concrete in relation to tensile behaviour, particularly to prevent crack development and to enhance mechanical performance. Some of the most integral enhancements consist of toughness, energy absorption capacity, fatigue resistance, tensile strength, and ductility (Bakhshi et al., 2014; Taengua, 2013; Zaini-Rijal & Rahman, 2017).

Most building codes agree that the positive impact of fibres does improve the anchorage bond performance since fibres take the role of confining reinforcement (Taengua, 2013). The effect of concrete confinement with steel fibres inhibits splitting failures so that the dominant mode of failure is reflected in shear pullout failure (Yeih, Huang, Chang, & Yang, 1997). Figure 1 illustrates that fibre confinement enhances the bond behaviour of deformed bars by delaying both splitting cracks and crushing of concrete between ribs (Hameed et al., 2013).

Since the application of FRC has found its way in the construction industry, it must be able to compete economically with the existing reinforcing systems. The FRC, which possesses composite properties, serves as reinforcement, promotes crack resistance, and increases toughness, relies on the mechanical properties of fibre, the bonding properties of fibre and concrete matrix, as well as the quantity and the distribution of fibres (Goud.E & Praveen, 2015).

Therefore, this paper discusses the optimisation of steel fibre volume fraction in steel fibre reinforced concrete (SFRC) for structural implementation. The parameters embedded were workability of fresh concrete, splitting tensile strength, and bond strength of hardened concrete between deformed steel bar and concrete. Concrete grade 40 served dual functions in this study; as control specimen and was mixed with steel fibre to produce SFRC. The significance of this study is to offer optimum performance in ascertaining maximum efficiency of the steel fibres within the structural system. Additionally, specimen failure modes were evaluated in this study.

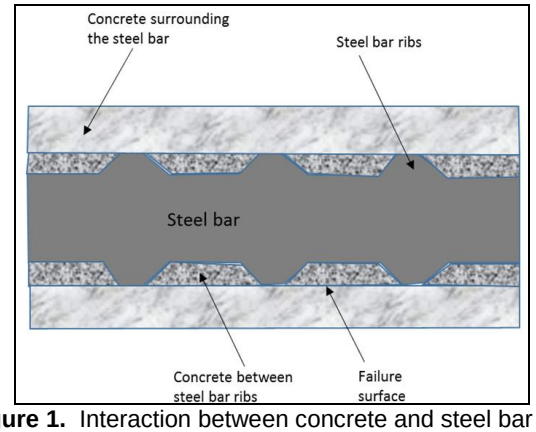

Figure 1. Interaction between concrete and steel bar ribs (Source: Hameed et al., 2013).

METHODOLOGY

Materials

Concrete

Table 1 lists the proportion of concrete mix applied in this study. The water/cement (w/c) ratio for this mix was 0.48. The target strength of normal concrete (NC) mix, which was used as control specimen, had been designed for 40 MPa at day 28. On the other hand, SFRC was made from the same concrete mix with incorporation of steel fibre. Both concrete types were mixed with aggregates and cement inside a concrete mixer. The mixing was performed by

adding water and super plasticiser until the solution was mixed well. The workability of SFRC mix declined with the augmenting FC. The compacting activities of concrete for all samples were performed by using a vibration table.

Table 1. Concrete mix proportion for 1 m^3 volume.

Components	Contents (kg/m^3)
Cement	485.0
Fine Aggregate	810.0
Coarse Aggregate	810.0
Water	235.0
Super Plasticizer	1.2

Steel Fibre

Figure 2 displays the steel fibre used in the SFRC mix, which had a hooked-end shape steel fibre of 0.55 mm diameter and 35 mm long with an aspect ratio of 64. The fibre manufacturer specified the minimum tensile strength value of 1100 MPa for the 35 mm-long fibres, hence adhering to A820/A820M-11 (2011). Table 2 summarises the properties of the fibre. The specimens for SFRC applied the following steel FCs: 0.25%, 0.50%, 0.75%, 1.00%, 1.25%, 1.50%, and 1.75% of the total concrete weight. The SFRC mixes were noted as CF 0.25, CF 0.50, CF 0.75, CF 1.00, CF 1.25, CF 1.50, and CF 1.75, based on the volume fraction in the mix. Concrete without FC served as the control specimen for comparison purpose.

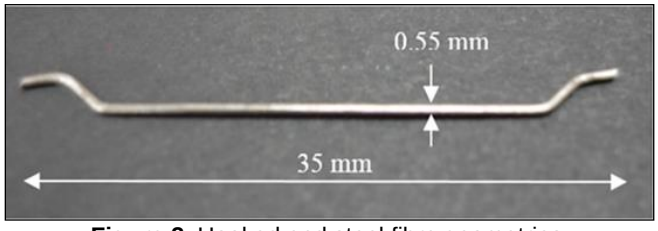

Figure 2. Hooked end steel fibre geometries.

Table 2. Properties of hooked end steel fibre

Diameter (mm)	0.55
Length (mm)	35
Density (kg/m^3)	7850
Tensile Strength (MPa)	1200
Elastic Modulus (GPa)	205

Deformed Steel Bar

Deformed steel bars of 16 and 20 mm diameters with nominal yield stress, fy, of 640 MPa had been employed in this study based on tensile strength test outcomes on T16 and T20 bar samples in accordance to procedures outlined in the specification of BS EN ISO 6892-1 (2009). Table 3 and Figure 3 portray the measured dimensions of the deformed steel bars and their geometries, respectively.

Table 3. Dimension of deformed steel bar.

Nominal Diameter (mm)	Dimension (mm)					
	d1	d2	t	s_r	t_r	r_h
16	15.6	17.3	3.7	9.6	4.6	1.7
20	19.6	21.3	5.2	11.7	4.6	1.7

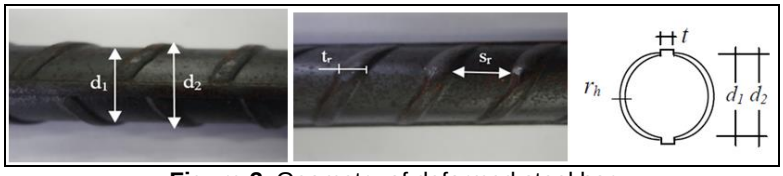

Figure 3. Geometry of deformed steel bar

Physical and Mechanical Tests

Workability Test

Slump test was carried out to measure the workability of concrete at fresh condition by adhering to BS EN 12350-2 (2009). The decrease in slump height was measured by the difference between the total height of the test cone and the slumped concrete, as illustrated in Figure 4. The slump of the concrete was designed between 60 and 180 mm.

Figure 4. Slump test

Splitting Tensile Test

Indirect tensile strength test was performed to assess the tensile splitting strength. Three cylinders with a diameter of 100 mm and height of 200 mm were prepared and casted for each concrete mix. Specimen preparation and testing procedure was in accordance to BS EN 12390-6 (2009). A universal testing machine with a capacity of 3000 kN had been used for this test (see Figure 5), while the loading rate was fixed at 0.04 ± 0.02 N/mm2s.

Figure 5. Splitting tensile test

Pullout Test

All concrete mixtures were evaluated to determine the effect of concrete strength on the performance of reinforced steel bar bond. Comparative judgement of bond capacity of the reinforced steel bars was embedded in all test series. The bond test program incorporated a direct tension pullout (DTP) test by using a universal testing machine with a capacity of 3000 kN. A modified version of the pullout test was selected as the most appropriate test for the study purpose. Figure 6 displays the pullout test applied in this study in accordance to ASTM C-234 specification. In the attempt to match with the samples geometry, the experiments were set up without a bond breaker (Yeih et al., 1997). As depicted in the test procedures, three samples were prepared for a given embedded length. The cross section of the specimen was set up to resist concrete tensile failure, along with the length of the embedded bar, mainly to prevent bond failure in the reinforced bar.

The proposed pullout specimen was composed of a concrete cylinder with 100 mm diameter and 150 mm height, along with fixed embedded concentric test bar of 65 mm length. Tests that applied standard five-diameter (5 D_b) with embedded length caused the steel bar to yield before it was pulled out (Dancygier, Katz, & Wexler, 2010). In the tests, 16 and 20 mm bars were used with an embedded length of 4.1 diameter (4.1 D_b) and 3.3 diameter (3.3 D_b), respectively, in order to ensure pullout prior to yielding of the bar. The pullout test was performed 28 days after casting. The slip of the bar, at its free end, was recorded using linear variable differential transducers (LVDT) on one side of the specimen (measure slip between reinforced steel bar and concrete). The load was applied at a rate of 0.2 kN/s. The data acquisition system was recorded at every 2.0 kN loading. The collected data were applied to generate the bond to slip curve relationship.

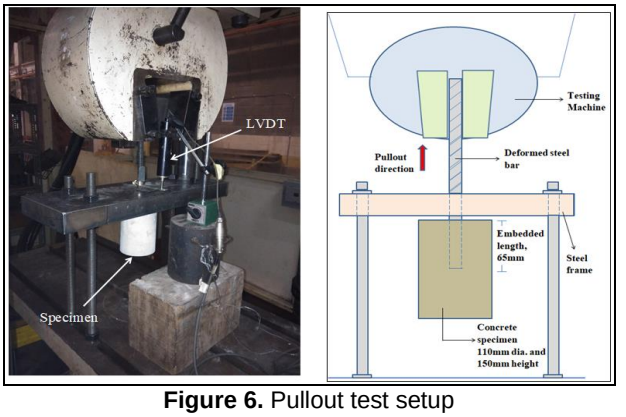

Figure 6. Pullout test setup

RESULTS AND DISCUSSION

Workability

At the fresh state condition, slump test was performed to determine workability properties. The composition of materials was similar for all mixes. Figure 7 illustrates that the higher the volume of steel fibres, the lower was the slump value. The noted decline in slump value clearly signifies that the addition of steel fibre lowered the workability of the concrete (Bentur & Mindess, 2007).

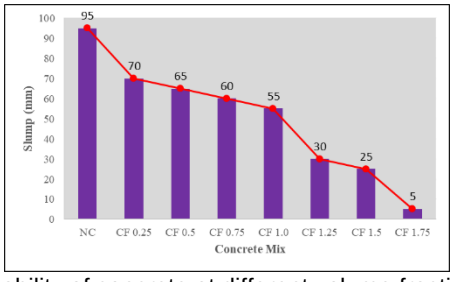

Figure 7. Workability of concrete at different volume fraction of steel fibre

Splitting tensile strength

Figure 8 portrays the outcomes retrieved from splitting tensile test, which displayed a marginal increase in tensile strength with steel fibres incorporated. The splitting tensile test was applied to determine the characteristics of tensile parameters in SFRC (Rao & Rao, 2009). Upon increment in fibre volume fraction, splitting tensile seemed to increase as well, thus indicating the effectiveness of the fibres in resisting tensile cracks. Based on Figure 8, tensile splitting strength appeared to be slightly higher for cylinder CF 1.25 (1.25% fibre content) than the rest of the cylinders. In fact, higher fibre volume fraction, such as 1.50% and 1.75%, displayed slight decrease in the value of splitting tensile strength. Increment of splitting tensile values clearly showed the positive impact of steel fibres on the tensile strength of the concrete as the fibres delayed the opening of cracks (Vairagade & Kene, 2012).

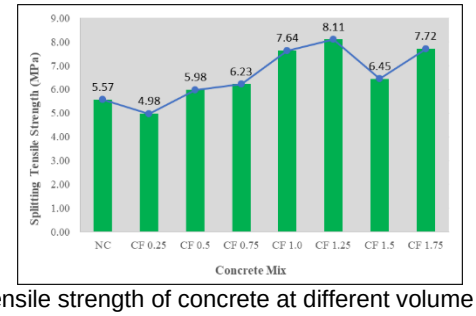

Figure 8. Splitting tensile strength of concrete at different volume fraction of steel fibre

Bond strength between deformed steel bars and surrounding concrete

The pullout tests showed that the mechanical interlocking between deformed steel bar and surrounding concrete induced bearing forces, which further led to inclined cracks within the concrete matrix. Figure 9 illustrates the failure mode of specimens during pullout test. The radial component of the bearing forces initiated tensile stresses, which led to bond failure and formation of splitting cracks (see Figure 9[a]). Typically, concrete crushing at the toe of the bar degrades bond strength and stiffness.

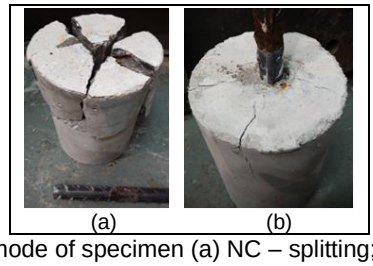

Figure 9. Failure mode of specimen (a) NC – splitting; (b) SFRC - pullout

As for SFRC, crack opening and propagation were minimised due to the impact of fibre bridging, hence enhancing bond strength. The presence of fibres in the matrix redistributed the radial compression applied to the concrete after initial cracking and augmented the bar pullout load (see Figure 9[b]). During further slippage, maximum bond strength was achieved in relation to the development of longitudinal cracks along the bar axis. In SFRC, the fibres obstructed the longitudinal cracks, as well as further propagation, which widened the internal inclined bond cracks.

Similar attribute is reported in prior studies, in which the effect of steel fibres on bond strength appeared to be more significant for bars with smaller diameter, in comparison to those with larger diameter (Ganesan, Indira, & Sabeena, 2014; García-taengua, Martí-vargas, & Serna, 2014). Incorporation of fibres is beneficial for bars with smaller diameter to increase the aspect of bond stress. This is due to the influence of steel fibres in controlling the development and spread of cracks. Nonetheless, at higher percentages of FC, the bond stress reduces, mainly due to the balling effect generated by the fibres. The effect of bar lugs is more effective for bars with smaller diameter (Ganesan et al., 2014).

Table 4 shows the values of bond stress and slip for all specimens, which were the maximum load and ultimate bond stress to pull the embedded deformed steel bars out from the concrete. Comparing the bond stress values, CF 1.5 gained higher value than those of other concrete mixes. It shows that the existence of fibres in concrete fibre positively developed the bond stress of 16 mm bars slightly by up to 209% compared to that of NC. Meanwhile, for 20 mm bars, the maximum bond stress value for CF 1.5 was about 179% increment compared to that of NC. Similarly, other researchers reported that steel fibres present a substantial contribution to the bond strength for specimens with smaller diameter bars compared to specimens with larger diameter bars (Dancygier et al., 2010; Taengua, 2013). In certain circumstances, higher percentage of FC minimised bond stress due to the balling effect of fibres.

Table 4. Percentage of bond strength increment of SFRC at different volume fraction of steel fibre

Specimen	16 mm diameter			20 mm diameter		
	Bond Strength (MPa)	Bond Increment (%)	Slip (mm)	Bond Strength (MPa)	Bond Increment (%)	Slip (mm)
NC	7.04	0	0.59	5.88	0	0.65
CF 0.25	7.96	13	1.18	6.37	8	1.7
CF 0.5	8.26	17	1.52	8.32	42	1.98
CF 0.75	13.16	87	3.55	8.81	50	4.9
CF 1.0	13.77	96	8.17	12.24	108	4.59
CF 1.25	14.69	109	4.17	12.24	108	6.58
CF 1.5	21.73	209	3.56	16.40	179	2.6
CF 1.75	19.38	174	1.75	15.67	166	3.58

*Bond increment (%) was compared to NC

Figures 10(a) and 10(b) display the monotonic average bond stress against slip for specimens with 16 and 20 mm diameter bars, respectively. All samples demonstrated linear bond stress-slip behaviour until development of microcracks was observed. Upon formation of microcracks, the reinforcement bar began to slip, the stiffness of the bond stress-slip curve decreased, and the curve peak was not uniform. Incorporation of fibres gave additional ductile bond behaviour and a decrease in bond strength, when compared to that in NC. Perhaps, the ductile behaviour was influenced by the fibre that bridged the crack (ACI 408R-03, 2003;

Dancygier et al., 2010; FIB 10, 2000). Fibre density also may affect a large confinement action, apart from minimising radial cracking near the reinforcement bar (García-taengua et al., 2014; Mohamed H. Harajli, 2006).

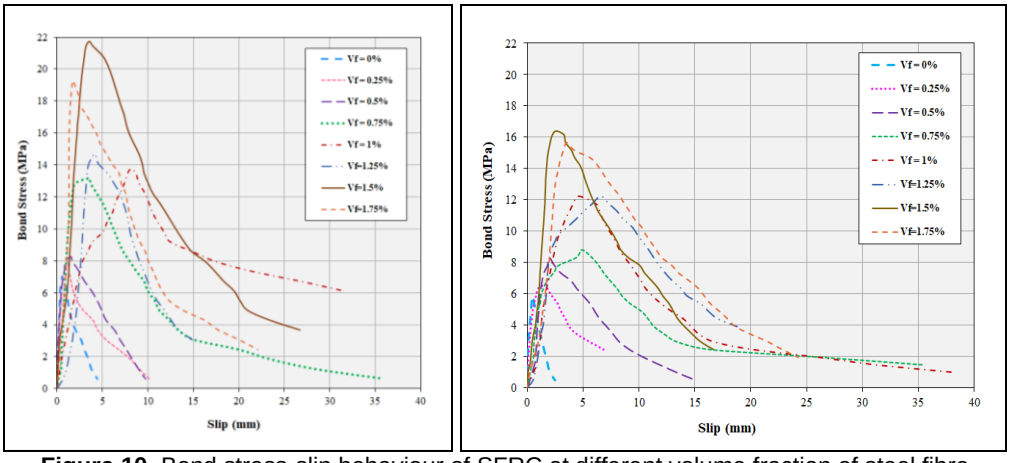

Figure 10. Bond stress-slip behaviour of SFRC at different volume fraction of steel fibre

Increment in FC resulted in an insignificant increase in the ultimate bond stress, when compared to that of NC (without fibre). This is probably caused by the lower workability of concrete at higher FCs, as a result of fibres balling effect (Bentur & Mindess, 2007; Salwan, 2016). The effect of fibre content on the ductility of bond failure is also dependent on flexural toughness strength. In some cases, the areas under the bond stress-slip curve were almost similar to the linear tendency with respect to fibre content (Dancygier et al., 2010; M.H Harajli & Mabsout, 2002).

Validation of Relationship to Determine Optimised SFRC Mix

In optimising the steel fibre volume fraction for structural implementation, the correlations between fresh state and hardened properties were taken into account. Figure 11 illustrates the relationship between splitting tensile strength and slump against fibre volume fraction. The slump of all mixes varied between 5 and 95 mm. As the percentages of steel fibre in concrete were increased, a slight decrease was noted in the slump. Although the presence of steel fibre adversely affected the workability of SFRC, it had managed to increase the splitting tensile strength. The study outcomes exhibited that the tensile splitting strength recorded the highest value for cylinder with 1.25% FC, in comparison to other cylinders. Nevertheless, based on the workability aspect, SFRC with 1.25% FC displayed a low slump value for 30 mm concrete mix. Since higher bond strength contributed by SFRC with 1.25% FC and 30 mm slump value fell within acceptable workability, 1.25% FC is suggested as the optimum steel fibre volume fraction in this study.

Figure 12 presents the correlation between splitting tensile strength and bond strength against steel fibre volume fraction. The highest value of splitting tensile strength was noted for 1.25% FC. The bond strength considered in this relationship reflects the bond strength between SFRC and 16 mm diameter deformed steel bar, primarily because it offers higher bond strength values, when compared to that generated by 20 mm diameter bar. The highest value of bond strength was observed at 1.5% FC. The intersection between the graph for

splitting tensile strength and bond strength fell between 1.25% and 1.50% volume fraction of fibres. Hence, the suggested optimum volume fraction for this study is 1.25%, since its workability appeared better than that of 1.50%. Therefore, based on Figures 11 and 12, one can conclude that the optimised volume fraction of steel fibre in SFRC is 1.25%.

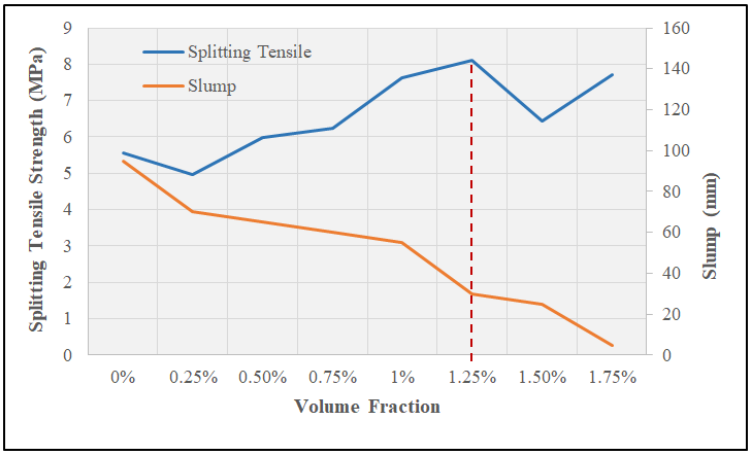

Figure 11. Relationship between splitting tensile strength and slump against different volume fraction

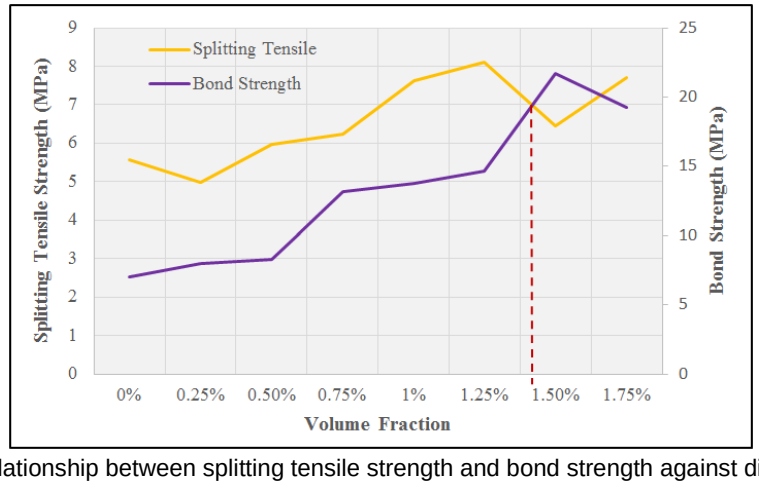

Figure 12. Relationship between splitting tensile strength and bond strength against different volume fraction

CONCLUSION

The study outcomes highlight the notion that increment in the amount of steel fibre increased both aspects of splitting tensile and bond strengths in the specimens. The confinement and the bridging effects of steel fibres enhanced the splitting tensile and bond strengths of the reinforced bars embedded in SFRC. The relationship between the outputs of fresh state and hardened properties emerged as significant to determine the optimum volume fraction of steel fibre. As a conclusion, the optimum volume fraction of steel fibre in SFRC for this study is 1.25% steel FC, which is deemed suitable for structural implementation. Therefore, the use of steel fibres in concrete is suitable for maximum efficiency, apart from addressing deformability of the structural system and integrity.

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THE FLEXURAL STRENGTH PROPERTIES OF STEEL FIBRE REINFORCED SELF-COMPACTING CONCRETE (SFRSCC)

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Abstract
Steel fibre reinforced self-compacting concrete (SFRSCC) offers two significant advantages: the ability to consolidate under its own weight, and the ability of delaying cracks due to enhancement of tensile strength and crack control of steel fibre incorporation. The experimental study considers the effects of hooked-end steel fibre on the flexural properties of the concrete. One plain self-compacting concrete, SCC and four SFRSCC mixes with steel fibre volume fraction of 0.5%, 0.75%, 1.0% and 1.25% were designed. The flowability of concrete was investigated by the slump flow test. Hardened concrete tests (flexural strength, cylinder compressive strength and modulus of elasticity) were conducted in accordance to British Standard. The flowability of SFRSCC was negatively affected by the increasing amount of the steel fibre content. Meanwhile, the hardened tests results showed that the flexural strength increased abruptly with the increase of steel fibre volume fraction, whereas the cylinder compressive strength and modulus of elasticity was not significantly affected. The inclusion of steel fibre also increased the stiffness of the concrete, where the SFRSCC specimens can sustain a larger load with small deflection as compared with plain SCC, resulting in the enhancement of ductility behavior of the concrete.

Keywords: *Self-compacting concrete; Steel fibre; Flexural strength*

INTRODUCTION

Self-compacting concrete (SCC) has been proposed by Okamura in 1986 to solve the durability problem of concrete structures in Japan (Okamura and Ouchi, 2003). Nowadays, the use of SCC has become popular and accepted by industry due to its technical advantages (Ouchi *et al.*, 2003). SCC can be used in complex moulds and congested reinforcement as it can consolidate under its own weight, ability to form a dense and homogeneous hardened concrete with similar mechanical properties, and durability as normal vibrated concrete (Sonebi, 2004) (The European Project Group, 2005). SCC contains high cement content in order to achieve the flowability and filling ability of SCC. This results in higher compressive strength than required and higher cost than normal concrete of equal strength. Therefore, researchers have carried out study on the development of SCC with lower cement content and the compressive strength less than 40 MPa (Su and Miao, 2003) (Rodríguez Viacava *et al.*, 2012).

The addition of steel fibre in concrete has improved the mechanical performance of the concrete. However, compressive strength of concrete was not significantly affected with the addition of steel fibre. (Gencel *et al.*, 2011) reported that the highest increment of compressive strength is only 3.2%, while (Siddique *et al.*, 2016) reported the increment of compressive strength about 12.1% for 1% of fibre volume content, after which the compressive strength of concrete started to decrease even though the steel fibre content is increased. The increases of entrapped air in the concrete was the reason for this decrement in compressive strength. The significant contribution of steel fibre is in flexural properties of the concrete. It has also

been reported that the effect of steel fibre was more pronounced on flexural properties of concrete than on tensile strength of concrete (AL-Ameeri, 2013). The addition of steel fibre increases the ultimate load of the concrete. The fibre bridging action enhances the flexural strength of concrete by bridging the gap between two sides of crack opening (Khaloo *et al.*, 2014). In addition to increasing the flexural strength of concrete, this bridging action also has positive influence on toughness, post-cracking behaviour after deformation until certain deflection (Khaloo and Afshari, 2005)(Yap *et al.*, 2014). As a result, many researchers have taken advantage of the bridging effect of steel fibre by conducted study about the possibility of replacing the conventional reinforcement, such as shear reinforcement, with steel fibre. The results shows that steel fibre has an ability to enhance the ductility of the concrete and act as crack arrestor in reinforced concrete member (Musa *et al.*, 2012), (Lamide *et al.*, 2016), (Mohsin *et al.*, 2016).

However, most of the studies related with the inclusion of steel fibre have either focused on various steel fibre volume fraction with normal types of concrete (Song and Hwang, 2004), (Abbass *et al.*, 2018) or high compressive strength of self-compacting concrete (Gencel *et al.*, 2011), (Tabatabaeian *et al.*, 2017). This shows that high strength self-compacting concrete is not economical for general construction use (Xu *et al.*, 2019). Therefore, the preliminary studies of properties of normal strength self-compacting concrete with the inclusion of steel fibre needs to be further investigated. Having the normal strength of SCC, it will enhance the possibility to be used practically and economically in construction industry by its possible ability to replace the secondary reinforcement.

In this paper, the prominent effects of steel fibre addition on flexural strength and load-deflection behaviour of SCC and SFRSCC were further discussed. The workability property of SCC and SFRSCC was observed through the slump flow diameter. The mechanical properties, including cylinder compressive strength, modulus of elasticity, flexural strength and load-deflection curve were also determined to investigate the prominent effects of steel fibre in flexural behaviour of the concrete.

MATERIALS AND CONCRETE MIX DESIGN

Cement

In this research, Ordinary Portland type of cement with concrete strength of 42.5 obtained from YTL Cement was used. This is a multi-purpose cement for general use which conforms to BS EN 197-1:2000 (European Standard, 2000).

Fly ash

SCC needs high cementitious materials to achieve good workability. It must also be able to consolidate under its own weight, which is in the range of 400 kg/m^3 to 600 kg/m^3 (The European Project Group, 2005). In order to ensure sufficient workability while limiting the risk of segregation due to the high cementitious content, 30% of cementitious materials was replaced by fly ash. The amount of replacement was based on the previous studies (Turk *et al.*, 2013), (Siddique *et al.*, 2012). The Class F fly ash was supplied by Tanjung Bin Power Plant, which is operated by Malakoff Power Berhad.

Fine and coarse aggregates

Crushed granite and local river sand were used for coarse and fine aggregates, respectively. Local river sand that passed through 4.75 mm sieve was used as fine aggregate. The maximum nominal size for crushed granite used for coarse aggregate was 10mm. All the aggregates were in saturated surface dry condition (SSD).

Water and superplasticizer

Water is crucial for controlling the rate of hydration in cement and influences the self-compactibility behavior of the concrete. In this study, tap water was used for concrete mixing and curing. Sika ViscoCrete-2044, a Polycarboxylate ether-based superplasticizer in the range of 1.2% to 2.0%, was used.

Steel fibres

The steel fibre used in this study was Dramix steel fibre. The type is hooked-end steel fibres with dimension of 35mm in length and 0.58 mm in diameter. The aspect ratio and density of steel fibre were 60 and 7850 kg/m^3, respectively.

Concrete mix compositions

Five mix proportions with different steel fibre volume fraction of 0%, 0.5%, 0.75%, 1.0% and 1.25% were casted. The concrete mix compositions were designed to achieve compressive strength of 30 MPa and were based on a modification of previous study and recommendation guidelines by European Federation (The European Project Group, 2005). To facilitate the inclusion of steel fibres, plain concrete, SCC mix was first developed. Then, the material composition with water-powder ratio of 0.51 was kept constant for all SFRSCC mixes as shown in Table 1. However, to maintain the self-compactability characteristics in the concrete, the amount of superplasticizer was adjusted to facilitate the incorporation of steel fibre.

Table 1. The composition for 1m^3 of SCC

Concrete mix	Cement (kg/m^3)	Fly ash (kg/m^3)	Coarse aggregates (kg/m^3)	Fine aggregates (kg/m^3)	Water (kg/m^3)	Steel fibre volume fraction (%)	Steel fibre content (kg/m^3)
SCC	342	147	675	1090	250	0	0
SFRSCC-0.5	342	147	675	1090	250	0.5	39
SFRSCC-0.75	342	147	675	1090	250	0.75	59
SFRSCC-1.0	342	147	675	1090	250	1.0	79
SFRSCC-1.25	342	147	675	1090	250	1.25	98

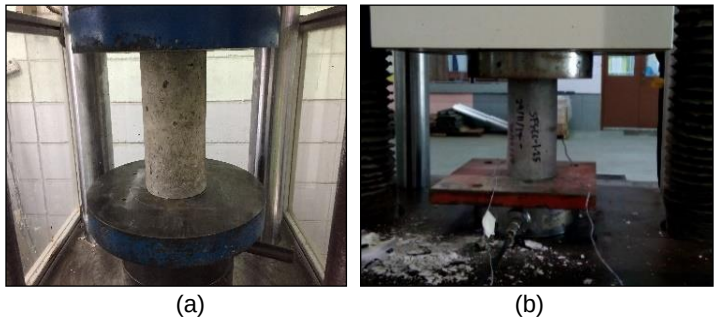
EXPERIMENTAL WORK

To test the workability of concrete, the concrete mix is filled into the slump cone and lifted up to allow the concrete to spread on the steel plate in accordance with BS EN 12350-8-2010 (British Standard Institute, 2010). The slump flow diameter was measured on two lengths and the average value is taken as shown in Figure 1.

For hardened concrete properties, all the testing procedures followed British Standard (BS). The compressive strength test and modulus of elasticity test were conducted in accordance with BS EN 12390-3:2009 (British Standard Institute, 2009b) and BS 1881-121:1983 (British Standard Institute, 1983), respectively. In total, four cylinders with dimension 100 mm diameter and 200 mm in height were casted for each concrete mix. All the specimens were moulded after 24 hours and cured in a water tank for 28 days according to BS EN 12390-2:2009 (British Standard Institute, 2009a). Three cylinders each were tested for compressive strength at a constant loading rate of 6 kN/s, while modulus of elasticity was performed on one cylinder at the constant loading rate of 0.3 N/mm^2. The average result value were taken for each concrete mix. Figure 2 shows the arrangement for compressive strength and modulus of elasticity tests.

For flexural strength test, three prisms with dimension 100 x 100 x 500 mm were tested in compliance with BS EN 12390-5:2009 (European Committee for Standardization, 2009). Similar to the cylinder specimens, the prism specimens were moulded after 24 hours and transferred to water tank for curing purpose. The prisms were tested in four-point load test with the clear span of 300 mm at the loading rate of 0.13 kN/s. In addition, load-deflection graph was plotted based on results obtained from residual flexural tensile strength test (BS EN 14651, 2005) However, in this paper, the result of residual flexural tensile strength test was not further discussed. Therefore, for residual flexural tensile strength arrangement, the prisms with dimension 150 mm x 150 mm x 550 mm used were notched at midspan with the dimension of 5mm in width and 25mm in depth. The early loading rate for this test is 0.05 mm/min. After crack mouth opening displacement (CMOD) reached 0.1mm or equivalent deflection of 0.13mm, the loading rate is increased to 0.2mm/min. To measure the deflection, one LVDT was placed at the steel plate on the notch area. The arrangement of both tests are shown in Figure 3.

Figure 1. The measurement of slump flow diameter



(a) (b)

Figure 2. The testing arrangement: (a) cylinder compressive strength test and (b) modulus of elasticity

(a) (b)

Figure 3. The testing arrangement of (a) flexural strength test and (b) residual flexural tensile strength test

RESULTS AND DISCUSSION

Workability of concrete

The fresh properties of concrete is discussed in terms of workability of concrete, which is through the result of slump flow test. The slump flow values of the SCC and SFRSCC with hooked-end steel fibre volume fraction of 0.5%, 0.75%, 1.0% and 1.25% were 715 mm, 690 mm, 685 mm, 673 mm and 665 mm, respectively. This shows a decrease of 3.5%, 4.2%, 5.9% and 7% in comparison to the plain concrete, SCC. The slump flow value and decrement percentage are graphically shown in Figure 4. In general, all mixes show slump flow in the range of 650-720mm and are within the limits set by European guidelines (The European Project Group, 2005). This can explain the negative influence steel fibre has on the flow resistance of the concrete. This is because the increment of fibre volume fraction also increase the internal resistance of the steel fibre in fresh concrete mixtures. Therefore, the high concentration of steel fibre in the concrete leads to the unworkable concrete.

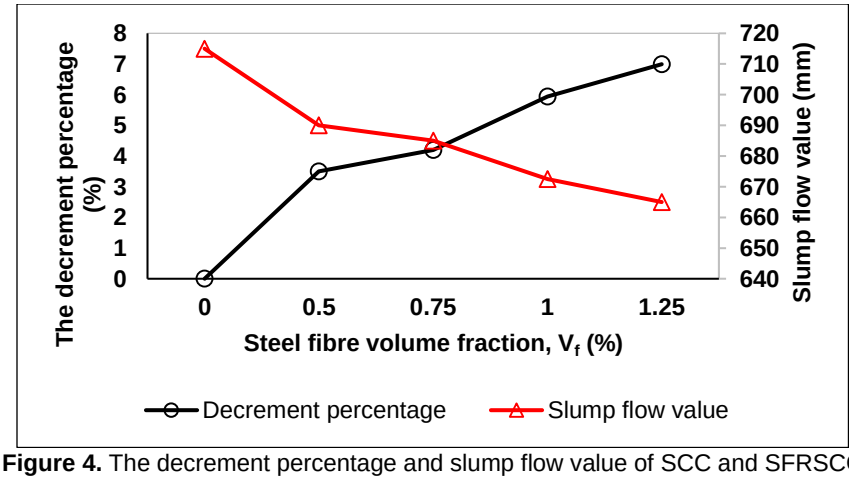


Figure 4. The decrement percentage and slump flow value of SCC and SFRSCC

The comparison of flexural properties of concrete, cylinder compressive strength and modulus of elasticity

The strength of concrete in terms of cylinder compressive strength, modulus of elasticity and flexural strength were shown in Figure 5. As shown in Figure 6, the compressive strength and modulus of elasticity of concrete were not significantly affected, where the highest

increment of these strength was only about 12%. On the other hand, it has noteworthy effects on the flexural strength of concrete. The increment of flexural strength of the SFRSCC with steel fibre of 0.5%, 0.75%, 1.0% and 1.25% were 50%, 90% (Zamri *et al.*, 2018), 60% and 65%, respectively, in comparison to the control SCC. The addition of steel fibre is significantly contributing to enhance the flexural strength due to the bridging effect of the steel fibre as shown in Figure 8, while bridging effect does not influence the compressive strength of concrete and modulus of elasticity. This is because the strength of concrete is in compression, thus the addition of steel fibre does not really affect the strength.

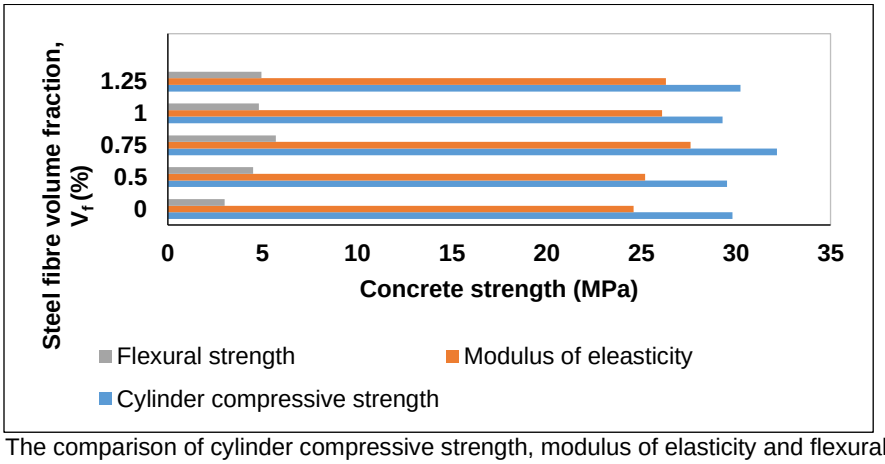


Figure 5. The comparison of cylinder compressive strength, modulus of elasticity and flexural strength of concrete

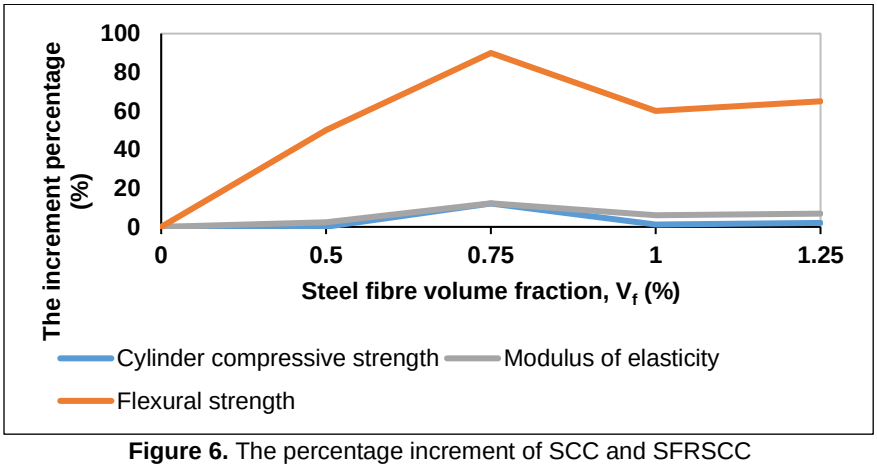
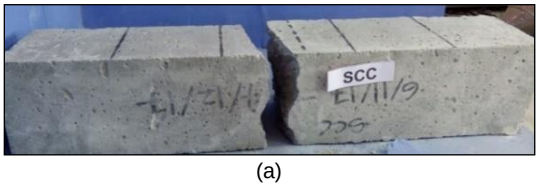


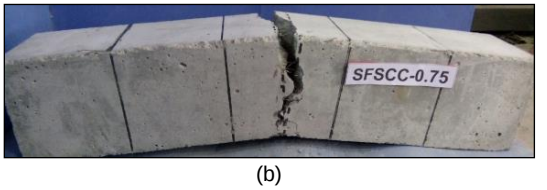
Figure 6. The percentage increment of SCC and SFRSCC

As shown in Figure 6, the flexural strength of the concrete is increased proportionally with the fibre volume fraction, V_f up to 0.75 %. After that, the strength is decreased even though the fibre volume fraction is increased. A possible explanation is that after certain amount of steel fibre has been added into the concrete, which reduces the workability of the concrete, the entrapped air in the concrete is increased. As a result, some of the steel fibre slipped out from the concrete phase as seen in Figure 8, which probably contributes to the reduction in concrete strength despite the increment of steel fibre volume fraction. Therefore, it is important to determine the optimum fibre volume for every concrete mix composition. This is because the maximum fibre content in SCC is not fixed, and various depending on the

concrete mixture compositions as well. However, the addition of steel fibre into the concrete mix helps to protect concrete from sudden failure. As shown in Figure 7, plain concrete SCC specimens were failed in brittle failure after reaching the ultimate load capacity of the concrete. On the other hand, for SFRSCC specimens, after cracking of brittle fracturing, ductile fibres continue to carry and transfer the load to other fibres. In other words, randomly distributed steel fibre in the fibre concrete bridge internal micro cracks and transferred the load by stitching the cracks in the concrete. This helps to improve the structural integrity and cohesion of material.



(a)



(b)

Figure 7. Mode of failure: (a) plain concrete sample, SCC and (b) fibre reinforced concrete sample, SFRSCC

Figure 8. Fibre bridging action in fibre reinforced concrete sample, SFRSCC

Moreover, the addition of fibre is able to increase the stiffness of the concrete. This can be explained through the load-deflection behaviour of the concrete as shown in Figure 9. In Figure 9(a), the load-deflection graph of SCC specimens shows the specimens ultimately failed after reaching the ultimate load of the concrete. The stiffness of the concrete suddenly dropped after reaching the ultimate load.

This differs from the SFSRSCC specimens as shown in Figure 9(b), Figure 9(c), Figure 9(d) and Figure 9(e), where the effects of post-cracking ductility is notable as compared to plain SCC. As the steel fibre content is increased, the stiffness of the concrete also increases. After the occurrence of first crack, the curve of load-deflection becomes less steep as the fibre volume fraction is increased. It is proved that the inclusion of steel fibres improves the mechanical performance and enhanced the fracture energy of the concrete.

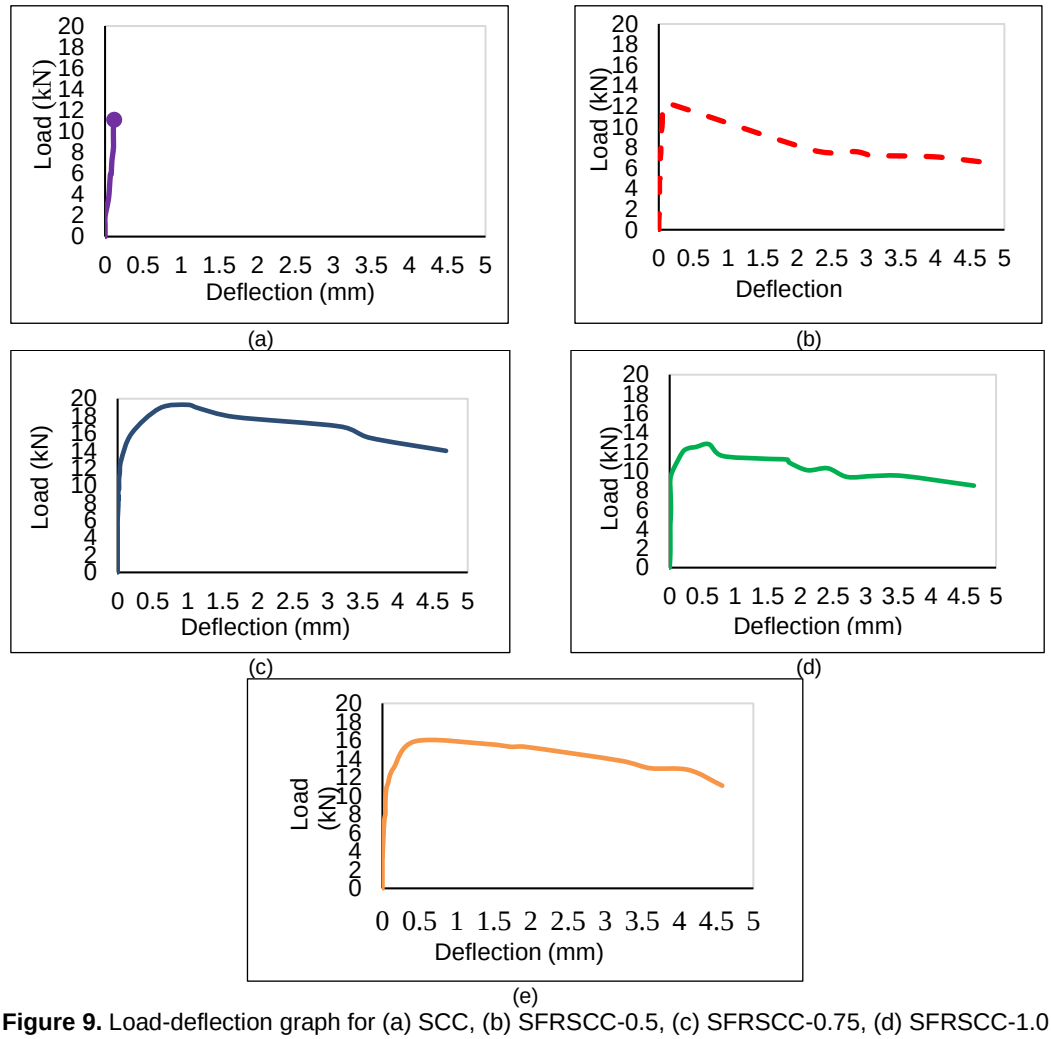


Figure 9. Load-deflection graph for (a) SCC, (b) SFRSCC-0.5, (c) SFRSCC-0.75, (d) SFRSCC-1.0 and (e) SFRSCC-1.25

Comparison of flexural properties with codes and prediction models

The values of the flexural strength was checked against available formulae included in codes and prediction models from previous researchers. Table 2 presents the list of equations acquired from the codes and previous researchers, which were used in the analysis shown in Figure 10. Prediction models from (Yazici *et al.*, 2007), (Thomas and Ananth, 2007), (Song and Hwang, 2004) and (Sumathi and Mohan, 2014) overestimated the flexural strength of the concrete, with the ACI 363 equations providing the closest prediction results to the SFRSCC data. The possible explanation is that percentage of steel fibre used in this study is still governed by the concrete matrix, as the compressive strength for all concrete mixed do not show significance difference. On the other hand, many factors have contributed to these significant differences between prediction model and the current results, such as the types and density of aggregates (ACI Committee 318, 2002), and concrete compositions. It is also believed that the strength of concrete was influenced by the amount of water, the effective of water-binder ratio in the concrete matrix (Erdem *et al.*, 2011) and the changes in SCC properties.

Table 2. Formulation table

Codes/Researcher	Formulae/Prediction models
ACI 363 Eq.5(ACI-363R, 2010)	$f_t = 0.94\sqrt{f'_c}$ for 25 MPa < f'_c< 85 MPa
Yazici et al.(Yazici *et al.*, 2007)	$f_{t,SFRC} = 0.8261 + 0.0638(L/d) + 3V_f$
Thomas and Ramaswamy (Thomas and Ananth, 2007)	$f_{t,SFRC} = 0.97f'_c + 0.295(f'_c)^{0.5}RI + 1.117RI$
Song and Hwang (Song and Hwang, 2004)	$F_{t,SFRC} = 6.4 + 3.43(V_f) + 0.3\ (V_f)^2$
Sumathi and Mohan (Sumathi and Mohan, 2014)	$F_{t,SFRC} = -1.25V_f^2 + 3.302V_f + 6.829$

Note: f'_c: cylinder compressive strength, L: length of fibre, d: diameter of fibre
RI: Fibre reinforcing index (V_f l/d).

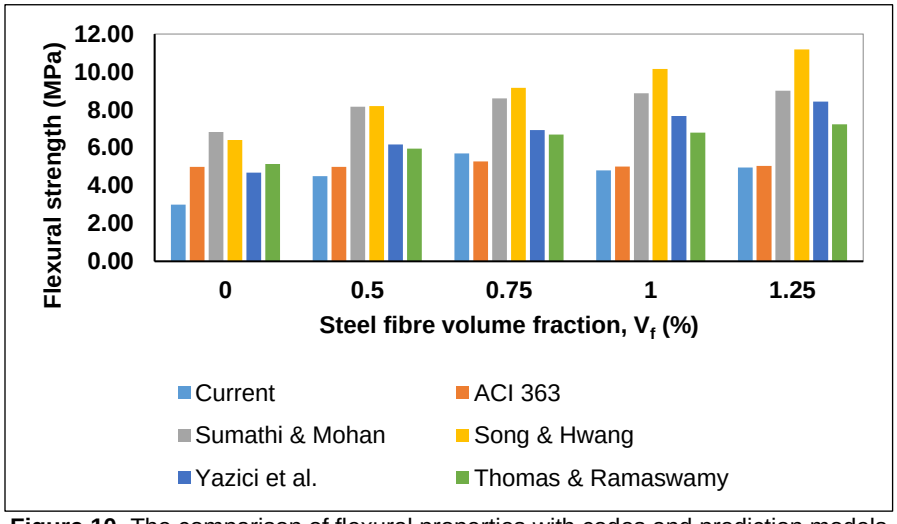


Figure 10. The comparison of flexural properties with codes and prediction models

CONCLUSION

It is essential to achieve proper workability and fibre dispersion in fibre reinforced concrete mix, as the effectiveness of fibre reinforcement depends on the properties of the concrete matrix. The use of self-compacting concrete with the ability to consolidate under its own weight would help for better dispersion of steel fibre in the concrete matrix. In this study, the fibre addition has reduced the ability of the concrete to flow and fill the mould. Yet, all mixes meet the requirement to be classified as self-compacting concrete.

The behavior of SFRSCC concerning flexural properties were investigated through the flexural strength, the failure mode, the load-deflection behavior and the comparison with codes and prediction models. Therefore, the following conclusions can be drawn:

i. Through the comparison of flexural strength with the cylinder compressive strength and modulus of elasticity of concrete, the addition of steel fibre has significant effect on the flexural strength of concrete. This confirmed the positive effects of the bridging action provided by steel fibre, which prevents the propagation of cracks and sudden failure in concrete.
ii. The post-cracking behavior of SFRSCC specimens was observed. The increment of steel fibre content increases the stiffness of the concrete, thus the SFRSCC specimens can sustain a larger load with small deflection as compared with plain SCC. Therefore, it has possibility to replace secondary reinforcement in reinforced concrete members.

iii. The significant differences between current result and prediction models estimation were influenced by many factors, such as the materials and self-compacting concrete properties and the effective water binder ratio in concrete compositions, which needs further investigation.

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FRESH AND HARDENED PROPERTIES OF HIGH-PERFORMANCE CONCRETE UTILISING MICRO AND NANO PALM OIL FUEL ASH

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Abstract

This study assessed the fresh and hardened properties of high-performance blended concrete (HPBC) containing 10% of micro palm oil fuel ash with an enhancement of 1–3% of nano palm oil fuel ash. The effect of micro and nano form of agricultural waste utilised on the fresh and hardened properties of HPBC was obtained from the slump and compressive strength test at 7, 28, 90 and 180 days. One of its durability properties was attained using the sorptivity test and measured at 28, 56 and 90 days of experiment. The utilisation of 10% of micro POFA and 1–3% of nano POFA was used as the supplementary cementitious materials in producing the HPBC. The results showed by the enhancement of 3% of nano POFA indicated that the workability of HPBC improved about 5–10 mm and the highest increment of about 4%, 3.6%, and 3.7% for the compressive strength at 7, 28 and 90 days curing age, respectively. In line with that, the sorptivity of the HPBC containing 1%, 2% and 3% of nano POFA was reduced by 7%, 9%, and 13% at 28 days; 8%, 19%, and 32% at 56 days; and 8%, 15%, and 15% at 90 days; respectively, than that of the control concrete. The utilisation of the micro and nano POFA in the high-performance concrete showed significant improvement in the workability and compressive strength at the early and later ages, as well as a reduction in initial absorption and sorptivity.

Keywords: *Nano POFA; Micro POFA; Sorptivity; Compressive strength*

INTRODUCTION

Malaysia is a country that undergoes a large-scale development to achieve its vision of year 2020 as a self-sufficient industrialised nation. In conjunction with the vision first stated in 1991 by Tun Dr Mahathir Mohamed as the 7th prime minister, there were so many developments that took place across the country. In achieving the vision, advance infrastructure was one of the key factors. These developments largely utilised concrete as one of the construction materials, hence, the need for improved technology in the production of concrete. In terms of global performance, Malaysia is known as the second largest player within the palm oil sector. It is expected by 2020, there will be 100 million dry tons of palm oil biomass (Malaysia Innovation Agency, 2013), with 5% of it known as palm oil fuel ash (POFA). These numbers were derived from the booming palm oil industry in Malaysia that contributed to 41% of the world's palm oil production (Al-Mulali et al, 2015). Realising the potential of POFA in improving the mechanical properties and durability of concrete contributed by the production of secondary calcium silicate hydrate (C-S-H) gel, POFA was utilised as the supplementary cementitious material (SCM) in the research of high-performance concrete (HPC). The interest in studying the effect of particle size of POFA in producing HPC arises upon referring to past research. For the micro sized of POFA, the optimum range between 10–30% has shown an increasing pattern in concrete strength and

durability (Chindaprasirt et al., 2007; Sata et al., 2007; Tangchirapat et al., 2009). However, the fresh and hardened properties of concrete showed that the utilisation of micro POFA has reduced the workability and early strength of the concrete (Kroehong et al., 2016). In studies done on durability, micro POFA was observed to improve the concrete resistance against chloride ion, increase resistance to chemical attack, and reduce heat development (Kroehong et al., 2016; Tangchirapat et al., 2009). Further studies have continued to improve the fresh and hardened properties of concrete by utilising a high volume of nano POFA as the SCM (Lim et al., 2015; Rajak et al., 2015). The nanomaterials used in the study have proven that the increase of surface area enhances the mechanical and durability properties of concrete by accelerating the pozzolanic reaction. Nanoparticles in cement paste also improve the properties of the concrete by filling the nano pore sized in the concrete matrix, thereby widening the phase of amorphous C-S-H gel that holds the concrete together (Chong and Garboczi, 2002; Sanchez and Sobolev, 2010). This was due to the uniform dispersion of the nano particles in the paste and the nucleation of hydration products that accelerates the hydration process (Bjornstrom et al., 2004). Meanwhile, other researchers have concluded that the concrete strength and rate of hydration were influenced by the reaction of silica and calcium hydroxide from cement hydration (Jaturapitakkul et al., 2007; Yusuf et al., 2014). It can be observed from the literature that there is a potential for micro and nano POFA as the SCM in the study of fresh and hardened properties of concrete. A majority of works done describe micro POFA, while very few of the researchers' studies on fresh and hardened properties of high-performance concrete utilise nano POFA. Hence, this study aimed to determine the fresh and hardened properties of high-performance concrete utilising micro and nano POFA as an effort to add to past research.

MATERIALS

The cement used in the study was Type 1 Portland Cement from Cahya Mata Sarawak. The specific gravity of the cement was 3.15. The requirements set by ASTM C150-12 (2012) regarding the chemical properties of the cement were fulfiled. Palm oil fuel ash (POFA) was obtained from MJM Palm Oil Mill, Bekenu, Sarawak. Checking was done in reference to the standards set by ASTM C-618-15 (2015), hence, the classification of class C for the POFA in relation to the oxide compounds from silica, aluminum and iron of 69.7%, which was below 70%. Coarse aggregates from the crushed granite ranging between 9.5 mm to 12 mm were utilised. ASTM C33-16 (2016) was utilised to grade the aggregates. It was ensured that the utilised aggregates to be in a saturated surface dry condition. The data obtained for the aggregates' fineness modulus, specific gravity, and water absorption were 2.2, 2.69 and 0.5%, accordingly. According to the ASTM C33-16 (2016), the grading of the local river sand through the sieve analysis produced a poor distribution, with a fineness modulus of 0.99. Hence, quarry dust was mixed with the river sand at a ratio of 1:1 as fine aggregates. Master Glenium Ace 8538 obtained from Basf Petronas was utilised as the superplasticiser. The superplasticiser conformed to the ASTM C494-16 (2016) with regards to the content of polycarboxylate ether polymers and was free of chloride.

Micro and nano POFA

Moisture in the raw POFA was dried out by heating it at 100°C for 24 hours. The 45 µm POFA particle was obtained by grinding the 150 micron POFA using a high energy ball mill. The optimum amount of grinding ball mill was set at 50% by volume of the pot size and 25%

by volume of the pot size for POFA to be grinded (Wan Hassan et al., 2017). The particle size of POFA was verified as 45 µm in size per conforming to the ASTM C 618-12, which required 90% of the POFA particles to pass through the 45 µm sieve. To remove the excess unburnt carbon, the POFA was heated up to 500℃ in a furnace for an hour. Hence, the value of LOI (loss on ignition) was reduced from 10% to 1.8%, and the colour changed from black to grey. The test was conducted in accordance with ASTM D7348-13 (2013). Figure 1 shows a single morphology image of the micro POFA that possesses a spherical, porous, and irregular shape. Further procedure required the grinding of micro POFA using the ball mill for 5 hours to obtain the nano POFA (Wan Hassan et al., 2017). The single size of the nano POFA was then verified using Transmission Electron Microscopy (TEM) analysis as shown in Figure 2.

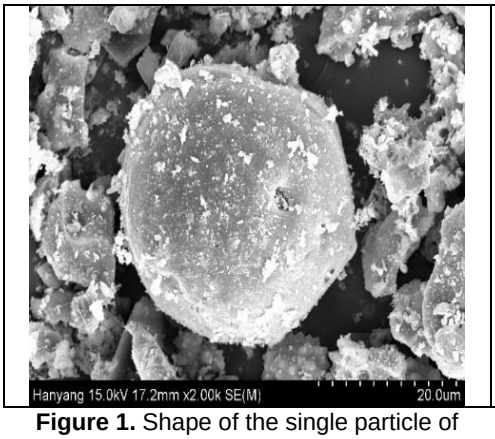

Figure 1. Shape of the single particle of micro POFA from SEM

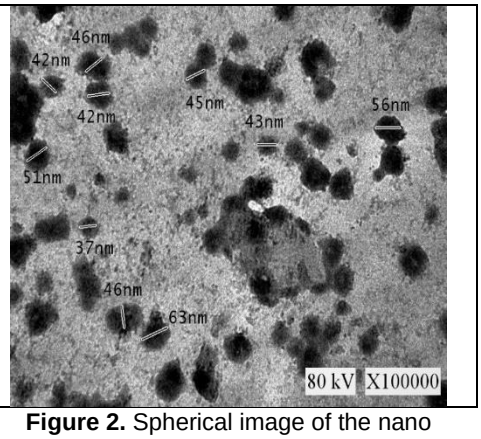

Figure 2. Spherical image of the nano POFA observed using TEM with the measurement of the size of nano POFA

Mix proportion

The design mix of HPBC was developed in accordance to the guidelines in ACI 211-4r (2008). The targeted compressive strength at 28 days for the mix was 60 MPa. Table 1 shows the mix design of HPBC with a partial cement replacement of the respective percentage of 10% micro POFA and 1–3% nano POFA. Table 2 shows the binder composition for different concrete mixes. Mix C represents the control specimen, whereby OS1, OS2, and OS3 containing 10% replacement of micro POFA by weight were combined with 1%, 2%, and 3% replacement of nano POFA by weight, respectively.

Table 3. Design mix of high performance concrete according to ACI 211-4r (2008)

Component	Weight
Cement (OPC)	588 kg/m^3
Coarse Aggregates	1093 kg/m^3
Fine sand	268 kg/m^3
Quarry dust	268 kg/m^3
Water with superplasticizer	183 kg/m^3

Table 2. Binder composition of different mix

Mix	OPC (%)	Micro POFA (%)	Nano POFA (%)
C	100	0	0
OS1	89	10	1
OS2	88	10	2
OS3	87	10	3

TESTING PROCEDURES

Slump

The guidelines from ASTM C143-15 (2015) outlined the procedure for the slump test of the concrete. Accordingly, the test was conducted by filling up three layers of equal volume into the cone and rod of 600 mm long and 16 mm diameter, which were then utilised to tamp the concrete.

Compressive strength test

The guidelines from ASTM C109-16 (2016) were followed to determine the compressive strength of concrete at the age of 7, 28, 90 and 180 days. A total of 48 cubes of specimens measuring 100 x 100 x 100 mm in dimensions were prepared to conduct this test.

Sorptivity test

This test was done in accordance with ASTM C1585-13 (2013). The rate of water absorption or sorptivity was conducted using concrete discs of 50 mm thickness and 100 mm diameter. The disk specimens were placed in an oven at 50ºC for 3 days until a constant weight was achieved. Then, the disc samples were kept in a sealed container to achieve the uniform moisture distribution before they were placed in a distilled water container. The weight gain measurements were taken from 0 second to the first of 6 hours to determine the initial absorptions. During the measurement, excessive surface water was wiped off. This test only allowed one-dimensional diffusion, whereby only one surface was in free contact with water, while the top and bottom of the disk specimens were sealed with an impermeable coating. The process was continued until the end of the 8th day. The test was conducted at the concrete age of 28, 56, and 90 days, respectively. The sorptivity of the HPBC may be obtained by measuring the increase in the mass of specimens at an interval time. The sorptivity, I is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. The initial rate of water absorption value ($mm/s^{1/2}$) was calculated as a slope of the linear part of the sorptivity, I versus the square root of time.

RESULTS

Workability

Workability of the concrete is very important because it represents its ability to flow during pouring of concrete. The slump test may indicate the workability of concrete. Previous researchers stated that workability is one of the challenges in overcoming the reduction of slump height (Farzadnia et al., 2015; Megat Johari et al., 2012; Sata et al., 2007; Tay, 1990). Pertaining to this study on HPBC, 10% of micro POFA and nano POFA ranged between 1% and 3% were utilised in the mix design. Figure 3 shows the results for all four mixes of HPBC. Referring to the result in Figure 3, OS3 containing 10% of micro POFA and 3% of nano POFA has the highest value of slump, which is 150 mm. Compared with the plain concrete (mix C), HPBC containing 10% micro POFA and 2% of nano POFA also showed improvement in workability of concrete by an increment of 3.6%. The morphology of the micro POFA having a spherical shape and porous structure explains the reduction of

workability and the enhancement of nano POFA filling the porous part, providing the rolling effects during mixing of concrete (Noorvand et al., 2013).

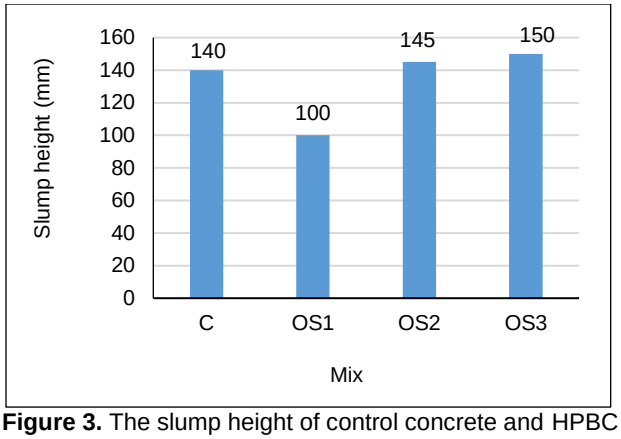

Figure 3. The slump height of control concrete and HPBC

Compressive strength

Figure 4 presents the compressive strength for each mix at 7, 28, 56, 90 and 180 days, respectively. The HPBC containing 10% micro POFA and 1–3% nano POFA has a higher compressive strength at curing ages of 7, 28, 90 and 180 days, respectively. The compression test for respective HPBC specimens mentioned previously exhibits an increment of compressive strength as follows: 4%, 2.9%, and 0% at 7 days; 2.3%, 0.5% and 3.6% at 28 days; and 3.2%, 3.2% and 3.7% at 90 days. The porous characteristic of micro POFA has resulted in the absorption of water content, which is required for cement hydration process during mixing, hence resulting in the reduction of compressive strength. Results also show that HPBC with 10% micro POFA and 1–2% nano POFA has the highest compressive strength at an early age. It can be explained due to the fast generation of CSH gel in relation to the high amount of silica content, hence resulting in the early maturation of concrete (Madani et al., 2012).

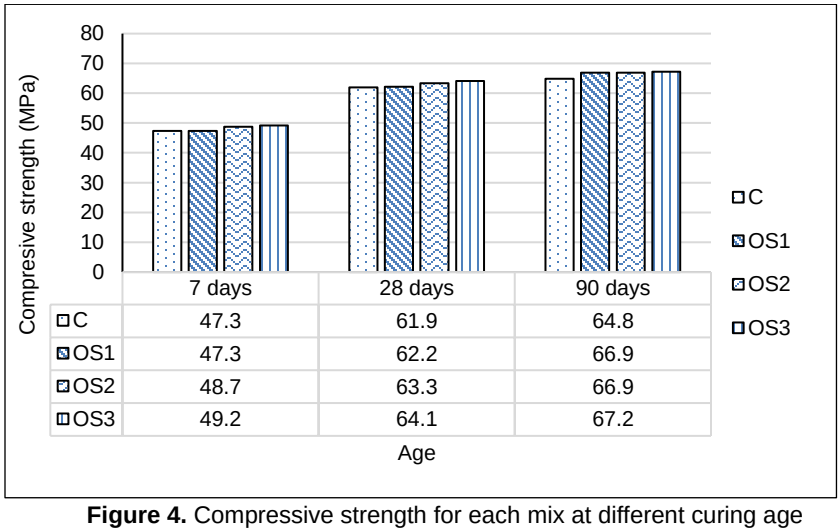

Figure 4. Compressive strength for each mix at different curing age

Sorptivity

The initial absorption (mm) of each mix at 28, 56 and 90 days are shown in Figures 5 to 7, respectively. The best fit of the linear graph for each mix at all curing ages are also presented in Figures 5 to 7, respectively. The R^2 value can be seen to be greater than 0.90 for all mixes. For each mix, the cumulative initial absorption in the concrete increases with the square root of time. The initial absorption indicates the first 6 hours of measurement. At 28, 56 and 90 days, the absorption in plain concrete obtained was the highest than that of the OS1, OS2 and OS3 mixes. The lowest moisture initial absorption can be found in mix OS3 that consists of 10% of micro POFA and 3% of nano POFA at all curing ages. Due to the uniform dispersion of nano POFA in HPBC, the higher surface energy of nanoparticles accelerates the hydration process, hence producing more 'glue' that binds the concrete (Bjornstorm et al., 2004). From the graphs of the initial absorption, the slope of the linear graph is represented as the sorptivity value for each mix. The sorptivity value calculated is shown in Figure 8. According to that figure, the maximum value of sorptivity can be clearly seen from the control mix, C at 28, 56 and 90 days with the values of 45, 37 and 13 ($x10^{-4}$ mm/$s^{1/2}$), respectively. A reduced sorptivity can be found in mixes OS1, OS2 and OS3 throughout the curing age, where the lowest value of sorptivity is $11x10^{-4}$ mm/$s^{1/2}$ at the 90 days of age. This is due to HPBC exhibiting the highest resistance for moisture absorption by capillary suction. HPBC containing 10% of micro POFA with 1%, 2% and 3% of nano POFA at the age of 28 days also show greater improvement in sorptivity with values of 41, 42, and 39 ($x10^{-4}$ mm/$s^{1/2}$) than that of plain concrete ($45x10^{-4}$ mm/$s^{1/2}$). In parallel with the 56 days of age, the sorptivity values for OS1, OS2, and OS3 were 34, 30 and 25 ($x10^{-4}$ mm/$s^{1/2}$), respectively; they are lower than plain concrete's value. The reduction of the water absorption due to capillary suction of HPBC is caused by the uniform dispersion of nano POFA, accelerating the hydration process between the nano POFA and weak product to produce more CSH gel. The more binding product formed, the better the bonding is in the concrete matrix. Hence, it provides greater water sorptivity resistance (Bjornstorm et al., 2004; Chong and Garboczi, 2002; Sanchez and Sobolev, 2010).

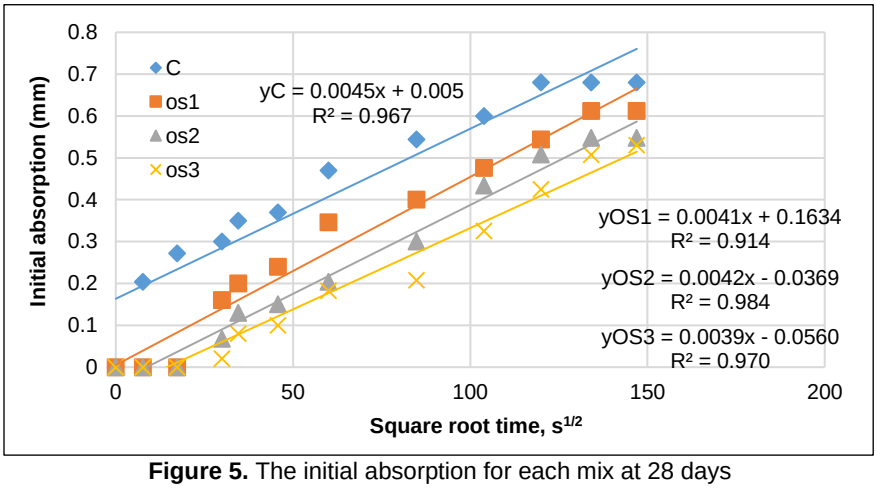

Figure 5. The initial absorption for each mix at 28 days

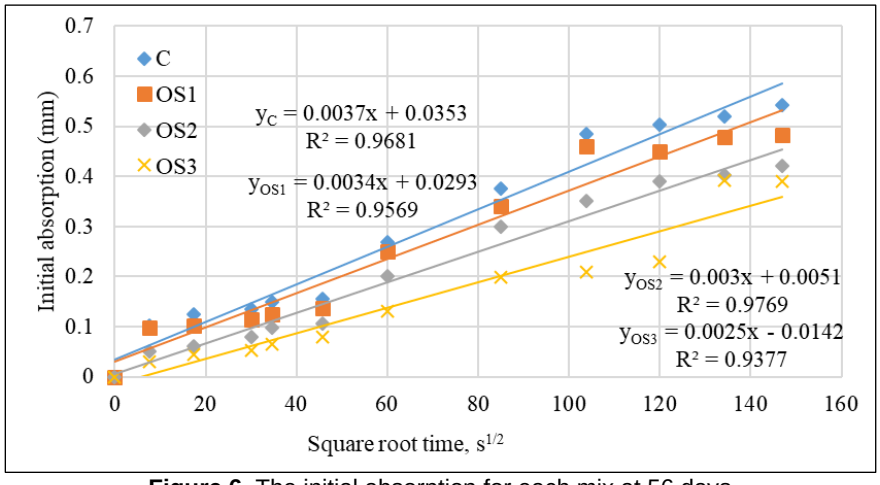

Figure 6. The initial absorption for each mix at 56 days

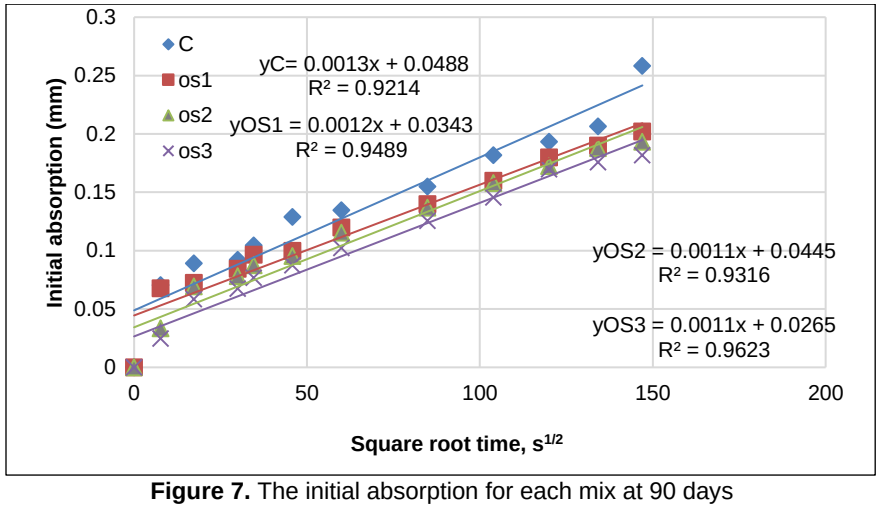

Figure 7. The initial absorption for each mix at 90 days

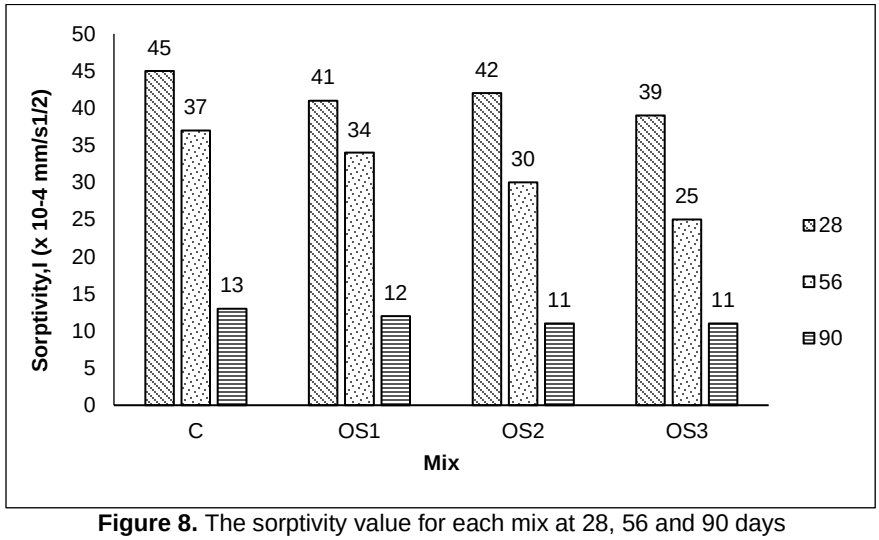

Figure 8. The sorptivity value for each mix at 28, 56 and 90 days

CONCLUSIONS

From the study, the HPBC containing micro POFA and an enhancement of 1–3% nano POFA was proven to be better in improving the workability, compressive strength, and sorptivity. In the context of its workability, the HPBC improved the workability by an increment of the slump height by 5–10 mm. In parallel with the fresh properties, the compressive strength at 7, 28, 90 and 180 days showed higher strength than that of the control concrete by the highest increment of 4%, 3.6% and 3.7% at curing age of 7, 28, 90 and 180 days, respectively. The initial absorption of the HPBC showed lower results than that of the control, and the R^2 value calculated from the linear graph was greater than 0.90. This indicated that the enhancement of nano POFA combined with micro POFA led to a denser concrete due to the effectiveness of the finer particles, which promotes the hydration process. The sorptivity in the HPBC also showed lower values than that of plain concrete. HPBC containing 1%, 2%, and 3% of nano POFA displayed reduced sorptivity values of about 7%, 9%, and 13% at 28 days; 8%, 19%, and 32% at 56 days; and 8%, 15%, and 15% at 90 days, respectively. The reduction of the initial absorption and sorptivity was presumably due to the dispersion of the nano POFA in HPBC, which made the concrete denser and thereby, providing a higher moisture absorption resistance.

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PROPERTIES OF MORTAR CONTAINING FINE INDUSTRIAL CERAMIC WASTE POWDER AS CEMENT REPLACEMENT MATERIAL

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Abstract
Emission of carbon dioxide during the production of cement has turned the attention of many researchers to find its solution. In addition, waste materials have become major concern in terms of disposal and their impact on environment. The utilization of pozzolanic waste materials in concrete has been investigated by many researchers and has shown positive effects on the strength and durability performance of concrete. Ceramic tiles as one of the waste materials which increases the problem of its disposal after their usage. Initial studies show that the ceramic waste is seen to be a potential pozzolanic material. This paper presents investigation on the effect of industrial ceramic waste powder (CWP) as a cement replacement material in mortar. The characterization of the CWP and tests on fresh and hardened properties of mortar containing CWP were conducted. Mortar cubes with the size of 50x50x50 mm containing 10%, 20%, 30%, 40%, and 50% CWP were cast and tested. The experimental results revealed that when compared with control mortar, mortar containing 20% CWP recorded better performance in terms of flowability, compressive strength, density, strength activity index, ultrasonic pulse velocity, and water absorption. The results indicate that the ceramic waste powder can be used as partial cement replacement and improve the properties of mortar.

Keywords: *Ceramic waste powder; Cement replacement; Compressive strength; Water absorption*

INTRODUCTION

The natural resources in the world are continuously decreasing due to manufacturing of products and their impact on the environment increase and disposing the unwanted products is becoming an issue which needs to be addressed and resolved. This can be done by adopting the policy of 3Rs; Reduce, Reuse, Recycle (Umar *et al*., 2016). Normally to manufacture a new product, a lot of energy and material is required. Most of the construction materials are expensive and the energy and cost required for their manufacture is very high. In this situation alternative materials are needed to be found in order to decrease the construction cost and save the natural resources.

It has been reported that certain waste materials produced by different industrial processes can be very useful in construction; they can provide the required properties, strength and safety (Dousoya *et al*., 2016). As these are waste materials so there is no manufacturing cost and hence they are very cheap. The advantages of using these waste materials include cost saving, energy saving, reducing pollution and sustaining the environment for the future generations.

Suitable proportions of waste materials can be used as a replacement of cement to produce a required strength mortar with desired workability (Sarkar *et al*., 20116). Ceramic waste including roof tiles and clay bricks can be considered as one of the mainstays in terms of construction materials (Brito *et al*., 2005). It has been reported that 30% of the daily production in the ceramic industry is considered as waste materials. However, such waste materials have good characteristics such as durable, hard and highly resistant to biological, chemical and physical degradation forces (Senthamarai and Manoharan, 2005). Cement has excellent cementitious properties and it works as a binding agent in concrete and mortar and is relatively expensive compared to other materials (Raval *et al.*, 2013).

Currently, the possibility of using ceramics waste is an ongoing research in different engineering areas including as aggregate replacement, cement replacement material and nanomaterials (Lim *et al*., 2018; Samadi *et al*., 2015; Zimbili *et al*., 2014). A study was made on the use of ceramic wastes in concrete production. Concrete produced using ceramic wastes have many advantages over normal concrete which are in terms of density, reducing permeability, enhance durability and compressive strength. The aim of the paper is to highlights the effects of industrial ceramic waste powder from the polishing process as partial cement replacement material at different percentages on the fresh and hardened properties of mortar.

EXPERIMENTAL PROGRAMME

Mix Proportions

The concept of mortar mixture design is to determine the required proportion of each constituent, which includes cement, fine aggregate, and water. This would produce mortar possessing the specified properties such as flow, strength, and durability. The cement to sand ratio for the mix proportions of the mortar used in this study was 1:3.42 with w/c ratio of 0.5. In the preparation of the samples the cement was replaced by the ceramic waste powder at 10%, 20%, 30%, 40% and 50%. The mix proportions of all mortar mixes are shown in Table 1. As indicated in Table 1 the NM stands for normal mortar and CM10, CM20, CM30, CM40, CM50 are ceramic mortar containing 10%, 20%, 30%, 40%, and 50% ceramic waste powder as cement replacement, respectively.

Table 1. Mortar mix proportion with CWP

Mix ID	Cement (g)	Ceramic (g)	Fine Aggregates (g)	Water content (g)
NM	570	0	1950	285
CM10	513	57	1950	285
CM20	455	115	1950	285
CM30	400	170	1950	285
CM40	340	230	1950	285
CM50	285	285	1950	285

RESULTS AND DISCUSSIONS

Characterization of Ceramic Waste Powder (CWP)

The characterization of ceramic waste powder was carried out including its specific gravity, density and percentage passing 45μm sieve. Table 2 shows the important properties of the ceramic waste powder that were determined in the study. The percentage of CWP was nearly to 90% indicating that the CWP particles were fine enough and suitable to be used as cement replacement material.

Table 2. Characterization of CWP

Properties	Ceramic Powder
Colour	Light grey
Density (Kg/m^3)	2320
Specific gravity	2.32
Percentage Passing 45μm sieve (%)	89

Chemical Composition of Ceramic Waste Powder (CWP)

The chemical composition of the CWP used in this work is shown in Table 3. As can be seen from the table the CWP used in the mortar mix was mainly consisted of SiO_2 and Al_2O_3 which represent about 84.8% of the total oxides. The higher percentages of silicate and aluminate in the CWP material indicates potential pozzolanic reactivity when incorporated in concrete or mortar mixes.

Table 3. Chemical composition of CWP

Main Oxides	Quantity (%)
SiO_2	72.6
Al_2O_3	12.2
Fe_2O_3	0.56
CaO	0.02
MgO	0.99
Na_2O	13.46
SO_3	0.01
K_2O	0.03

Flowability

The results of flowability test for mortar containing different percentage of CWP is shown in Figure 1. As can be seen from Figure 1, it is noticeable that at 0% of CWP, the value of mortar flowability was 138 mm. When the percentage of the CWP is increased, the flowability was found to be increased. This occur until the ceramic particles content included in the mix up to 20% where the optimum value is achieved. It is most likely due to the higher amount of finer ceramic particles combined with cement that enhances the flow of the mortar. However, at higher percentage of waste ceramic content, the flowability starts to decrease possibly because the fine CWP particles may absorbs more water which reduces the water quantity in the mixtures. However, at 50% CWP replacement the result shows that the flowability of the mortar is still better than the control mortar by about 7%.

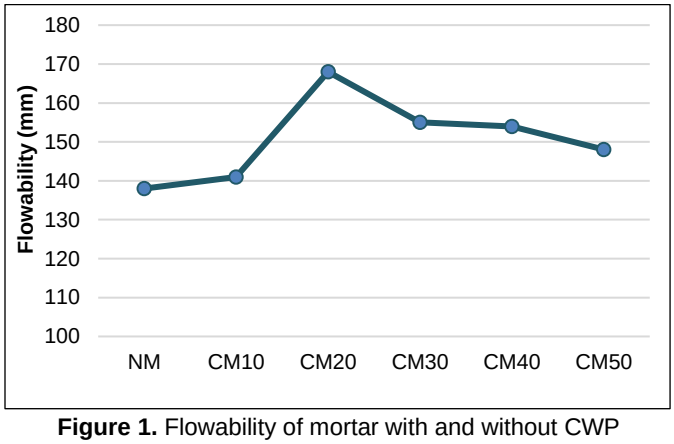

Figure 1. Flowability of mortar with and without CWP

Density

The density of mortar recorded containing CWP during this study is shown in Figure 2. It can be seen from the figure that as the cement is replaced with CWP from 0 to 50%, the density of CM20 recorded to be similar as compared to normal mortar at 3 day of curing and then slightly increase in density as curing age increases to 7 and 28 days. This may indicate that the CWP in the mortar is contributing on the C-S-H gel formation in the mortar due to the pozzolanic reaction. However, the density tends to decrease from 40% replacement of the CWP in mortar as shown in the same figure. It is probably due to the higher percentage of CWP oppose cement particle to make binding with the sand particles which results in voids in the sample and thus, decreasing the density of the mortar.

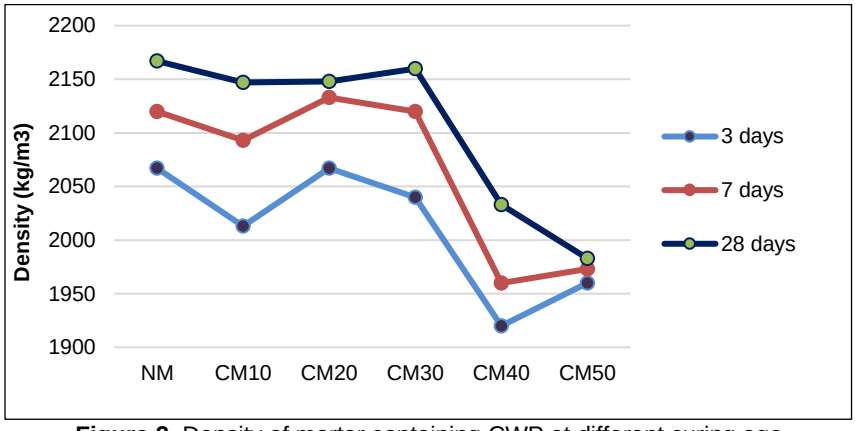

Figure 2. Density of mortar containing CWP at different curing age

Compressive Strength

Figure 3 shows the compressive strength recorded from the compression test for mortar mixes containing different percentage of CWP. It can be seen from the figure that the compressive strength was higher for the CWP mortar at 3, 7, and 28 days as compared to normal mortar when the CWP percentage increases. Mortar mixes CM10, CM20, and CM30 recorded higher compressive strength in which the optimum strength recorded to be at 20% replacement of cement by CWP. It can be said that probably the main reason of the high compressive strength of the CWP mortar at low level of waste is that the micro-cracks will be generated at low content of waste ceramic particles without linkage to another neighbour cracks. In other words, the cracks did not propagate to the surface of the sample due to the pozzolanic reaction occurred between the silicon dioxide (SiO_2) and calcium hydroxide ($Ca(OH)_2$), which was liberated from the hydration process of the cement producing more Calcium Silicate Hydrate (CSH) gel. From the results of compressive strength test it can be seen that the optimum replacement of CWP in mortar for this study is 20%. Higher replacement of cement with CWP resulting in the decrease of compressive strength and most likely due to less $Ca(OH)_2$ available for further pozzolanic reaction with CWP. Thus, the extra unreacted CWP will act as a filler only in the mortar sample.

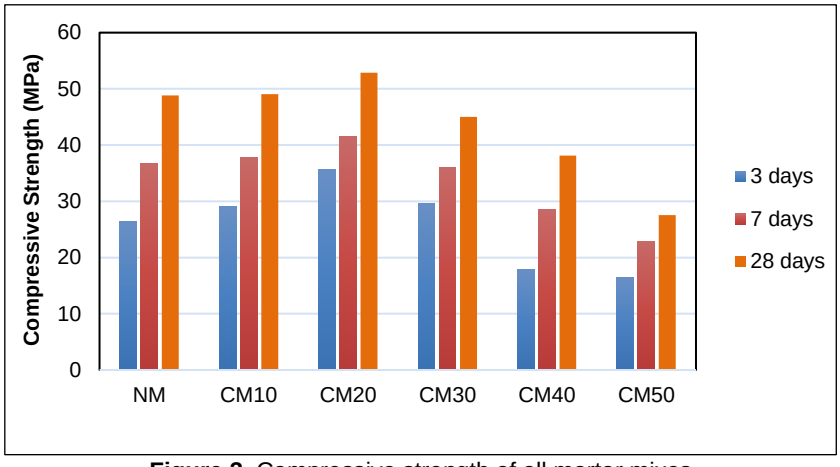

Figure 3. Compressive strength of all mortar mixes

Strength Activity Index

Figure 4 shows almost all CWP mortars are showing strength activity index (SAI) value more than 75% after 28 days except for CM50, which is recorded only 56%. Every sample recorded high SAI value at 3 days of curing but it starts to decrease as the curing age increases.

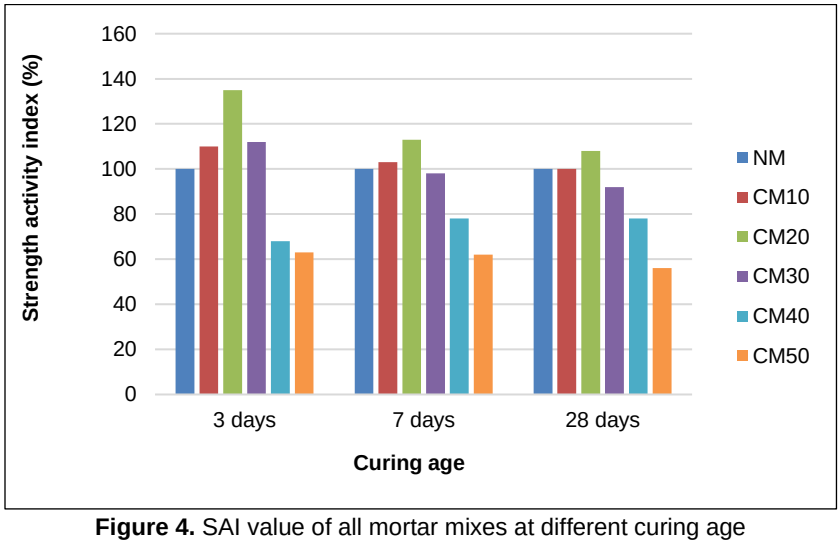

Figure 4. SAI value of all mortar mixes at different curing age

Ultrasonic pulse velocity

As shown in Figure 5, the UPV test outcomes revealed that after 28 days of curing, all mortar mixtures showed better mortar quality except for the 40% and 50% CWP mixture. The results show that at lower CWP replacement level the UPV values increased as curing days are increases. This could be attributed to the densification of the microstructure and lower pores connectivity owing to the pozzolanic activity and micro-filling effect of the CWP particles.

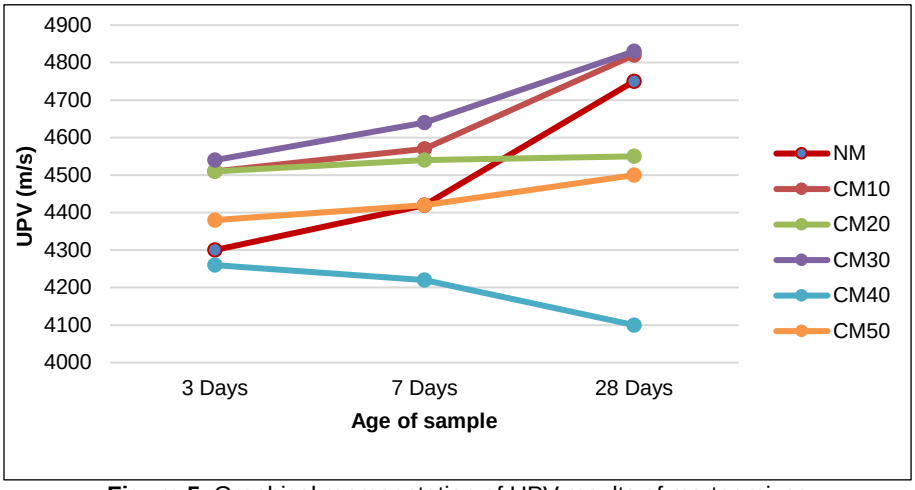

Figure 5. Graphical representation of UPV results of mortar mixes

Water Absorption

Figure 6 shows the results of water absorption in the mortar samples containing different percentages of CWP at the age of 3, 7, and 28 days. The water absorption for control mortar specimens after 28 days was 5.8% whereas, mortar containing 10%, 20% and 30% shows absorption of about 4.35%, 5.00% and 5.66%, respectively. After 28 days, the ceramic mortar shows lower water absorption compared to control mortar specimens except those with higher CWP percentage. This performance was most likely due to the decreasing in the porosity of mortar with the formations of calcium silicate hydrate gel from the pozzolanic reaction that gradually fills the pore in the mortar sample.

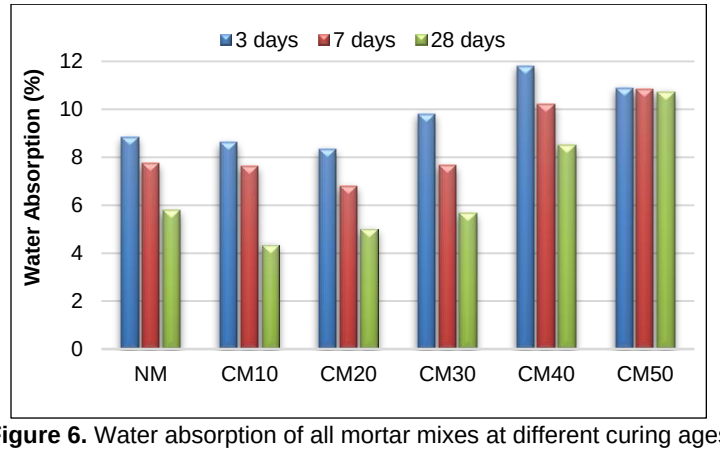

Figure 6. Water absorption of all mortar mixes at different curing ages

CONCLUSIONS

The conclusions that can be drawn based on the results of this study are as follows:

i. The physical and chemical investigations of ceramic waste powder (CWP) has revealed that it has the potential to be used as supplementary cementitious material (SCM) in mortar.

ii. Based on the flowability test results it shows that the workability of mortar containing 20% CWP is improved up to 22% compared to normal mortar.
iii. Mortar containing 20% CWP as cement replacement has shown higher compressive strength as compared to normal mortar by 8%. This was possibly as a result of pozzolanic reactions between CWP and calcium hydroxide from the hydration of cement. Similar result also can be seen from the strength activity index (SAI) value of 20% ceramic mortar at 28 days.
iv. Ultrasonic pulse velocity (UPV) results for 10%, 20% and 30% of CWP mortars were better than normal mortar at 28 days indicating denser microstructure of the mortar samples.
v. Mortar containing CWP shows reduction in water absorption as compared to normal mortar after 28 days. A low water absorption values was recorded in 10% and 20% CWP replacement. This indicates that the microstructure of the mortar most likely becomes denser due to the formation of CSH gel as a results from pozzolanic reaction activity of the CWP in the mix.

ACKNOWLEDGMENTS

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CLEAN STRENGTH, LEACHING AND MICROSTRUCTURE OF POLYMER MODIFIED CONCRETE INCORPORATING VINYL ACETATE EFFLUENTS

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Abstract
The increasing waste generation from paint industries accounts for the occupation of useful land spaces for disposal purposes. Waste products associated with these industries need attention during handling and treatment due to possible harmful effects on human health and the environment. This problem can be mitigated by incorporating it into concrete production. This study aims at investigating the effects of polymer vinyl acetate effluents on normal strength concrete. The incorporation of the effluents by weight of cement were 0%, 2.5%, 5%, 10%, 15% and 20%, and tested at 28, 56 and 84 days. The tests performed were compressive strength, leaching test and microstructure characterization of the specimen using FESEM and XRD. The results indicate that incorporation of polymer vinyl acetate waste in the range of 2.5% - 15% gave compressive strength of concrete comparable to that of the control specimen. The entire specimen in leaching test met the standard requirement for effluents. The FESEM of polymer modified concrete incorporating 5% effluents showed a well-dispersed morphology of the polymer. This concludes that the incorporation of vinyl acetate effluents up to 5% in normal strength concrete is beneficial to strength development and can consequently minimize pollution caused by these wastes.

Keywords: *Compressive strength; Concrete; Leaching; Vinyl acetate effluents; Polymer*

INTRODUCTION

Paint sludge is a hazardous waste that poses a serious risk for both human health and the environment. It is typically a final by-product resulting mainly from cleaning the paint of manufacturing facilities which accounts for about 80 % of the industry wastes (Lorton, 1988; Salihoglu and Salihoglu, 2016). The by-products contain several components of wastes such as solvent emulsion, pigment dust, rinsed water, paint sludge, and many more. Moreover, paint sludge is a complicated combination whereas polymeric compounds form approximately 50% - 90% of sludge weight which may be unbaked (Dabiri, 2006; Feng *et al.*, 2018). The production of paints, thus contributes significantly to the amount of waste generated annually. This problem becomes worse with improper management of solid wastes that leads to serious environmental pollution and the disruption of the ecosystem, as well as short or long-term impact on human health.

In Malaysia, paint wastes have been grouped under category of scheduled hazardous waste which is toxic to the populace and impacts negatively on the environment. Wastes generated from paint industries have increased tremendously due to rapid development and urbanization resulting from increase in economic activities. The volume of waste generation is connected to paint consumption estimated to have increased from 140,000 tonnes in 2009 to 166,000 tonnes in 2014 (Reg, 2010). This consumption increases the volume of wastes generated by paint industries and in turn increases land space for recovery and disposal purposes. Due to many negative impacts to the environment, water-based paint is commonly used to replace the solvent paint. Water-based paint commonly uses polymer vinyl acetate as

the main ingredient in the production of emulsion paint for interior application. Polyvinyl acetate emulsions are milky white liquids containing 30-55% polymer solids, water, small amounts of emulsifiers, protective colloids and other additives (Erbil., 2000). Compared to other polymers, paints containing vinyl acetate are more durable, flexible, adhere strongly, dry quickly, colourless, as well as low cost (Randall, 1992; Miller, 2005). In general, paint effluents are alkaline, having high BOD, COD, and contain some heavy metals, suspended solids and coloured materials (Dey *et al*., 2004). However, the increase in production of this type of paint is responsible for the increase in wastes in the form of effluents for disposal and this enhances the necessity for utilisation of this waste material for environmental preservation. Concrete is the largest man-made material with global productions of 3.8 billion annually (Abukersh and Fairfield, 2011). Ease of application, low cost and strong compressive strength have become the main reasons for universal acceptance (Muthukumar and Mohan, 2004).

However, some properties of concrete manifest its shortcomings specifically concerning low chemical resistance, delayed hardening, low tensile strength and higher drying shrinkage. These shortcomings of concrete can be solved by introducing polymer as modifiers. Such a polymeric compound is polymer latex, redispersible polymer powder, water-soluble polymer or liquid polymer (Ohama, 1995). The synergic action between polymers and concrete gives better performance for durable and sustainable construction materials (Gemert, 2013). There is a growing concern to recycle waste materials from paint production by using it to modify concrete mixes. Several works have been done in the utilization of paint waste in concrete as addition or replacement by weight of cement to improve the strength and durability properties of concrete (Almesfer *et al.*, 2012; M. Ismail *et al*., 2011; Ismail and Al-Hashmi, 2011; Nehdi and Adawi, 2008; Nehdi and Sumner, 2003). However, there is scanty information on researches utilising vinyl acetate effluents in liquid form as an addition in normal strength concrete. This research aims at investigating the effects of incorporation of vinyl acetate effluents on strength, microstructure and leaching of the concrete.

MATERIALS AND METHODS

Materials

Ordinary Portland Cement (OPC) complying with BS EN 197-1: 2000 specification was used. Table 1 presents the chemical compositions and physical properties of the cement. Vinyl acetate effluents used as an admixture in concrete were waste generated from the production of polymer dispersion factory in southern Malaysia. The chemical properties of vinyl acetate effluents are shown in Table 2.

Table 1. Composition of cement

Constituents	Percentages (%)	Constituents	Percentages (%)
SiO_2	20.1	CaO	65
AlO_3	4.9	SO_3	2.3
Fe_2O_3	2.4	MgO	3.1
Loss on Ignition	2	Lime Saturated Factor	0.85

Table 2. The composition of waste latex paint (all values in mg/l except for pH)

Parameter	Units	Parameter	Units	Parameter	Units
pH	7.12	Cl^{-1}	56.23	Mn	0.91
BOD	13363.00	NO_3^{2-}	27.53	Ni	0.08
COD	77800.00	Zn^{2+}	1.04	Hg	3.50
TSS	8200.00	Fe^{2+}	1.70	Pb^{2+}	0.13
TDS	5460.00	Ca^{2+}	72.75	P_2O_5	222.00
DO	2.72	Mg^{2+}	9.72	SO_4^{2-}	4514.00
Cr^{3+}	0.14	Na	1199.00	Cu^{2+}	2.69

Mixture Proportion of The Samples

Table 3 shows the mix design used in this study. Concrete sample containing vinyl acetate effluents were cured in accordance to JIS A1171: 2000, and the control following BS 12390-2: 2009.

Table 3. Mix proportion

Specimens	Vinyl acetate effluents (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
WLP 0%	-	380	824	1009	209
WLP 2.5%	9.5	380	824	1009	204
WLP 5%	19	380	824	1009	198
WLP 10%	38	380	824	1009	187
WLP 15%	57	380	824	1009	176
WLP 20%	76	380	824	1009	165

Compressive strength

The compressive strength test was conducted in accordance with BS EN 12390-3:2000. Concrete specimens were prepared by addition of vinyl acetate effluents by weight of cement, as well as control specimen in 100 mm size cubes. Average values of three samples were taken.

FESEM

Field emission scanning microscopy (FESEM) was used to produce morphological photographs, in order to study the microstructural features of polymer modified concrete vinyl acetate waste and control specimen using GEMINI FESEM instrument. The analyzer was fitted to energy dispersive X-ray detector for elemental analysis (EDX). In order to develop a good morphological photograph, the specimens were spotted with platinum gold in an Auto Fine coater instrument. The analyzer utilizes low magnetic field outside the objective lens enabling investigation of magnetic materials and devices. It has magnification in the range of 12-900,000X and a working distance in the range of 1-50 mm, depending on the working condition.

X-Ray Diffraction (XRD)

The hydration of the specimens was analyzed using x-ray diffraction technique. In this study, a Siemens Diffractometer D5000 with X-ray source of Cu Kα radiation was used. The scan step was 0.02^o using a scanning rate of 0.5^o/min and in the range 2-theta-scale from 5^oC to 80^oC. The scale on the x-axis (diffraction angle) of usual XRD pattern gives the crystal lattice spacing, and y-axis scale (peak height) shows the intensity of the diffraction ray.

Leaching Test

Leaching test was carried out according to the Montgomery method (Montgomery *et al*, 1988). The mix with 2.5%, 5% and 10% of vinyl acetate effluents were prepared in cement paste. Samples of cube size 25 mm x 25 mm x 25 mm were cast and cured in air at room temperature for 28 days before immersed in 100 ml distilled water in the sealed high-density polyethylene bottle. The water leaching samples were tested at 1, 3, 5, 7, 15 and 31 days, and the parameters studied were copper - Cu (II), lead - Pb (II) and Zinc - Zn (II).

RESULTS AND DISCUSSION

Compressive Strength

The mix proportion of concrete is designed to achieve grade 25 concrete with a target mean strength of 33 MPa. However, the control specimen achieves a mean strength of 35 MPa at 28 days. Compressive strength shows remarkably higher value when 2.5% of vinyl acetate effluents is added into the mix. However, the incorporation of 5% - 15% of vinyl acetate effluents in concrete still achieves a substantial compressive strength at 28 days. The one-way Analysis of Variance (AoV) indicates the population means of control mix and 2.5% vinyl acetate effluents are significantly different. However, the population mean of control mix is not significantly different from the mix with 5% vinyl acetate effluents specimen. The implication is that the incorporation of 5 % vinyl acetate effluents can be said to yield compressive strength which is not statistically different from the control mix. While 2.5% vinyl acetate effluents is observed to improve the compressive strength, addition of up to 5 % may provide strength not significantly different from the control mix. The objective of adding latex is not mainly enhancing the compressive strength, although some increases in compressive may be achieved with addition of latex as a result of reduction in water/cement ratio by the total solid content of the waste (Ramakrishnan, 1992). Figure 1 illustrates that the compressive strength of polymer modified concrete increases with prolonged curing period. As the water is withdrawn by hydration process or evaporates, the closed packed polymer particles coalescent into continuous film to form a co-matrix intermingled with the hydrated cement paste and binding aggregates (Beeldens *et al*, 2005; Kardon, 1997; Ramakrishnan, 1992). Similar results are also observed by other researcher (Kim *et al*, 1999), where the addition of small amounts of poly (vinyl alcohol) up to 2% by weight of cement causes significant change in the properties of the concrete. Higher concentration of waste latex paints consisting of vinyl acetate effluents in concrete leads to gradual decrease in compressive strength. This trend of results is comparable to other findings (Almesfer *et al*., 2012; Ohama, 1995; Ribeiro *et al*., 2008). The observed decrease in compressive strength with increase in polymer effluent could be associated with combination of phenomena which may include delay in hydration of cement as well as increased air content leading to reduction in density in gel forming the reacted cement skeleton (Ribeiro *et al.*, 2008).

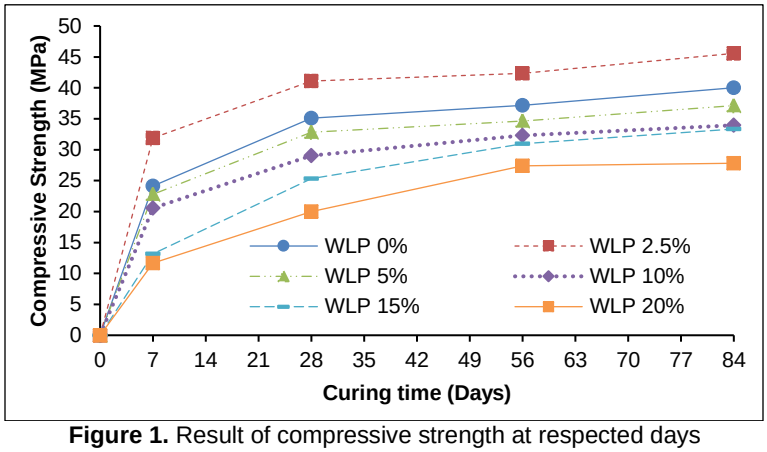

Figure 1. Result of compressive strength at respected days

Morphology

Incorporating polymer vinyl acetate effluents with cement as polymer admixture interacts with the microstructure as evident in Field Emission Scanning Electron Microscopy (FESEM) micrographs at 28 days as shown in Figure 2. The coalescence polymer particles are seen to reside on the surface of cement gel, as well as occupy some spaces in the voids of the cement gel leading to the formation of a polymeric film at the interface with other constituents of the microstructure. The mix with 2.5 % vinyl acetate effluents is observed to reveal minimal cluster of the polymer particles which tends to fill the voids contained in the microstructure and the thin polymeric film may be responsible for its improved strength performance. However, this cluster of polymer particles increases with increase in percentage of vinyl acetate effluents and tends to create more spaces within the gel particles. The diminishing compressive strength as the vinyl acetate effluents addition increased beyond 5 % is attributable to the formation of the thick film of vinyl acetate effluent particles that weaken the interfacial transition zone. The results found are similar to other findings (Mansur *et al.*, 2007; Silva *et al.*, 2001; Silva *et al.*, 2002; Silva and Monteiro, 2005). EDX results show that there are possible chemical interactions between polymer and hydration products of Portland. In Figure 2, the weight percentages of calcium carbonate show decrease with increase of polymer cement ratio content. Some polymers containing vinyl acetate group can suffer hydrolysis when dispersed in alkaline medium. The product of this hydrolysis is the acetate anion $(CH_3COO)^-$ which reacts to Ca^{++} ion from C_2S and C_3S hydration, and forms an organic salt (Calcium acetate). The formation of calcium acetate $Ca(CH_3COO)_2$ increases the loss of weight of the carbonate phases (Gomes and Ferreira, 2005).

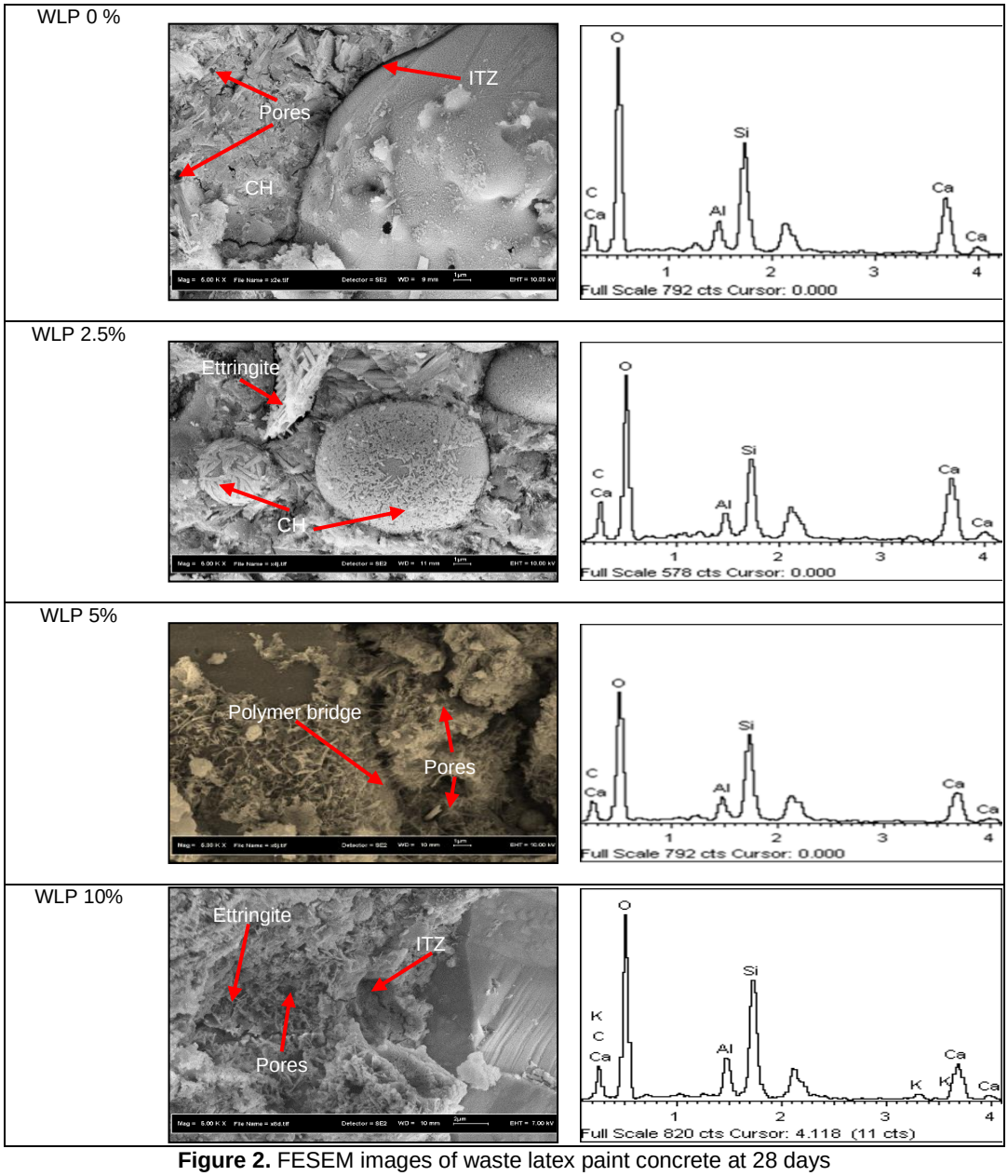

Figure 2. FESEM images of waste latex paint concrete at 28 days

X-ray diffraction (XRD) Analysis of Polymer Effluents

Figure 3 shows the typical XRD curves obtained from vinyl acetate effluents sample. The XRD curve presents the characteristic pattern of amorphous materials with some crystalline peaks associated with an inorganic material, which is calcium carbonate. This inorganic part, known as anti-blocking agent, is added to the formulation to prevent adhesion between polymer particles during manufacturing, transporting and storage.

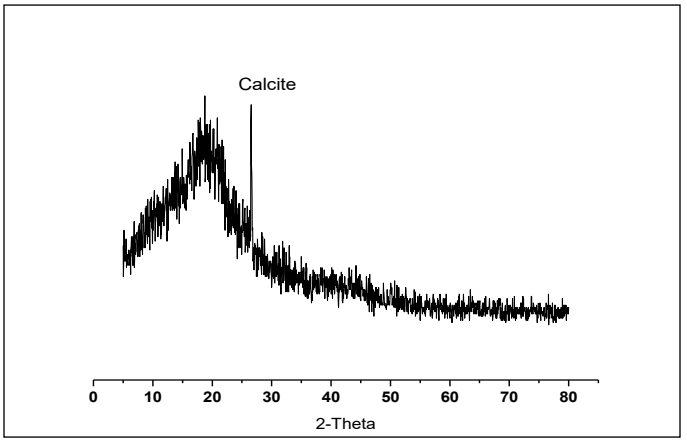

Figure 3. X-ray diffraction (XRD) results of the polyvinyl acetate effluents

X-ray diffraction (XRD) Analysis of Waste Latex Paint Concrete

In order to investigate the influence of the polymer on the cement hydration in the modified paste, XRD patterns of the pastes with and without polymer vinyl acetate effluents are obtained and displayed in Figure 4. Upon hydration of the Portland cement main phases, C_3S (tricalcium silicate-alite) and C_2S (dicalcium silicate-belite) produce mainly portlandite $Ca(OH)_2$ and amorphous calcium – silicate – hydrate (CSH). The degree of hydration could be estimated by comparing the peaks corresponding to Ca(OH) and C_3S. With more hydration, the relative surface area of the peak associated with portlandite will increase and the C_3S will decrease (Wang *et al.*, 2005). It is seen that $Ca(OH)_2$ peak for specimen incorporating polymer vinyl acetate effluents 2.5%-10% are similar to the control on the same spectrum. However, the incorporation of vinyl acetate effluents sample shows smaller peak of $Ca(OH)_2$ with 10% modified sample. These indicate lesser hydration has occurred in this sample. This is possibly due to the surfactant layer at the cement granules surface that prohibits the hydration of water.

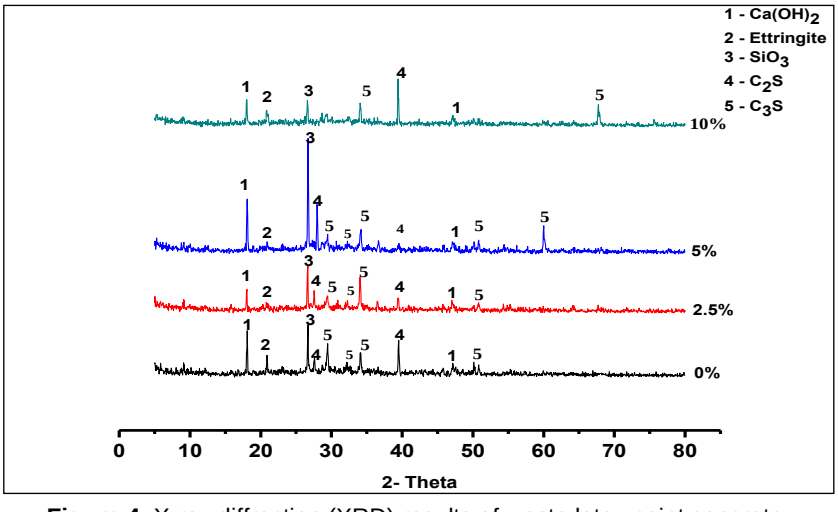

Figure 4. X-ray diffraction (XRD) results of waste latex paint concrete

Heavy Metal Analysis

Table 4 shows the results of leaching test from the incorporation of vinyl acetate effluents in cement paste. Heavy metal compounds such as ions of copper, zinc and lead from vinyl acetate effluents were observed to be reduced after a one-month period. According to the World Health Organization (WHO) data, the maximum contaminant levels for Cu (II), Zn (II) and Fb (II) are 0.5, 3.0 and 0.01 mg/l, respectively, while the Department of Environment Malaysia (DOE) reveals the tolerable limit for the substances are 1.0, 1.0 and 0.5 mg/l, respectively. All the metals are within the prescribed limits. These results were found similar to previous work by Avci *et al* (2017) using paint sludge with cement and lime at 3 days. On the other hand, it was also shown that high content of vinyl acetate effluents, for instance 10% in cement paste reduced the concentration of heavy metal compounds, which could probably be due to the waste ion immobilization. The properties of hardened cement matrix have been used for many years as an effective way and a safe material to solidify hazardous wastes (Kuterasińska-Warwas and Król, 2017).

Organic particles are among the factors that affect cement hydration by adsorption as chemical precipitate forms surface compound on any several cement component surface, forms inclusions, or is chemically incorporated into the cement structures or has simultaneous occurrence of several of these situations (Cocke and Mollah, 1993; Spence and Shi, 2004). Stabilization/solidification using cement based or cementitious material is common worldwide for disposal of hazardous, mixed waste and radioactive material (Gougar *et al*, 1996). The production of solidified waste reduces the surface area available for leaching and the high alkaline environment produced by cementitious binders which ensures that heavy metals are effectively immobilized (Asavapisit *et al*, 1997).

Table 4. Results of the leaching test

Samples	**Day**						**Tolerable Limits**	
							DOE	**WHO**
CP 2.5%	Initial	1	3	7	15	31	Mg/l	Mg/l
Cu (II)	1.344162	0.001226	0.003038	0.003455	0.003512	0.003005	1	0.5
Zn (II)	1.969869	0.002017	0.003054	0.002725	0.002842	0.002594	1	3.0
Pb (II)	0.401441	0.000057	0.000034	0.000073	0.000049	0.000031	0.5	0.01
CP 5.0%	Initial	1	3	7	15	31	Mg/l	Mg/l
Cu	0.062261	0.000383	0.000339	0.000531	0.000474	0.000469	1	0.5
Zn	0.121488	0.000296	0.000323	0.000288	0.000318	0.004699	1	3.0
Pb	9.139098	0.014657	0.034297	0.008525	0.003075	0.001950	0.5	0.01
CP 10.0%	Initial	1	3	7	15	31	Mg/l	Mg/l
Cu	0.059383	0.000464	0.000258	0.000347	0.000369	0.000468	1	0.5
Zn	0.119482	0.000288	0.000311	0.000290	0.000363	0.000577	1	3.0
Pb	7.795460	0.021127	0.024180	0.024629	0.010561	0.040921	0.5	0.01

(Source: (MDC, 1997; WHO, 2008)

CONCLUSIONS

While the addition of 2.5 % vinyl acetate effluent increases the compressive strength above the control, the addition of up to 5 % vinyl acetate effluent achieves strength comparable to the control mix. However, incorporation of waste latex paint (vinyl acetate effluent) above 5% tends to reduce the compressive strength of concrete. The utilisation of 5 % of waste latex paint in concrete would be beneficial to the objective of waste minimisation.

The incorporation of vinyl acetate effluents interacts with the concrete microstructure. Polymer film formation does exist in the interfacial transition zone layer that provides network structure between cement hydration and aggregate bonding which could prevent microcrack propagation. While the thin polymer film observed in the 2.5 % effluent mix is responsible for strength increase, an excessive thickening of the polymer film in the specimen with higher effluent content weakens the interfacial transition zone, hence leading to a reduction in strength.

The XRD patterns of the vinyl acetate effluent sample confirms its amorphous nature, and its ability to interact in the hydration process. The interaction is confirmed in the concrete specimens with the $Ca(OH)_2$ peaks that reduce with increasing effluents as a result of reduced hydration reaction. The patterns of the control sample and varying waste latex paint mixes are not significantly different in terms of the types of hydration products (ettringite, portlandite, alite, belite and silica) identified. It is observed that the XRD patterns show little difference in the quantity of hydration products between the mixes.

Leaching tests show that the incorporation of waste latex paints in cement paste up to 10% meets the tolerable limit provided by the relevant standard.

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MODELLING THE RELATIONSHIP BETWEEN IEQ TOWARDS ECONOMIC ASPECT OF SUSTAINABILITY FOR MALAYSIAN GREEN COMMERCIAL OFFICE BUILDING USING STRUCTURAL EQUATION MODELLING TECHNIQUE

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Abstract
Certified green commercial office buildings are claimed to exhibit higher real-estate values, presumably reflecting expectations for reduced operating costs, and improved organizational productivity through better indoor environmental quality (IEQ) for employees. However, in Malaysia, the economic opportunity aspect resulted from the improvements of IEQ in the green commercial office building is untapped. Therefore, this paper presents the importance of economic recognition of green commercial office buildings by establishing linkages between IEQ's attributes towards the economic aspect of sustainability from the Malaysian context. The Structural Equation Modelling technique has been applied in this study in order to analyse the related IEQ and economic attributes and then modelling the linkages. The results show that there is a significant relationship between IEQ towards the economic aspect of sustainability. The IEQ through the attributes such as indoor air quality, air change effectiveness, less pollution, thermal comfort, noise level, access to sufficient fresh air and glare reduction contribute to the reduction of risk, greater marketability, faster sales and rents and also resulting to higher net operating income (NOI) and return on investment (ROI). These attributes act as an indicator in impacting the value of green commercial office building. The knowledge established as part of this paper would be helpful to the real estate practitioners to better understand the relevance of IEQ attributes as they relate to the property market value.

Keywords: *Indoor environmental quality (IEQ); Economic aspect; Green commercial office building; Structural equation modelling technique*

INTRODUCTION

The development of green building has rapidly risen in response to the mounting concerns about climate change and environmental degradation. Despite the immaturity of the green property market, Malaysia's green building movement is acquiring momentum and becoming the main focus area especially within the commercial sector (Jasimin, 2016). The scenario due to the fact that Malaysia is ranked 26th in the list of international electricity consumption (CEIC, 2018) and according to Kamaruzzaman et. Al. (2009), commercial buildings found to consume almost a third of Malaysia's electricity consumption. Therefore, the green building initiative may be an effective catalyst to reduce the impact that buildings have on the environment. Green building may incorporate sustainable development principles with the strategies mainly relate to land-use, building design, construction, and operation to ensure that the ongoing operation and maintenance of the green building minimize or mitigate a building's overall impact on the environment.

Green Building Index (GBI) certification was formed in 2009 in response to the sustainability movement through the national policies on the environment and technology that has been enacted by the Malaysian government. GBI is a Malaysian green rating system

providing a comprehensive framework for building assessment, which is similar to BREEAM in the UK, LEED in the USA, Green Star in Australia and Green Mark in Singapore.

Certified "green" commercial buildings exhibit higher real-estate values, presumably reflecting expectations for reduced operating costs, and improved organizational productivity through better indoor environmental quality (IEQ) for employees (Appraisal Institute, 2019; Patel, 2019; Smart Market Report, 2018; Birt and Newsham, 2009). Thus, this paper explores the relationship of IEQ towards the economic aspect of sustainability for green commercial office building from Malaysian context to distinguish to what extent of influence among each of IEQ attributes which underlying the principle of sustainability. Therefore, this study is significant to be conducted to ensure that the green commercial office buildings' values are not mispriced and increase continuously in the market.

LITERATURE REVIEW

The connection between sustainability and its impact on a building's market value is increasingly important to the investment community. Investors and occupiers need to know the extent to which sustainability is impacting property worth if they are to respond effectively to sustainability issues (Sayce and Lorenz 2011). Appraisal Institute (2018) and World Green Building Council (2013) in their report reveals that green buildings attract a financial premium in terms of rental and sales value through sustainability aspects including IEQ which identified as significant elements of the environmental aspect of sustainability.

Indoor Environmental Quality (IEQ)

Sustainable buildings offer a lower level of environmental risk by helping to minimize the environmental footprint of the real estate industry on the environment. The considerations of environmental aspect toward the building especially on IEQ are very significant to be explored. According to GBI, IEQ is among the crucial criteria to be highlighted in order to recognize green commercial office building as green (GBI 2018). In this paper, IEQ has been categorised into several attributes including indoor air quality, air change effectiveness, less pollution, thermal comfort, noise level, access to sufficient fresh air and glare reduction. As according to the previous study, these attributes commands an increment in asset value through higher rental rates, lower operating expenses, higher occupancy rates and lower yield (Patel, 2019; Jasimin, 2016).

Indoor Air Quality (IAQ)

Green building has been designed with indoor air quality requirement as a considerable impact on the environment aspect (Lorenz 2009, Elforgani and Rahmat 2011, Burnett et. al. 2005) and become an indicator to IEQ (Burnett et al. 2005, Daruz and Hashim 2012, Wan Ismail and Abdul Majid 2014). This is supported with Lojuntin (2012) who mentioned that green technology in a building has an impact on the environmental aspect through indoor air quality element. Robinson (2005) revealed that indoor air quality that embraced the green office building to have operational costs of 10%-15% lower than a conventional building, thus can contribute to the financial benefit of the building (Ries et al. 2006, Magnus 2013). In Malaysia, GBI has promoted the strategies in achieving the good indoor environment quality (IEQ) through the achievement of good quality performance in indoor air quality, acoustics,

visual and thermal comfort. Indoor air quality is among the criteria needed for an environmental assessment which will enhance by utilizing materials that meet the criteria of low-emitting or non-toxic materials, including paints, coatings, and carpeting (Shivaji 2011). Besides, indoor air quality influenced by the application of quality air filtration, proper control of air temperature, movement and humidity (GBI 2018), improved building structure, and form better heating, cooling and ventilation systems (Eicholtz et al. 2010).

Air Change Effectiveness (ACE)

Air Change Effectiveness (ACE) is the ventilation effectiveness, which is an indication of the interior airflow pattern. ACE plays an important role in the compliance of IAQ management plan in green building design (Elforgani and Rahmat 2011, Burnwtt et al. 2005), that contributes to the sufficient fresh air in the building (Shari 2011). For example, in green building, the heating, ventilation, and air-conditioning (HVAC) and also air-conditioning and mechanical ventilation (ACMV) systems offer occupants the option of natural ventilation through operable windows or energy efficient air conditioning. Operable windows and adjustable air diffusers in the raised floor allow occupants to control their environments without involving building management. GBI office buildings also maximize openings and cross-ventilation in naturally ventilated spaces (Shari 2011).

Pollution

Green buildings aim to prevent pollution (Nurul and Abidin 2012) of noise, water, air, soil, and light as much as possible and thus to remain harmonious with nature throughout the life cycle of the building. Pollution element became among the main important sustainability category in global rating systems such as LEED, GREEN STAR, GREEN MARK and GBI (Ting 2012) that would contribute to the lower environmental impacts. Another commonly used tool for assessing the broader sustainability performance of new buildings such as BREEAM in the UK (Eicholtz et al. 2010) and NABERS in Australia also evaluates the intended performance of not only energy but also a more comprehensive set of environmental areas in a building including pollution aspect. In Malaysia, a group of architects also recognized that Malaysian office buildings had been characterized by less pollution and a pleasant outdoor environment to rest/socialized (Shari 2011).

Thermal Comfort

Thermal Comfort is defined as the "condition of mind which expresses satisfaction with the thermal environment". All of the GBI commercial office buildings studied claimed better Indoor Environment Quality (IEQ) compared to conventional buildings via various aspects including improved thermal comfort. Attributes of green buildings as revealed by World Green Building Council (2013) were associated with healthy indoor environments including high levels of natural daylighting, appropriate levels and types of artificial light, use of materials with minimal toxins, appropriate outdoor air ventilation, thermal comfort and open and inviting spaces that increase interaction and physical movement. The GBI office building needs to provide optimum air movement for thermal comfort in mechanically ventilated spaces (Shari 2011). More user controls for windows, blinds, lights and ventilators can mean that needs (like thermal comfort) are met more quickly even though the conditions may only be ‘good enough'.

Noise Level

Noise abatement has been accepted globally as one of the thematic strategy on the urban development (Lorenz 2006). It was because the ambient noise of the area or within site would affect the health quality of the occupants and those that work nearby. In conventional office property development, people prefer to be connected from the outside, especially if they are sitting in the middle of deep-plan offices. However, with an increasing trend (concurrent with green office developments) away from individual offices towards an open plan, users often perceive an increased noise level in their work environments as a necessary element. In Malaysia, the GBI office building also requires a minimized noise level and provides a satisfactory level of acoustic performance (Shari 2011).

Access to Sufficient Fresh Air

Sufficient fresh air is taken into consideration as an attribute for the indoor environmental quality of green building (Adnan et al. 2010). Sufficient fresh air generated from certain feature of green building for instance operable windows. Fresh air is an important attribute in the green building especially after having the building painted, there is a certain period aimed to flush out the building with fresh air for gases to escape (Shari 2011). GBI office building also practices building flush-out system to reduce possible indoor air quality contamination after construction completion and prior to occupancy.

Glare Reduction

The green office building should maximize glare conditions in main occupancy areas (Shari 2011). Armitage, Murugan, & Kato (2011) through their survey on occupant's perception of green office in Australia revealed that reduction of glare is among the important attributes which promote healthy indoor environments in a green office building.

Economic Aspect of Sustainability

The uptake of sustainability aspects in the buildings would be accelerated by understanding the direct impact on their value. The ownership of green building results in multiple benefits to investors due to the various characteristics of such properties, ranging from lower operating costs to improved marketability, longer useful life spans, increased occupant productivity and well-being as well as more stable cash-flows. As a result, economically quantifiable benefits will obtain through ease of sale and rent, high tenant retention and higher occupancy rates which results in higher achievable rents and the potential of increasing the value of the property and higher relative investment returns.

The economic aspect of sustainability consists of few factors including rental growth, duration of sale, and cash flow which definitely through various research undertaken globally, have a significant direct impact to the value of green commercial office property (Patel, 2019; Appraisal Institute, 2019; Eichholtz, Kok, & Quigley, 2008; Ellison & Sayce, 2006).

Eichholtz, Kok, & Quigley (2008), Patel (2019) and Jasimin (2016) mentioned that labeling green buildings have a positive effect on its rent level. Hence, through a qualitative study, all experts agreed that rental growth was identified as a significant factor to be

considered into the valuation process as it has a significant impact on property value. They also mentioned that all attributes do affect the value of the green commercial office building. An efficient asset management team plays an important role and among the significant attribute in order to manage and control property to ensure the rents increase, and thus affect the value of the property. This was because annual operating costs could be reduced through more efficient asset management as mentioned by Myers et al. (2007).

According to Ellison & Sayce (2006), properties that perform poorly under specific sustainability criteria may take longer to sell than better performing assets. This delay problem lead should reflect in the risk premium for the property, hence would reduce the present value of the capital sum eventually received by an amount equivalent to the appropriate discount rate and period of the delay while cash flow has been identified to reflect the green commercial office value as revealed by Ellison & Sayce (2006) and Jasimin (2016). Lower risk of exposure to the instability of price, tenant retention and also depreciation and obsolescence are among the factors that contribute to the cash flow factor.

Theoretical Framework between IEQ and Economic Aspect

The theoretical framework regarding the IEQ and economic aspect of the green commercial office building is represented by a schematic diagram as shown in Figure 1. The development of this theoretical framework was based on the reviewed of the related literature that has been done before. The theoretical framework, represented by a schematic diagram, indicates how the existence of the relationship among the constructs involved in the study has been theorized. Figure 1 illustrates that there is one independent construct namely the IEQ which have been theorized to have a direct influence the economic aspect of sustainability. In the end, the determination of whether the proposed relationship is significant or not is required based on the data gathered.

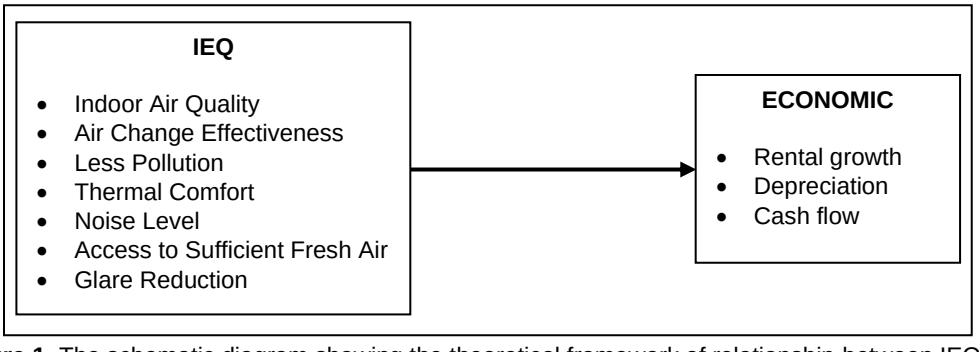

Figure 1. The schematic diagram showing the theoretical framework of relationship between IEQ and economic aspect

DATA ANALYSIS

Since this study is a confirmatory research type with the development of a model with some underlying theory, Structural Equation Modelling (SEM) was employed during the analysis process by analyzing the regression path coefficient or regression weights for the model. The data have been gathered using a questionnaire survey towards the green commercial office buildings' occupants. Before modelling the interrelationship between

constructs in an SEM, the confirmatory factor analysis (CFA) should be conducted first to confirm their unidimensionality, validity, and reliability (Zainudin, 2015). However, the CFA procedure will not be part of the discussion in this paper.

The Relationship between IEQ and Economic Aspect of Sustainability in Green Commercial Office Building

The exploration of relationship is needed to be conducted in order to examine the most significant attributes for the environmental aspect that influence the economic aspect based on the actual beta value in the model. Therefore, the following structural model as depicted in Figure 2 was developed for the path of interest to be tested for each attribute of IEQ under the environmental aspect of sustainability in a green commercial office building. Figure 2 indicates the Regression Path coefficients estimated through SEM. In a model, IEQ denoted by Envi1 was modeled directly towards the endogenous construct namely economic aspect.

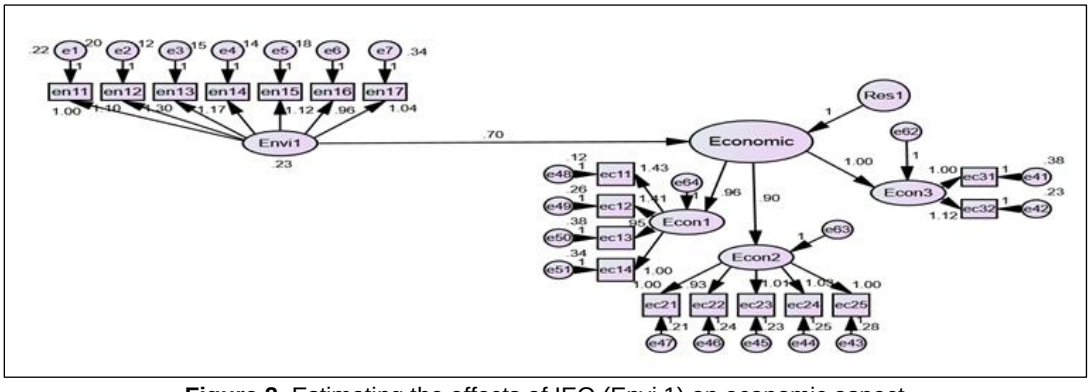

Figure 2. Estimating the effects of IEQ (Envi 1) on economic aspect

Table 1 shows the regression weight for IEQ towards the economic aspect (endogenous construct). All seven accessed (7) items under IEQ are (i) sufficient fresh air; (ii) thermal comfort; (iii) indoor air quality; (iv) air change effectiveness; (v) less pollution; (vi) reduction of glare and; (vii) noise level. The interpretation would be when IEQ increase by 1 unit, and Economic would increase by 0.704 units. The regression weight estimate of 0.704 has a standard error of about 0.1. The probability of getting a critical ratio of 7.027 in absolute value is 0.001. In other words, the regression weight for Indoor Environment in the prediction of Economic aspect is significantly different from zero at the 0.001 level (two-tailed).

Table 1. The regression path coefficient and its significance of IEQ (Envi1) on economic aspect

			Estimate	S.E	C.R	P-Value	Results
Economic	<---	Indoor Environment	0.704	0.100	7.027	***	Significant
Access to sufficient fresh air	<---	Indoor Environment	1.000				
Thermal comfort	<---	Indoor Environment	1.103	0.071	15.441	***	Significant
Indoor air quality	<---	Indoor Environment	1.299	0.095	13.653	***	Significant
Air change effectiveness	<---	Indoor Environment	1.169	0.090	12.995	***	Significant
Less pollution	<---	Indoor Environment	1.122	0.087	12.938	***	Significant
Reduction of glare	<---	Indoor Environment	0.964	0.083	11.620	***	Significant
Satisfying noise level	<---	Indoor Environment	1.043	0.102	10.271	***	Significant

(*** Indicate highly significant at <0.001)

Table 2 shows the important attributes of IEQ. The attributes are measured based on the factor loading values for every item. The required value of factor loading as minimum as 0.6, has been used as a reference. The attributes are ordered based on the highest factor loading value to the lowest factor loading value for each factor under the environmental aspect (The highest factor loading value, indicate the most important attributes).

Table 2. The important attributes of IEQ

Factors	Attributes	Significant Factor Loading
Indoor Environment Quality (IEQ)	Less pollution	0.87
	Thermal comfort	0.82
	Satisfying noise level	0.82
	Air change effectiveness	0.77
	Access to sufficient fresh air	0.75
	Indoor air quality	0.71
	Reduction of glare	0.66

DISCUSSION

Indoor Environmental Quality (IEQ)

The factor of indoor environmental quality (IEQ) has received increasing attention and importance as the move toward energy efficiency and high-performance green building in the commercial real estate world has gained momentum globally. All of the sustainable rating schemes award credits for actions intended to improve indoor environment quality (IEQ). The rating system is due to the significant considerations on the development of green building focused on IEQ (GBI 2018, Shari 2011). Birt & Newsham (2009) have conducted a post-occupancy study on certified "green" commercial buildings and revealed that in the long run, higher market value could not be maintained if these buildings do not deliver their expected benefits of IEQ.

Previous studies undertaken on certified green buildings have determined that a rental rate premium exists in many cases through lower operating costs and enhanced marketability. The rental rate attributes to the attractiveness of green buildings to prospective tenants in terms of their superior indoor environment (World Green Building Council, 2013).

Certified green buildings tend to use less energy and water and are therefore often cheaper to own and operate, making them more attractive to prospective tenants and owner-occupiers where energy and water costs are a significant consideration relative to overall costs, including rents (World Green Building Council, 2013). Accordingly, the water efficiency in green commercial office building will reduce the operating cost and thus enhanced net income for gross lease buildings. Besides, the energy efficiency through the strategies such as use passive solar heating/cooling and enhancing penetration of daylight to interior space might lower operating cost and resulting to higher net operating income (NOI) and return on investment (ROI) (RICS, 2005).

Certified green buildings may be able to achieve higher rates of occupancy. It also offering the owners and developers with the assurance of a lower volatility in the rate of return, displaying an improved performance in the rental market compared to non-certified buildings, lower operating and maintenance cost, lower depreciation and obsolescence and also higher net operating income (NOI) and return on investment (ROI) (RICS, 2005 ; World Green Building Council, 2013).

Economic Aspect

It was paramount significant for producing more sustainable economies through the implementation of the sustainable development principles in the property and construction. Three main factors determine the economic aspect of sustainability in this study as a reference to the result of SEM analysis. The most important factor was rental growth, followed by duration to sale and cash flow factor. All of these factors were measured by some attributes which through the analysis and gave an impact to the value of the green commercial office property World Green Building Council (2013). As a result, their report have concluded that in the longer term, the industry expectation is that rental growth, tenant retention and operating cost savings will become the key drivers for the market value of green buildings, relative to non-green buildings.

Rental Growth

Rental growth was measured by some attributes such as occupancy rate, higher rent, building operating and maintenance expenses and also easier to rent. The respondents rated these attributes as important attributes for rental growth. The respondents agree that the green building has experienced high levels of occupancy that reflect the higher rent, which in turn is affecting the value of the property. The reflection of early and continued high occupancy levels in the green commercial office building attributed to the attractiveness/marketability and quality of the asset, good property management, and other market factors.

Building operating and maintenance expenses analyzed as one of the important attributes for rental growth. Green buildings have been revealed to save money through lower long-term operations and maintenance costs and also reduced the use of energy and water (World Green Building Council 2013). On a simple business cost basis, the escalating costs associated with energy, water, and waste management all feed into the ability to pay.

A building which is energy inefficient, is metered for water use and has no water conservation provisions (such as sprinkler taps and water reuse systems) and has no provisions for waste sorting on site may well cost more to operate currently and will require more as resources and energy become progressively more expensive. While the costs of energy and water have been low for many years, globally this position is changing, and the impact of resource efficiency can be expected to be of increasing significance to the rental bid. At its worst, properties without better resource efficiency will suffer from lower rental growth that offsets, at least in part, the increased cost to the occupier. It is highly unlikely that the rent trade-off will be a one for one, but even a one to three would have an impact on the rental bid and, more importantly, levels of rental growth.

Duration to Sale

The second most important factor for the economic aspect was duration to a sale where the green commercial office building is more accessible to sell compared to conventional property and also easier to be marketed. The period that property takes to let or to sell will always relate to market conditions. When the demand for property outstrips supply considerably, the intrinsic quality of specific characteristics of the property may not have a significant impact on the period to sell or let. However, during periods of low activity when supply outstrips demand, the reverse is true. An increasing supply of sustainable buildings

may also have an impact on demand. Where such supply anticipated, it may render those who do not display sustainability features less attractive to occupiers and purchasers.

A Relationship between IEQ and Economic Aspect of Sustainability for Green Commercial Office Building

Green buildings attract a financial premium in terms of rental and sales value through sustainability aspects including IEQ which recognized under the environmental element. Through SEM analysis, the relationship between IEQ and economic aspect concluded a positive effect, which in turn gave a positive impact on the sustainable aspects on green commercial office building value.

Indoor environment quality (recognizes as latent construct in SEM) under the environmental aspect that was measured using 7 attributes in this study, namely: 1) less pollution; 2) thermal comfort; 3) satisfying noise level; 4) air change effectiveness; 5) access to sufficient fresh air; 6) indoor air quality and; 7) reduction of glare. All of seven attributes obtained through standardized estimate in AMOS output significantly correlated to indoor environments.

This finding denotes that all seven attributes are important components of indoor environment quality that are affecting the property value through the contribution of risk reduction, great marketability, faster sales and rents, higher net operating income (NOI) and also resulting to higher return on investment (ROI). These elements influence the attractiveness of green buildings to prospective tenants in terms of their superior indoor environmental quality.

CONCLUSION

This study has successfully established the linkages between IEQ and the economic aspect of sustainability for green commercial office. The linkages analyzed quantitatively through SEM analysis indicate the significant relationships among the IEQ attributes namely indoor air quality, air change effectiveness, less pollution, thermal comfort, noise level, access to sufficient fresh air and glare reduction, hence have an impact to the value of green commercial office building through rental growth, property depreciation rate, and property cash flow.

The results of this study show that certified "green" commercial buildings indicate higher real-estate values, improved organizational productivity through better indoor environments quality for employees and also presumably reflecting expectations for reduced operating costs.

Therefore, there is a need to accurately determine the impact of sustainability on the market value to ensure the green building increase continuously in the market. It is due to the market value of the property that is most sensitive to the growth of the rental rate. As the rent level is of significant influence on the value or price of a property, this could show a price premium for sustainable buildings. Thus, through the developed structural model, the attributes of IEQ have demonstrated the significant effects on the economic aspect, involving the rental growth and other economic factors as has been discussed in this paper.

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THE POTENTIAL USE OF GAME-BASED VIRTUAL REALITY TRAINING FOR CONSTRUCTION PROJECT MANAGERS

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Abstract
In today's challenging construction world, successful project delivery requires project managers to have the right competencies. Training in both the theory and practice of project management is essential to ensure the enhancement of knowledge and skills. Training in the digital area is challenging and requires creativity and innovative strategies. Based on the Cone of Learning, the training retention rate differs from one approach to another. Hence, this paper presents results from an empirical study that probes the training concept of using game and virtual reality (VR) technology as a learning approach for construction project managers. A survey is conducted with project management professionals attached to the government sector. The objective of the study is to assess whether the Game-based Virtual Reality (VR) training concept is acceptable and effective for project management training. This training concept is reviewed by selected experienced Project Managers who are in agreement that the training concept has the potential to increase the knowledge and skills of project managers. To be recommended as a complement to existing project manager classroom training, some aspects of the game need to be improved. The virtual reality input will enhance the visualization of a real project site.

Keywords: *Game-based learning; Project management learning; Virtual reality application*

INTRODUCTION

Advances in technology have impacted our daily life, whether at home or at work. This is due to the tremendous changes in data, communication and network technologies since the third industrial revolution which began during the late 1960s (Davis, 2016). The emergence of digital systems, information technology and automated production is highly promoted in the fourth industrial revolution where technologies have become part of our lives by connecting billions of people via mobile phone technologies (Schwab, 2017). Communications technology is rapidly developing due to new technology discoveries, including artificial intelligence, robotics, the Internet of Things and autonomous vehicles, which will change how people work (Rogers & Junga, 2017). A key aspect of the birth of the new technology is the growth in information technology and its simultaneous impact on people's learning processes (Davis, 2016; Schwab, 2017). Hence, the need to gain new knowledge and skills is of the utmost importance in any industry.

The construction industry, like any other, is influenced by the digital technologies. The significant impact of digital technology in construction could be seen via the application of Building Information Modelling (BIM). BIM involves the building of 3-dimensional models by integrating non-graphical object data into the model (Demian & Walters, 2014). BIM could be used throughout the project lifecycle in many forms, i.e. as design, monitoring and training tools. However, to explore the design model and get an understanding of the complexity of the construction process, an immersive visualization in BIM is needed. Therefore, visualization technology changes the way people learn by enabling the project manager and

project team to understand the construction processes realistically, accurately and effectively in 3-dimensional ways via virtual reality tools (Guo, Yu, & Skitmore, 2017).

For project managers, the learning process usually happens throughout their job. Organizations conduct classroom training to expose the theory of project management. This approach uses face-to-face training and it is appropriate for theoretical-level learning (Gao, 2017). However, to experience the real scenarios of project management requires a hands-on approach. The on-site training approach has constraints in terms of time and site availability. It also involves a risk to the project environment if the decisions made are not correct. The need for theory and practical training is essential to increase competency and management capabilities. Henceforth, the shortcomings of the existing training system need to be addressed.

The introduction of project management training using visualization technology will mitigate the above issues. The Project Management World is an online project management training using game-based virtual reality. The challenges in Project Management World are developed using various project scenarios in the different phases of a project lifecycle. This learning approach concept was introduced at project management talk conducted at the Government Technical Department in Malaysia and a presentation was made using a low-fidelity prototype to subject matter experts in project management field. However, for this prototype, the focus was on the planning phase. The learning application was run via a low-fidelity prototype, i.e. Microsoft PowerPoint™, without any interactive function for respondents to test (Walker, Takayama, & Landay, 2002). This research paper seeks to answer the underlying question; how could game-based virtual training assist construction project managers in enhancing their knowledge and skills? Moreover, the integration between visualization and game technologies contributes to an interactive learning approach. This approach stimulates 'learning by doing' and as a result enhances the learning effectiveness. This research paper also seeks to identify the acceptability of the game-based virtual reality (VR) training among selected experienced project managers.

LITERATURE REVIEW

Project management is a systematic approach towards achieving project goals whereby the project manager uses his/her knowledge, skills, tools and techniques to manage project processes (Nicholas & Steyn, 2017). It also may be viewed as the science and art of managing all aspects of any given project requiring both hard skills and soft skills (Reddy, 2015). The needs for project management are to ensure projects are systematically managed, have predictable outcomes, use resources effectively and produce well-documented lessons learned (Mir & Pinnington, 2014). Thus, having project management knowledge and skills is important in understanding and executing projects successfully and thus, achieving project success. For those involved in any project, management competency needs to be developed, hence there is a need to develop a project management competency framework such as those produced by the Project Management Institute, U.S.A. and the Australian International Project Management Association (IPMA, 2006; PMI, 2002). These frameworks include the baseline competency requirements. Both organizations provide a certification of competence to any project management professionals who meet their standards. The project management learning structure could be tailored according to any framework. Generally, the basis of project management is to understand and apply the project management knowledge areas

outlined by the Project Management Institute using a low-fidelity prototype using a low-fidelity prototype (Institute, 2017; PMI, 2008). Other competencies required will be soft skills or behavioural competencies, which relate to the human dimension, e.g. interpersonal skills and leadership. Based on the study by (Derus, Abdul-Aziz, & Enshassi, 2015), there are seven types of behavioural skills which are critical, i.e. teamwork and cooperation, self-confidence, communication skills, commitment to organization, concern for order and quality, and technical motivation. Therefore, the training provided must be attractive to increase motivation and self-learning.

Games are perceived as entertaining and engaging but can separate an individual from the real world. Games with challenges, risks and meaningful outcomes could become addictive (Garris, Ahlers, & Driskell, 2002). Games have goals, specific rules and challenges. These criteria are similar to managing a project whereby there are project objectives, standards and guidelines to follow and the need to manage risks throughout the project. Hence, using games in project management learning provides realistic experience (Aslan & Balci, 2015; Barough, Shoubi, & Skardi, 2012; Trybus, 2015). Furthermore, project management game-based learning provides a risk-free learning environment wherein the learners could make mistakes and learn from them. Learning by doing is considered as giving more effective and enduring experience (Lee, Nikolic, & Messner, 2014). On top of that, according to Edgar Dale's Cone of Learning (Dale, 1969), when a person learns by doing the required task the retention learning rate is 90%. In view of the need for project management competency (Yong & Mustaffa, 2012), an interactive project management learning application for project managers in the construction industry has been developed using a game-based approach. Hence, the learning application is named 'Project Management World'. The content of this learning application covers project management knowledge areas throughout the project lifecycle.

At each phase, there are challenges that the project managers have to face before they can advance to the next phase. These challenges will provide the motivation for the learners to play and learn from the games (Mayer, 2014). To further immerse the learner in the learning environment, virtual reality features are included in the learning application. With virtual reality (VR) tools, the learner, i.e. a project manager in this context, could visualize the project site without even going to the real site (Kim & Watson, 2017). Table 1 illustrates the retention rate against the different learning approaches.

Table 1. Learning Approaches vs Retention Rate

Learning Approaches	Retention Rate
Reading	10% of what we READ
Hearing words (e.g. classroom training or lecture based)	20% of what we HEAR
Seeing	30% of what we SEE
Watching a movie Looking at an exhibit Watching a demonstration Seeing it done on location	50% of what we SEE and HEAR
Participating in a discussion Giving a talk	70% of what we SAY
Doing a dramatic presentation Simulating the real experience Doing the real thing	90% of what we SAY and DO

Adapted from 'The Cone of Learning', Edgar Dale (Dale, 1969).

Studies show that the retention rate for learning approaches that rely on reading, hearing and seeing is low because in these approaches the learners are in a passive state. In order to acquire knowledge, learners need to participate in a learning environment (Wouters, Van der Spek, & Van Oostendorp, 2009). Henceforth, the other learning approaches in Table 1 above are considered as active learning. Active learning approaches push learners to a higher level of thinking that is stimulated in conjunction with practical experiences. The link between learning approach and the retention rate has been investigated further by Thomas Lord (Lord, 2007) and similar results obtained. The result from the Cone of Learning is also in line with the US philosopher, Benjamin Franklin, who said "Tell me and I forget. Teach me and I remember. Involve me and I learn" which could result in higher retention rates for learners.

The development of virtual reality (VR) started in the early 1990s. There are multiple definitions of VR. Among others are: a creation of the real world using computer-generated simulation or a three-dimensional environment in the real world (Mazuryk & Gervautz, 1996). At the early stage, VR's most known application is the flight simulator. Enhanced visualization technology has spread the use of VR in other industries. Past studies show that the adoption of VR has a positive impact (Bouchlaghem & Liyanage, 1996; Lee *et al.*, 2014). VR engages and motivates people to learn in an immersive and interactive environment. The largest application of VR in construction training is related to architectural visualization (Wang, Wu, Wang, Chi, & Wang, 2018). Using VR in architectural design entails improved graphic and detailed modelling. The next largest application of VR is construction safety training. With VR, safety training can be done in a low-risk environment with real construction site conditions.

METHODOLOGY

Instrument

A questionnaire survey was developed to explore the respondents' perceptions of game-based virtual reality training for construction project managers. Data collected from the questionnaire are respondents' demographic details and their attitudes toward project management learning. A comments section was also included in the survey forms. Three criteria were taken into account in considering the potential of game-based virtual reality training as a learning tool: perceived usefulness (PU), perceived ease of use (PEU) and intention to use (ITU) (Baharum, 2013; Zakaria, Salleh, & Nawi, 2017). The survey was designed to allow conclusions on game-based virtual training acceptability to be drawn. The survey method was favoured because of the economy of design and quick analysis of the collected data (Creswell & Creswell, 2017). A Likert Scale from 1 to 5, ranging from strongly disagree or strongly agree, is used to measure the respondents' perspectives which could quantify people's attitudes towards ease of use and versatility (Johns, 2010).

In order to support the questionnaire findings and answer the research question, interview sessions were carried out with three professionals who are subject matter experts in the project management field. All three of them were from the same department as the respondents from the questionnaire session. The sessions took place separately on different dates. The interviews were conducted based on structured questions covering three main areas: respondent's background, factors influencing the acceptability of the learning approach and the benefits, barriers, intention to use and any recommendations concerning the approach.

Sample

This study is an exploratory study which was carried out at one of Malaysia's Government Departments. Professionals from this Department were involved in one or more of the following areas: technical consultation, project management and maintenance management. The questionnaires were distributed to the professionals during a talk held on project management practice for an international project in Mecca, Saudi Arabia. These professionals were not presented with the actual game-based virtual reality learning approach, only the concept of game-based virtual reality learning as explained in the questionnaire. The questionnaire was distributed by hand and respondents could ask any question if they had any queries. About 300 professionals attended the talk, 179 questionnaire forms were received.

Technology Acceptance Model (TAM)

Learning is effective when there is a change in behaviour. When something new is introduced, there is a fear of uncertainty or not knowing the positive or negative impact of the technology (Skoumpopoulou, Wong, Ng, & Lo, 2018). Hence, user acceptance is a critical factor to be considered as it helps determine the usage of the technology. TAM is used to anticipate the user acceptance and to measure the user's reaction towards the new technology. User behaviour, perceived usefulness and perceived ease of use are the key factors which influence individual mindsets and reactions when he/she uses specific technology (Hsu & Chang, 2013). TAM also foresees the intention to use and adopt the new technology. The model is adjustable to be extended by incorporating other variables which can justify the acceptance despite not being included in the original model (Lorenzo-Romero, Alarcón-del-Amo, & Constantinides, 2014). Hence, the used of TAM has been validated under many conditions (Baharum, 2013; Hsu & Chang, 2013; Lorenzo-Romero *et al.*, 2014; Zakaria *et al.*, 2017).

RESULTS AND DISCUSSION

Findings from the Questionnaire

Demographic Data

61% of the professionals at the talk have given their feedback. The demographics of these professionals are as follows:

- Gender: 51% are female professionals;
- Work disciplines: civil (67%); electrical (10%); mechanical (10%); quantity surveying (10%) and architectural (3%).
- Age Range: 23% are professionals between 20 – 31 years old; 56% between 32 – 49 years old and 21% are 50 years old and above.

Professionals' Perceptions of Game-based Learning (GBL)

Three aspects are considered to evaluate the professionals' perceptions of GBL: perceived usefulness (PU); perceived ease of use (PEU); and intention to use (IU) (Baharum, 2013; Hsu & Chang, 2013; Lorenzo-Romero *et al.*, 2014; Zakaria *et al.*, 2017). Descriptive statistics were used to determine the professionals' responses. Table 2 summarizes the percentage of professionals' scores against these three aspects.

Table 2. Descriptive Statistics of Professionals' Scores for PU, PEU and IU

	Mean	Scores	Percentage
PU	23.71	12 – 18	22.9%
		21 – 30	77.1%
PEU	22.23	12 – 18	29.0%
		19 – 30	71.0%
IU	18.76	10 – 15	27.2%
		16 – 25	72.8%

As presented in Table 2, professionals' scores on the perceived usefulness range from 12 to 30 with a mean of 23.71. The scores from 12 – 18 are categorized as representing a lower level of usefulness whereas scores more than 21 reflect higher usefulness. Since the scores of 77.1% ranged from 21–30, it is obvious to say that the professionals agree that game-based virtual reality training is useful for project management learning. With regards to ease of use, Table 2 shows that professionals' scores range from 12-30, with a mean of 22.23. Scores from 12-18 are indicated as "not perceiving ease of use", whereas scores from 19-30 give a "perceived ease of use" indication. Based on Table 2 above, 71.0% of professionals believe that project management using game-based virtual reality training will be easy to use. Next, the score range for the item on "intention to use" is from 10-25 with a mean of 18.76. The professionals who got scores from 10 – 15 do not have the intention of using game-based virtual reality training. On the other hand, those scoring from 16 – 25 intend to use game-based virtual reality training. From Table 2, the result shows that 72.8% of professionals have positive attitudes towards using game-based virtual reality training. From the results above, it is important to realize that, even though the professionals were not given a real game, they are accepting this type of learning approach . These results are also supported by their comments written in the questionnaires. Some of the written comments are:

- It is enjoyable and easy to practice;
- It is fun;
- It is a new thing that could attract people to learn;
- It is more interesting;
- It is interactive learning; and
- It is a new method and suitable for new generations.

These responses were significantly supported by the previous findings from studies on the advantages of game-based virtual reality training (Aslan & Balci, 2015; Dzeng & Wang, 2017; Garris *et al.*, 2002; Lee *et al.*, 2014; Wang *et al.*, 2018).

Attitudes towards Project Management Learning (APML)

Since game-based virtual reality training involves online learning where the learner could access it anytime and anywhere, it is considered to be a "learner centered approach". Hence, the professionals must have positive attitudes towards learning project management. Descriptive analysis gives the following results.

Table 3. Descriptive Statistics of Professionals' Scores against APML

	Mean	Scores	Percentage
APML	41.27	27 - 30	8.1%
		31 - 50	91.9%

As illustrated in Table 3, professionals' scores for the item that calculates their attitudes towards project management learning range from 27 to 50 with a mean of 41.27. The scores from 27-30 indicate negative attitudes. At the same time, the scores 31-50 represent positive attitudes for project management learning. As only 8.1% claim to have a negative attitude, generally speaking, the professionals recognized that project management is important and that continuous learning is required.

Relationships between APML, PU, PEU and IU

To identify the relationships between APML, PU, PEU and IU, correlation analysis was conducted. Table 4 depicts the scores from the analysis.

Table 4. Correlations between APML, PU, PEU and IU

	APML	PU	PEU	IU
APML	1	0.536**	0.435*	0.592**
PU	0.536**	1	0.884**	0.742**
PEU	0.435*	0.884**	1	0.804**
IU	0.592**	0.742**	0.804**	1
Mean	41.27	23.71	22.23	18.76
Std. deviation	6.09	4.81	4.59	3.96

Note. ** Correlation is significant at $p < 0.01$; * Correlation is significant at $p < 0.05$

As seen from Table 4, there is a positive and significant relationship between APML, PU, PEU and IU. Comparing the correlation coefficient (r) values reveals that there is a relationship between attitudes towards project management learning and the three aspects of game-based virtual reality training acceptance. However, the strength of the relationship is only moderate and low, as summarized below:

- The strength of relationships between APML and PU (r=0.536) and IU (r=0.592) is moderate;
- The strength of relationship between APML and PEU (r=0.435) is low.

From Table 4, the highest value of correlation is between PU and PEU (r=0.884), which means that the higher the ease of use of game-based virtual reality training, the more people perceived it to be useful for project management learning.

Findings from the Interviews

Initially, five subject matter experts (SMEs) were identified for interview on this training approach. Only three SMEs were available for the interviews. The interview sessions were conducted on three separate days. All the three SMEs have worked for more than 30 years. Their project experience ranges from 20 years to 34 years. They are Certified Workplace Assessors for project managers and Certified Practising Project Managers under the Australian Institute of Project Management (AIPM). Hence, their input on this topic is valuable.

The objectives of the interview were to evaluate the training approach, test its usefulness and ease of use, and to identify user needs for this approach. Before, the sessions began, the SMEs were presented with a low-fidelity prototype of a project management game, i.e. Microsoft PowerPoint, without any interactive function for SMEs to test (Walker *et al.*, 2002).

The content of the game includes project management knowledge areas (based on Project Management Institute Standards), tools and templates, and project management best practices (Institute, 2017).

The interviews were conducted using structured questions based on these aspects: architecture, effectiveness, usefulness, usability and ease of use. Under the architectural aspect, the SMEs were asked about the realistic look of the game, understanding the game processes and ease of navigation. All three gave different answers on the realistic look of the game. SME1 stated that the learning environment needs to suit the outcome of project management competency standard. SME2 agreed that the game is sufficiently realistic. SME3 stated that the concept is good. However, the quality of video and presentation needs to be improved. In term of processes understanding, all three SMEs acknowledge that the processes are understandable. As there are no interactive functions, SME3 stated difficulty in commenting on this aspect. SME1 suggested a touch screen option. While, SME2 felt that navigation through short steps encourages users to stay focused and understand the game successfully.

On the aspect of effectiveness, all three SMEs concurred that game-based virtual reality training could improve knowledge and skills, heighten learning interest and become an effective adult learning approach (Wouters *et al.*, 2009).

Many views were received on the aspect of usefulness. SME1's feedback was that if the game is interesting, it will motivate learners. It can cultivate learning and best practices by creating project management scenarios. This approach has a low cost of development, whilst providing a rich experience. Long term success is only achieved if there is repetition. SME2's opinion stressed that the learning environment must be based on actual project scenarios to increase interest. The realistic interactive learning environment provides valuable experience. Visual and interactive functions provide long lasting effects and better understanding in adult learning. SME3 agreed with SME1 that this approach can cultivate learning because all the required knowledge is there, and this approach has a low cost of development whilst giving a rich experience.

Usability looks at aspects of simplicity, game objectives and learnability. The SMEs accept that the game is simple and that the game objectives could be achieved effectively and efficiently. SME3 added that it will be more effective if the game involved lots of decision-making challenges. All the SMEs agreed that the game could enhance individual learning.

The SMEs agreed that the game is able to test the learner's senses through an interesting learning environment and evaluate the learner's performance. SME3 commented that the element of fun is not clearly seen in the game and needed to be improved.

Other feedback from the SMEs on game-based virtual reality training notes that it can reach an infinite number of people, as long there is an internet connection; it is cheap; it does not need a teacher; the 3D visual approach reinforces effective learning and creates a lasting impact on user competency and performance; it is not time consuming; can be accessed anywhere in any free time; it allows private learning wherein users can make mistakes and try out different actions.

CONCLUSION

This study was executed to evaluate the perceptions of construction project managers, who are Government professionals, towards using game-based virtual reality training in project management learning. The project management learning using this training approach provides a web-based interactive learning experience which gives the learner flexibility in learning, i.e. anytime and anywhere. This approach was new to the construction project managers. Hence, it is wise to explore further their acceptance of this approach before suggesting it for general implementation and execution. Their perceptions were evaluated using three aspects: perceived usefulness, perceived ease of use and intention to use. A relationship between attitudes towards project management learning and the perceived acceptance aspects was also studied. Based on the collected data, it was found that the construction project managers perceived that game-based virtual reality training is useful for project management learning. They also confirm that game-based virtual reality training is easy to use and that they have the intention of using it. With regards to attitudes towards project management learning, the professionals show positive attitudes. Since there is a relationship between the attitudes which accept game-based virtual reality training, this contributes to their positive perceptions on game-based virtual reality training. With these perceptions, the study opens an opportunity to create a need for project management games. This learning approach is fun and engaging. Thus, it motivates continuous learning and enhances project management learning and development. As a result, a construction project manager's competency is enhanced. Having a competent construction project manager is essential for project success. This is an exploratory study of Government professionals' perspectives on project management learning using a game-based virtual reality training approach. Future activity to build on this study involves the development of a real project management game and the evaluation of its acceptability.

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PERSPECTIVE ANALYSIS ON IBS PROVISION IN STANDARD FORM OF CONTRACT IN MALAYSIA

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Abstract
Even though the Industrialized Building System (IBS) has been introduced for over 40 years in Malaysia but the pace of adaptation of IBS is still slow and below the government's target. Construction players are still facing various issues and challenges when adopting IBS particularly on contractual and procurement aspects; thus it contributes to the low adoption of IBS in Malaysia. As of to date, there is still the lack of provisions in the Malaysia standard form of contract to suit the IBS construction approach. Therefore this research will attempt to provide statistical evidence on this issue. Literature review and questionnaire survey to IBS players in the construction industry were used in the data collection exercise. Varies statistical test was done using SPSS Software. The findings from the analysis provide overall perception from the IBS players and identify mean differences between two or more groups. The outcome will be the basis for drawing the general conclusion about the groups on the issues. The study revealed useful statistical evidence related to the contractual aspect in the IBS construction approach that will be useful in order to enhance the local standard form of contract to suit IBS construction approach hence able to accelerate the adoption of IBS construction in Malaysia.

Keywords: *IBS; Standard form of contract; Contract; Procurement; Malaysia*

INTRODUCTION

According to (Construction Industry Development Board (CIDB), 2015a) stated that Malaysia's economic growth has been steady over the past five (5) years with 6% per annum. Construction Industry Transformation Programme 2016 – 2020 (CITP) was launched back in September 2015 with the vision to transform the construction industry to become highly productive, sustainable and globally competitive while raising the professional bar in the industry. One of the key initiatives in raising the productivity of the construction workforce is to drive higher technology adoption used in advanced construction methods (IBS). (Kamaruddin *et al.*, 2013) Reported that the Malaysia government has always been committed pushing the IBS as national agenda since the nineties (90s). Numerous initiatives were done throughout the years namely Construction Industry Master Plan (CIMP) in 2006, IBS roadmap in 2010 and the latest is CITP in 2015 as stated by (Mohd Fateh and Mohammad, 2017). Nevertheless, according to the report by (CIDB, 2015b) and (Construction Industry Development Board (CIDB), 2015b) stated that the IBS adoption rate in Malaysia is still low.

From the findings by (Mohd Fateh and Mohammad, 2017), it shows that Malaysia's standard forms of contract still lack in the provision for IBS or prefabricated construction activities. It creates uncertainty and potential risk to the industry players thus low adoption in IBS construction approach. (Mohd Fateh and Mohammad, 2017) Also reported that the current standard form of contract does not provide enough provision for the IBS construction approach. Therefore, it is necessary to enhance the standard form of contract to suit the IBS construction approach hence accelerate the adoption of IBS construction.

Therefore, this paper will be looking at the statistical point of view on the issues. Varies statistical test will be done based on the findings from the questionnaire survey. This research will provide statistical evidence regarding the matters thus give an insight of information and guidance to all the related stakeholders such as CIDB, Public Works Department (PWD), expert panels, academicians and related IBS players. It will give a value-added impact on the adaptation of IBS construction approach.

This paper is structured into three parts. Firstly, the review covers a broad range of literature providing an overview of the construction industry, IBS scenario in Malaysia and the summary comparison of provision for IBS construction approach in the standard form of contract from varies countries. The second part discussed the methodology used for this research. The last part discussed findings and conclusions derived from evidence from the literature review and the questionnaire survey.

THE CONSTRUCTION INDUSTRY

The construction industry today faces many challenges. One issue that always been plagued will be the fragmentation issues as stated by (Abd Shukor, Mohammad and Mahbub, 2011). Due to the challenges and issues faced, productivity within the construction industry has dipped over the years, currently lagging behind other developed economies and other economic sectors in Malaysia as reported by (Construction Industry Development Board (CIDB), 2015a). There is an urgent need to push for higher productivity in the workforce and technology within the construction sector to increase GDP and ensure international competitiveness, driving toward our national high-income agenda.

CITP calls for adoption and utilisation of modern construction methods and technologies (IBS) to address the productivity and quality issues in the industry. (Mohammad *et al.*, 2017) reported that moving towards industrialisation is not only applied in Malaysia, it has been a global trend in moving towards that direction.

IBS IN MALAYSIA

IBS is defined as a construction technique in which components are manufactured in a controlled environment (on or offsite), transported, positioned and assembled into a structure with minimal additional site work according to (CIDB, 2014a). Various previous researches done has been done previously locally and internationally. Findings have proved that IBS can offer considerable benefits in terms of cost and time certainty, attaining better construction quality and productivity. Nevertheless, the adoption rate for IBS construction is still low as reported by CIDB (2015a) and Nawi et al., (2011). This is alarming because (CIDB, 2017b) and (Yusof, 2015) reported that the government intends to make the adoption of IBS in construction projects compulsory in 2018; thus few issues need to look into to able the acceleration of adoption of the IBS.

According to Mohd Fateh et al., (2016) and Mohamad Kamar et al., (2009) stated that the construction players are still facing some issues and challenges in contractual aspects when adopting IBS; thus it contributes to the low adoption of IBS in Malaysia. Based on the preliminary study being done by Mohd Fateh et al., (2016) stated that all respondents agreed that it is a necessity to enhance existing Malaysia's standard form of contract to suit IBS

construction approach. Findings from (Mohd Fateh and Mohammad, 2017) also proved that there are lacking in the standard form of contract that is used in Malaysia, compare to other developed countries.

Therefore, this research is to provide statistical evidence on the provision in the standard form of contract and identify the critical provision that needs to be enhanced to suit IBS construction approach, hence propel the acceleration adoption of IBS construction approach parallel with the CITP's vision.

SUMMARY OF COMPARISON ON STANDARD FORM OF CONTRACT

The standard form of contract can be defined as a printed form and published by an authoritative body of the industry, which recognised by both parties in the contract reported by Singh (2011b), Kalsum et al., (2011) and Mahdi (2001). The forms set out the terms or condition on which the contract between the parties is to be carried out. As highlighted by Singh (2011a) and Zakaria et al., (2013), the purposes of the standard of form contract are as follows:

- Provide the necessary legal framework evidencing the legal relationship between the parties.
- Furnish a mechanism for regulating the conduct of the commercial relationship between parties.
- Put in place the administrative procedures necessary to effect the legal and commercial relationship between parties.
- Establish the ambit of powers and duties of the contract administrators under the contract between the parties.
- To facilitate the contractual arrangements between all players in a project.

In summary, the standard form of contract is multifold governing not only legalities but also administrative issues to ensure that both parties can discharge and can discharge their side of the bargain through full performance as stated by Singh (2011b) and Zakaria et al., (2013).

As of to date, there is still a lack of provisions in the Malaysia standard form of contract to suit the IBS construction approach as reported by (Mohd Fateh, Mohammad and Abd Shukor, 2016). From the document analysis done by (Mohd Fateh and Mohammad, 2017) which compared provision in the standard form of contract local and internationally, there is few provision that is the difference in Malaysia's standard form of contract. The comparison is illustrated in table 1. Details elaboration on the differences can be found in (Mohd Fateh and Mohammad, 2017).

Therefore this research will attempt to provide statistical evidence related to the provision highlighted that would be useful in order to enhance the local standard form of contract to suit IBS construction approach hence able to accelerate the adoption of IBS construction in Malaysia.

Table 1. Summaries findings from the document analysis

PROVISIONS	PWD 203A 2010	PWD DB 2010	PAM 2006	PSS 2014	FIDIC 2010	AS 4300	JCT 2011
Definition of unfixed material and goods							
• need to be onsite	√	√	√	√	√	√	√
• can be offsite				√		√	√
Evaluation of interim payment							
• progress work done	√	√	√	√	√	√	√
• the material on site	√	√	√	√	√	√	√
• material offsite				√		√	√
Inspection, testing of material, goods, and equipment							
• already incorporated onsite	√	√	√	√	√	√	√
• not yet incorporated onsite	√			√	√		√
Insurance/Bond							
• Unfixed material onsite (any loss or damages)	√	√		√	√	√	√
• Unfixed material offsite(any loss or damages)						√	√
Submission offsite supervision report							
• on-site progress		√			√	√	
• off-site progress					√		
Extension of Time (relevant events)							
• occurred onsite	√	√	√	√	√	√	√
• occurred offsite			√	√			√

METHODOLOGY

Questionnaire Survey

Questionnaire survey methods are useful when the researcher know what is required and how to measure the data collected. According to (Awang, 2012) the advantages of using questionnaire are the researcher able to collect a more extensive array of data. While according to (Muhamad Halil, 2013) questionnaire survey is an effective method to attain a large sample size to collect quantitative data for analysis. Thus, sample groups stated in table 2 was chosen as they have vast experience in IBS construction approach. At this day and age, researchers are encouraged to integrate the benefits of technology with a questionnaire survey that enable faster data collection and analysis as reported by (Awang, 2012). This was agreed by (Kothari, 2004) stated that applying technology integration is a better approach to apply when dealing with significant populations of respondents. Questionnaire survey can be administered personally, mailed or electronically distributed.

Table 2. Summary of the questionnaire survey key information

STRATIFIED GROUP	ROLES IN CONTRACT	SOURCE	TOTAL NO.	SCOPE LIMITATION	QUESTIONNAIRE SEND	RETURN	%
Government Agencies	Client	• (CIDB, 2017a) • CIDB's workshop	20 agencies	Three agencies were excluded	20	17	85
Private organisations	Client	• CIDB's workshop	15 agencies	Invitation by CIDB based on the activeness of the organisations in IBS. Only selected and critical players are invited. Designation of participants consists of the owner, managing director or director of the organisation itself.	15	11	73
Consultant	Consultant	• (CIDB, 2014b) • CIDB's workshop	37 consultants	• Consist of Engineer, Architect and Quantity Surveyor • Registered as IBS Consultant with CIDB	37	8	22
Contractor	Contractor	• (CIDB, 2014b) • (CIDB, 2016) • CIDB's workshop	230 contractor	• G7 contractors • Registered as IBS Precast contractor with CIDB	230	64	28
Manufacturer	Manufacturer	• (CIDB, 2014b) • CIDB's workshop	25 manufacturer	Registered as IBS Precast manufacturer	25	18	72
				TOTAL	**371**	**118**	**32**

Pilot study was done before proceeding with the questionnaire survey. The purpose of performing the pilot study is to detect any weakness in the questionnaire and its instrumentations. This was agreed by (Awang, 2012) stated that pilot study is critical to ensure that the researcher did not overlook specific aspect which would affect the outcome of the research. Amendments were made after completing the pilot exercise, reduce the number of questions, restructure the questionnaire formats and adjust the scale used.

In this research, a questionnaire survey via electronically and face to face was used. The questionnaire survey was done online, where a web-based questionnaire landing page link was emailed to the respondents. Upon receiving the email, respondents click the link and start the questionnaire survey. Report by (Couper, Conrad and Tourangeau, 2007) and (Couper, 2012) stated that web surveys as a new mode of conducting surveys via websites had gained significant popularity. (Fan and Yan, 2010)added that compared with traditional modes of surveys, web surveys have several advantages, including shorter transmitting time, lower delivery cost, more design options, and less data entry time.

For this research, the questionnaire survey is broken into four sections. The summaries of the sections are as follows:

- **Section 1:** This will be the front or landing page, where the respondents can identify the research title, background and the objectives of the questionnaire survey.
- **Section 2:** in this section, it focuses on the respondent's demographic (background). This includes the respondent's organisation sector, designation, years of experiences in IBS projects and construction industry as a whole.
- **Section 3:** the information on the process and adoption of IBS construction were recorded in this section. This includes issues in adopting IBS construction in term of contractual aspect. types of standard contract that frequently used, types of procurement arrangement they frequently used and the most important part is which clauses that need to be enhance in the standard form of contract for adopting IBS construction using 5 points Likert Scale.
- **Section 4:** while in this section, the researcher wants to capture the background of the IBS project that the respondents involved. Such as types of IBS system that they used. Respondents are allowed to write down any comments or suggestion that relevant the research.

A total of 371 questionnaire sets were sent to the IBS players in the construction industry. The IBS players were stratified into five (5) groups namely Government, Private Client, Consultant, Contractor, and Manufacturer. The justifications for the grouping are based on their roles in contract and sectors that they involve. All the contact details of the respondents were taken from reliable and trustworthy sources (CIDB, 2016) and (CIDB, 2017a). Table 2 summarises the critical information for the questionnaire survey exercise.

118 responses were received out of the total of 371 sent out, which translate to a response rate of 32%. According to (Fellows and Liu, 2008) for a self-administered questionnaire for construction research usually the response rate is about 25% to 35%; thus this is acceptable. This was agreed from some previous researcher stated that it is a norm response rate in the construction industry survey is an around 20%-30% as reported by (Takim and Adnan, 2008).

Frequency and Percentage Analysis (Positive and Negative)

The frequency analysis was used to analyse the overall scenario on the perception and importance given by the respondents towards the implementation of IBS construction approach. In order to conducts, the five-point Likert scale is recoded into two responses which are the positive and negative. This allows a better analysis rather than using a 5 point scale as reported by (Yarnold, Ph and Soltysik, 2014). This was agreed by (Dolnicar, Grun and Leisch, 2011) stated that the recode into positive and negative allows more natural interpretation in descriptive analysis. This is because there is less need for interval scales such Likert scale for descriptive analysis. The response was recoded in a dichotomous scale (two-point scale) which allows a more meaningful interpretation rather that Likert scale. A dichotomous scale can easily use for descriptive analysis such as frequency and percentage while Likert scale can be used for more inferential analysis.

Analysis of Variance (Anova)- Kruskal Wallis

Analysis of variance also known as (ANOVA) is a procedure that is used to evaluate mean differences between two or more populations as stated by (Gravetter and Wallanau, 2011). The outcome of ANOVA will be the basis for drawing the general conclusion about the populations. The ANOVA analysis is used because of it able to compare two or more populations. Therefore, it provides researchers with great flexibility in designing the analysis and interpreting the results.

In the context of this research, mean analysis is used to enable the ranking of the perception and importance by the respondents. Overall mean analyses are used for the mean for all the respondents (N=118).

As the data is ranked, in Kruskal-Wallis, means ranks in each group are tested. In the applications of the test, the null and alternative hypotheses are:

- Ho: there is no difference in the opinion of the groups.
- Ha: there is a difference in the opinion of the groups (significant difference between at least two sectors).
- Where *k r*epresents the numbers of groups to be compared (for this research, *k*=5).

RESULTS AND DISCUSSION

Internal Consistency (Reliability Test)

In the context of this research, the reliability of each item of the instruments was measured using the Cronbach's Alpha. Based on 52 items calculated the Cronbach's Alpha obtained is 0.819 which indicates the items are interrelated and consistent with the sample of the study; therefore the interval consistency level is good stated by (Pallant, 2011). According to (Sekaran and Bougie, 2009) the closer, Cronbach's alpha is to 1, the higher the internal consistency reliability. This was agreed by (George and Mallery, 2003), (Kline, 2000) and (DeVellis, 2011).

Parametric Test

In the context of this research, the normality of the variables was tested using the Kolmogorov-Smirnov test. The results obtained for the Kolmogorov-Smirnov test indicates that all the quantitative variables were not normally distributed (Sig value<0.05). Therefore a non-parametric technique needs to be used for the analysis.

Frequency Analysis of Problem Statements That is Always Referred to IBS Construction

Table 3 shows the frequency analysis of problem statements that are always referred to as IBS construction. Based on the table, it is indicated that the respondents agree that the entire problem statements stated are always referred to as IBS construction. These findings are similar to what is reported in the literature review and findings from the preliminary survey by (Mohd Fateh, Mohammad and Abd Shukor, 2016). Although IBS has been introduced for over 40 years, with well-documented benefits and strong support from the government, the pace of implementation and usage of IBS is still slow and below the government target as reported by (Construction Industry Development Board (CIDB), 2015a) and (Nawi *et al*., 2011).

Table 3. Frequency analysis of problem statements that are always referred to as IBS construction

STATEMENTS	NEGATIVE/DISAGREE		POSITIVE/AGREE	
	***f* (SD,D,N)**	**%**	***f* (A,SA)**	**%**
Still low adaptions in IBS	24	20.3	94	**79.7**
Lack of integration among IBS players	34	28.8	84	**71.2**
Lack of standard for IBS projects	39	33.1	79	**66.9**
No standard form of contract to tailor IBS construction	32	27.1	86	**72.9**

Note: f-frequency, SD- Strongly Disagree, D-Disagree, N-Neutral, A-Agree, SA-Strongly Agree

Frequency Analysis of Clauses in Standard Form Of Contract Which Need To Enhance For Adopting IBS Construction

Table 4 illustrated the frequency analysis of clauses in standard form of contract which need to enhance for adopting IBS construction in. From table 4, it is indicated that agree that all the clauses in standard form of contract need to enhanced for adopting IBS construction in except the clause insurance/bond. From this finding, it is clear that all respondents have the same opinion on the necessity of the enhancement of the clauses in the standard form of contract for adopting IBS construction approach. The findings are similar to the findings from the literature review and preliminary survey being done earlier.

Table 4. Frequency analysis of clauses in standard form of contract which need to enhance for adopting IBS construction

CLAUSES	NEGATIVE/DISAGREE		POSITIVE/AGREE	
	***f* (SD,D,N)**	**%**	***f* (A,SA)**	**%**
Definition of unfixed material and goods	47	39.8	71	**60.2**
Evaluation of interim payment	32	27.1	86	**72.9**
Inspection, testing of material, goods, and equipment	37	31.4	81	**68.6**
Insurance/Bond	72	***61.0***	46	39.0
Submission supervision report	50	42.4	68	**57.6**
Extension of time (relevant events)	51	43.2	67	**56.8**

Note: f-frequency, SD- Strongly Disagree, D-Disagree, N-Neutral, A-Agree, SA-Strongly Agree

Frequency Analysis of Importance of the Correct Standard Form of Contract and Procurement Arrangement in Adopting IBS Construction in Organization

Table 5 shows the frequency analysis of the importance of the correct standard form of contract and procurement arrangement in adopting IBS construction in an organisation. From the table, it is indicated that all respondents agree that the correct standard form of contract and procurement arrangements is important in adopting IBS construction. The majority agreed that proper contractual links are the essential criteria it choosing the right standard form of contract. Most of the IBS players are using either conventional or design and build. Fundamentally it is incorrect. The processes and contractual links are different from the IBS construction approach., (Mohammad *et al.*, 2014) already suggested that procurement system play essential roles in the adoption of IBS.

Furthermore, (Yusof *et al.*, 2014) stated the introduction of different project procurement systems is needed to ensure more efficient and speedier project delivery system and better project performance as one of the critical success factor in the adoption of IBS. The various procurement will bring changes not only to the process and procedure of project delivery but also the aspects of management and organisation. Therefore, the findings from the research are similar in what is highlighted in the literature review.

Table 5. Frequency analysis of the importance of the correct standard form of contract and procurement arrangement in adopting IBS construction in the organisation

IMPORTANCE OF THE CORRECT STANDARD OF CONTRACT AND PROCUREMENTS ARRANGEMENT	NEGATIVE/DISAGREE		POSITIVE/AGREE	
	f **(NI,LI,MI)**	**%**	***f*** **(I,VI)**	**%**
Risk allocation	33	29.7	85	***70.3***
Human resources allocation	39	33.1	79	***66.9***
Responsibilities allocation	24	20.3	94	***79.7***
Proper contractual links	19	16.1	99	***83.9***
Proper communication links	33	28.0	85	***72.0***
Right and enforcement	36	30.5	82	***69.5***
Report and command	34	28.8	84	***71.2***

Note: f-frequency, NI-Not important, LI – Little Important, MI-Moderately Important, I-Important, VI-Very Important

Frequency Analysis of Types of Standard Form of Contract Frequently Used in Adopting IBS Construction in Projects

Table 6 shows the frequency analysis of types of standard form of contract frequently used in adopting IBS construction in projects. From the table, it is indicated that the top three of the standard form of contract used in adopting IBS are PWD 203, PWD DB and PAM 2006. This is expected as this three (3) standard form contract is commonly used in the construction industry. For the government sector, it is compulsory to use the PWD series while for the private sector, PAM series is the standard form of contract that is usually used.

Table 6. Frequency analysis of types of standard form of contract frequently used in adopting IBS construction in projects

TYPES of STANDARD FORM CONTRACT	NEGATIVE/DISAGREE		POSITIVE/AGREE	
	f **(N,R,O)**	**%**	***f*** **(F,VF)**	**%**
PWD 203	58	49.2	60	***50.8***
PWD DB	53	44.9	65	***55.1***
PAM Series 2006	52	44.1	66	***55.9***
PS 2014	118	***100.0***	0	0.0
FIDIC 2010	118	***100.0***	0	0.0
AS 4300	118	***100.0***	0	0.0
JCT 2011	115	***97.5***	3	2.5
IEM Series	107	***90.7***	11	9.3
CIDB Series	106	***89.8***	12	10.2

Note: f-frequency, N-Never, R-Rarely, O-Occasionally, F-Frequently, VF-Very Frequently

Descriptive and Kruskal-Wallis test for problem statements that always referred to IBS construction

Table 7 shows the descriptive and Kruskal-Wallis test for problem statements that always referred to as IBS construction. The problem statement that is referred to as perceived the most by the respondents is still low adoptions in IBS (Mean=3.92) followed by no standard form of contract to tailor IBS construction (Mean=3.86). The problem statements are that it is perceived the least by respondents are both lacks of standard for IBS projects and Lack of integration among IBS players (Mean=3.74). The problem statement that is perceived the most by the government sector is both lacks of integration among IBS players and no standard form of contract to tailor IBS construction (Mean=3.88). Meanwhile, the problem statement that perceived the least is lack of the standard for IBS projects (Mean=3.59). The problem statement that is perceived the most by the client based respondents is still low adaptions in IBS (Mean=3.73).

Meanwhile, the problem statement that perceived the least is both lacks of the standard for IBS projects and no standard form of contract to tailor IBS construction (Mean=3.55). The problem statement that is perceived the most by the consultants is still low adaptions in IBS (Mean=4.13) and perceived the least is lack of the standard for IBS projects (Mean=3.38). The problem statement that is perceived the most by the manufacturers is no standard form of contract to tailor IBS construction (Mean=4.00) and perceived the least is lack of integration among IBS players (Mean=3.39). The problem statement that is perceived the most by the contractors is still low adaptions in IBS (Mean=4.05) and perceived the least is lack of integration among IBS players (Mean=3.80). From these statistical findings, it shows that it is similar to findings from the literature review and preliminary survey by (Mohd Fateh, Mohammad and Abd Shukor, 2016). It is proven that it is still lack of adoption for IBS construction approach and there is no standard form of contract to suit with IBS construction approach as problem statements that always referred to IBS construction. Therefore, this research is expected to give some valuable insight into the IBS construction players and the construction industry as a whole, thus making the research significant and relevant to the current construction industry in Malaysia.

Based on the Kruskal-Wallis test, there is no significant difference among various sectors for problem statements that always referred to IBS construction. Therefore, the null hypothesis is accepted since there is no supporting statistical evidence to indicate any differences between groups. All groups agreed that all the statements stated always referred

to IBS construction. This indicates that the problems statements presented in the research are valid and relevant as it is agreed by all IBS players in the construction industry.

Table 7. Descriptive and Kruskal-Wallis test for problem statements that always referred to IBS construction

STATEMENTS	OVERALL (N=118)		RESPONDENT'S SECTORS					*p* - value	χ^2
	OM	Rk	Gov	Cli	Cs	Man	Ct	Sig	
Still low adaptions in IBS	***3.92***	***1***	3.82	3.73	***4.13***	3.61	4.05	0.390	4.123
Lack of integration among IBS players	3.74	3	***3.88***	3.64	***3.88***	3.39	3.80	0.665	2.388
Lack of standard for IBS projects	3.74	3	3.59	3.55	3.38	***3.83***	***3.83***	0.360	4.353
No standard form of contract to tailor IBS construction	3.86	2	3.88	3.55	3.63	***4.00***	3.89	0.486	3.447

Note: OM – Overall Mean, Rk – Rank, Gov – Government, Cli – Client, Cs – Consultant, Man – Manufacturer, Ct – Contractor, χ^2 – Chi-Square value, Sig – Significant *p*-value (*Significant at $p < 0.05$)

Descriptive and Kruskal-Wallis test for clauses in standard form of contract which need to enhance for adopting IBS construction

Table 8 shows the descriptive and Kruskal-Wallis test for Descriptive and Kruskal-Wallis test for clauses in standard form of contract which need to enhance for adopting IBS construction. The clause that is agreed by the respondents that need the most enhancement is the evaluation of interim payment (Mean=3.88). This is followed by the clause inspection, testing of material, goods and equipment (Mean=3.75), submission supervision report (Mean=3.60), the definition of unfixed material and goods (Mean=3.56) and extension of time (relevant events) (Mean=3.51). The clause that agreed by the respondents that need the least enhancement is Insurance/Bond (Mean=3.36). The clause that is agreed by government respondents which need most enhancement is submission supervision report (Mean=3.71), and the least enhancement is the extension of time (relevant events) (Mean=3.24). The clause that is agreed by client based respondents which need most enhancement is the evaluation of interim payment and inspection, testing of material, goods and equipment (Mean=3.82) and the least enhancement is Insurance/Bond (Mean=3.27). The clause that is agreed by consultant respondents which need the most enhancement is the evaluation of interim payment (Mean=3.88), and the least enhancement is Insurance/Bond (Mean=3.00). The clause that is agreed by manufacturer respondents which need the most enhancement is the evaluation of interim payment (Mean=4.11), and the least enhancement is the evaluation of interim payment (Mean=3.00). The clause that is agreed by contractor respondents which need the most enhancement is the evaluation of interim payment (Mean=3.91), and the least enhancement is Insurance/Bond (Mean=3.23). Based on these statistical findings, it shows that the issues being highlighted in the literature review and the preliminary survey is valid and consistent. Evaluation of interim payment has been a profound issue in IBS construction approach. (Construction Research Institute of Malaysia (CREAM), 2011) Already suggested to rethink the payment term and deliveries to suit with IBS construction. This was agreed by (Musa *et al.*, 2015) stated that the payment and procurement mechanism need to be reviewed to tailor to IBS activities which are reliable and safer payment and procurement. The adopters require safer and more reliable payment mechanism and contracts as reported by (Construction Research Institute of Malaysia (CREAM), 2011). Change in construction method and processes from conventional to IBS will affect the change in the mode of payment and any related clauses in the contract. At this time, there is no security of payment designed for IBS project and contractor need to deposit to manufacturers results in cash flows issues as reported

by (Construction Research Institute of Malaysia (CREAM), 2011), (Construction Industry Development Board (CIDB), 2015a) and (Abd Shukor, Mohammad and Mahbub, 2011). Therefore, this research aims to enhance the related clauses for adoption IBS construction approach.

Based on Kruskal-Wallis, test there is no significant difference among any of the sectors for clauses in standard form of contract which needs to enhance for adopting IBS construction in. Therefore, the null hypothesis is accepted since there is no supporting statistical evidence to indicate any differences between groups. This is clear-cut statistical evidence to illustrate that, all sectors have the same opinion on the clauses enhancement in the standard form of contract for adoption IBS construction approach. Therefore it is a necessity for the clauses enhancement in the standard form of contract for adoption IBS construction approach thus able to accelerate the adoption of the IBS construction approach.

Table 8. Descriptive and Kruskal-Wallis test for clauses in standard form of contract which need to enhance for adopting IBS construction

CLAUSES	OVERALL (N=118)		RESPONDENT'S SECTORS					*p* - value	χ^2
	OM	Rk	Gov	Cli	Cs	Man	Ct	Sig	
Definition of unfixed material and goods	3.56	4	3.53	3.45	3.25	***3.67***	3.59	0.594	2.785
Evaluation of interim payment	***3.88***	***1***	3.59	3.82	3.88	***4.11***	3.91	0.510	3.295
Inspection, testing of material, goods, and equipment	3.75	2	3.65	3.82	3.63	***4.00***	3.72	0.579	2.875
Insurance/Bond	3.36	6	3.65	3.27	3.00	***3.78***	3.23	0.061	9.011
Submission supervision report	3.60	3	3.71	3.64	3.25	***3.83***	3.55	0.202	5.961
Extension of time (relevant events)	3.51	5	3.24	3.36	***3.75***	3.50	3.58	0.238	5.521

Note: OM – Overall Mean, Rk – Rank, Gov – Government, Cli – Client, Cs – Consultant, Man – Manufacturer, Ct – Contractor, χ^2 – Chi-Square value, Sig – Significant *p*-value (*Significant at $p < 0.05$)

Descriptive and Kruskal-Wallis test for the importance of the correct standard form of contract and procurements arrangement in adopting IBS construction in the organisation

Table 9 shows the descriptives and Kruskal-Wallis test for the importance of the correct standard form of contract and procurements arrangement in adopting IBS construction in the organisation. The correct standard form of contract and procurements arrangement that is deemed the most important by the respondents is proper contractual links (Mean=4.03). This is followed by responsibilities allocation (Mean=4.00), report and command (Mean=3.93), proper communication links (Mean=3.86), risk allocation (Mean=3.85) and human resources allocation (Mean=3.65). The correct standard form of contract and procurements arrangement that is deemed the least important is right and enforcement (Mean=3.76). The correct standard form of contract and procurements arrangement that deemed the most important by the government sector is proper contractual links (Mean=4.18). The correct standard form of contract and procurements arrangement that is deemed the least important by the government sector is human resources allocation (Mean=3.65). The correct standard form of contract and procurements arrangement that deemed the most important by the client based respondents is responsibilities allocation (Mean=4.91). The correct standard form of contract and procurements arrangement that is deemed the least important by the client based respondents is proper contractual links (Mean=3.45). The correct standard form of contract and procurements arrangement that deemed the most important by the consultants is proper

contractual links and responsibilities allocation (Mean=4.00). The correct standard form of contract and procurements arrangement that is deemed the least important by the consultants is proper communication links and risk allocation (Mean=3.50). The correct standard form of contract and procurements arrangement that deemed the most important by the manufacturers is proper contractual links (Mean=4.11). The correct standard form of contract and procurements arrangement that is deemed the least important by the manufacturers are right and enforcement (Mean=3.83). The correct standard form of contract and procurements arrangement that deemed the most important by the contractors is proper contractual links (Mean=4.06). The correct standard form of contract and procurements arrangement that is deemed the least important by the contractors is right and enforcement (Mean=3.78). The statistical findings show the same outcome from the literature review. According to Jaafar & Radzi (2012) concluded that the procurement system in Malaysia is obsolete. Many clients in the local industry prefer to choose procurement systems considered familiar, even though the criteria and purposes or every project are different. Previous research by (Mohd Fateh, Mohammad and Abd Shukor, 2016) stated that every project is unique and dynamic in term of processes, resource allocation, risk exposure and responsibilities between all parties, therefore, there is a necessity to enhance the existing Malaysia standard form of contract for IBS construction approach in Malaysia. Jaafar & Radzi (2013) agreed this suggested that when there are changes in the method of construction, there is also a need to adopt a new procurement system.

Using unsuitable procurement methods in IBS will not only affect the progress of the project but also will affect the construction team in term of understanding and interpretation of the regulation. According to Gandu et al., (2009) and Lutz Preuss (2009) concluded that the system of procurements is considered as the key to project success. Blismas & Wakefield (2009) also agreed to this, that in producing a successful IBS project, the procurement approach must be suitable. Findings by Abd Jalil et al., (2016) highlighted that a specific procurement system is required as IBS construction approach involves unique producers and processes which are different from traditional construction. Previous researchers had concluded that the current traditional standard form of contract was not suitable for IBS construction approach especially in term of payment and project coordination as reported by Abd Jalil et al., (2016). Mohamad Kamar et al., (2009) agreed that the existing standard form of contract does not favour the industry players that want to adopt an IBS construction approach. IBS Centre (2007) also highlighted that several of the barriers factors that hinder the adoption of IBS construction approach is the lack of procurement method and provision in the standard form of contract.

Based on the Kruskal-Wallis test, there is no significant difference among any of the sectors for the correct standard form of contract and procurements arrangement. Therefore, the null hypothesis is accepted since there is no supporting statistical evidence to indicate any differences between groups.

Table 9. Descriptive and Kruskal-Wallis test for the importance of the correct standard form of contract and procurements arrangement in adopting IBS construction in an organisation.

IMPORTANCE OF THE CORRECT STANDARD OF CONTRACT AND PROCUREMENTS ARRANGEMENT	OVERALL (N=118)		RESPONDENT'S SECTORS					*p* - value	χ^2
	OM	Rk	Gov	Cli	Cs	Man	Ct	Sig	
Risk allocation	3.85	5	3.76	3.64	3.50	***3.94***	3.92	0.518	3.240
Human resources allocation	3.82	6	3.65	3.73	3.63	***4.00***	3.86	0.712	2.132
Responsibilities allocation	4.00	2	***4.06***	3.91	4.00	***4.06***	3.98	0.981	0.418
Proper contractual links	***4.03***	***1***	***4.18***	3.45	4.00	4.11	4.06	0.159	6.586
Proper communication links	3.86	4	***4.00***	3.55	3.50	3.89	3.91	0.370	4.278
Right and enforcement	3.76	7	3.76	3.55	3.75	***3.83***	3.78	0.866	1.271
Report and command	3.93	3	3.88	3.82	3.75	***4.06***	3.95	0.784	1.736

Note: OM – Overall Mean, Rk – Rank, Gov – Government, Cli – Client, Cs – Consultant, Man – Manufacturer, Ct – Contractor, χ^2 – Chi-Square value, Sig – Significant *p*-value (*Significant at $p < 0.05$)

Descriptive and Kruskal-Wallis Test For Types Of Standard Form Of Contract Frequently Used In Adopting IBS Construction

Table 10 shows the descriptive and Kruskal-Wallis test for types of standard form of contract frequently used in adopting IBS construction projects. For overall respondents, the standard form of contract is used most frequently is PWD 203A (Mean=3.09). This followed by PWD DB (Mean=2.85), PAM Series 2006 (Mean=2.83), IEM Series (Mean=1.49), CIDB Series (Mean=1.48), JCT 2011 (Mean=1.19), PS 2014 (Mean=1.19), and FIDIC 2010 (Mean=1.12). The standard form of contract that used the least frequently is AS 4300 (Mean=1.11). The standard form of contract that is used most frequently according to government sector is PWD 203A (Mean=3.76). The standard form of contract that is used most frequently according to clients based is PWD DB (Mean=3.36) and the least frequently is FIDIC 2010, AS 4300, JCT 2011 and CIDB Series (Mean=1.00). The standard form of contract that is used most frequently according to the consultant based is PAM Series 2006 (Mean=3.75) and the least frequently is FIDIC 2010, AS 4300, CIDB Series and Others (Mean=1.00). The standard form of contract that is used most frequently according to the manufacturer is PAM Series 2006 (Mean=2.83), and the least frequently is AS 4300 and JCT 2011 (Mean=1.00). The standard form of contract that is used most frequently according to the contractor is PWD 203A (Mean=3.08), and the least frequently is FIDIC 2010 and AS 4300 (Mean=1.09). From table 9, it shows that the PWD series are dominating the usage of standard form contract for IBS construction. As reported by (Yusof, 2015) in the literature review, for the Government project that exceeds RM10 million and private project exceed RM50 million is compulsory to use IBS starting from 2016. Therefore, both sectors will only use their preferred standard form of contract which is PWD series for the government and PAM series for the private sector.

Table 10. Descriptive and Kruskal-Wallis test for types of standard form of contract frequently used in adopting IBS construction

TYPES of STANDARD FORM CONTRACT	OVERALL (N=118)		RESPONDENT'S SECTORS					*p* - value	χ^2
	OM	Rk	Gov	Cli	Cs	Man	Ct	Sig	
PWD 203A	***3.09***	***1***	***3.76***	3.27	3.38	2.28	3.08	0.054	9.284
PWD DB	2.85	2	3.24	***3.36***	3.38	2.06	2.81	0.094	7.935
PAM Series 2006	2.83	3	1.65	3.18	***3.75***	2.83	2.97	***0.014****	12.463
PS 2014	1.15	7	***1.41***	1.18	1.13	1.00	1.13	0.061	9.006
FIDIC 2010	1.12	9	***1.41***	1.00	1.00	1.06	1.09	***0.010****	13.359
AS 4300	1.11	10	***1.41***	1.00	1.00	1.00	1.09	***0.003****	16.165
JCT 2011	1.19	6	***1.41***	1.00	1.38	1.00	1.19	***0.035****	10.324
IEM Series	1.49	4	1.41	***1.73***	1.50	1.39	1.50	0.955	0.672
CIDB Series	1.48	5	***1.94***	1.00	1.00	1.83	1.41	***0.008****	13.691

Note: OM – Overall Mean, Rk – Rank, Gov – Government, Cli – Client, Cs – Consultant, Man – Manufacturer, Ct – Contractor, χ^2 – Chi-Square value, Sig – Significant *p*-value (*Significant at $p < 0.05$)

CONCLUSION

From the questionnaire survey done, the absence of standard forms of contracts for IBS construction was ranked first as issue and challenges in adoption of IBS. The preparation of contracts in the construction industry is considered very important. As such, the adoption of IBS in the industry would imply that procurement and payment procedures be appropriately written in the contract. Applicants need a safer and more secure procurement, and payment mechanism in response to changes in conventional methods and construction processes which will, in turn, affect the way payment is structured vis-à-vis the relevant clauses in the contract. Existing procurement structures can hinder contractors by requiring them to have the high capital to obtain IBS components from suppliers as reported by (CIDB, 2015a). Apart from the evaluation of interim payment clause, there are also other clauses that need to look into for enhancement as proven from the statistical test such as inspection, testing of material, goods, and equipment and submission supervision report which ranked second and third respectively. It also reported that slow IBS adoption which is occasioned by constraints or weaknesses in regulations, specifications, requirements, and standards following the IBS environment and processes affects its smooth implementation.

Based on the statistical findings, the usage of PWD and PAM series standard form of contract are dominating the construction industry. PWD series is compulsory for government project while PAM series is widely used for private sectors. The PWD series was modelled on the Royal Institute of British Architects (RIBA) in 1931. According to (Ashworth, 2006)in this type of contract, there is a separation of construction and planning activities. Construction and design teams are treated as a different entity. This arrangement is not suitable for IBS construction approach because for IBS construction approach proper contractual links and responsibilities allocation is vital for IBS construction approach. Therefore, the existing standard form of contract needs to have clauses that encourage the IBS construction approach. As reported by (Singh, 2011b), both PWD and PAM series been reviewed and revised over the years to meet industry needs and kept accordance of industrial developments. Therefore, this research is a parallel effort to enhance several key clauses to suit with IBS construction approach thus can accelerate the adoption of IBS construction approach. Given the above statistical findings, it has become a necessity to enhance the standard form of contract to suit the IBS construction approach hence accelerate the adoption of IBS construction. The output

of this research will hopefully illustrate good insights into the industry and help to accelerate the adoption of IBS construction in Malaysia as a whole.

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EFFECTIVENESS OF THE IMPLEMENTATION OF PREFABRICATED COMPONENTS FOR LOW-INCOME GROUP HOUSING SUPPLY: A PRELIMINARY STUDY

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Abstract

The use of prefabricated components in an Industrialised Building System (IBS) is the main priority for the Malaysian's government projects, including the erection of low-cost housing. This is due to the government's concern which is to provide affordable housing for the low and middle-income groups. By leveraging the IBS initiative, the faster completion of high quality houses in a cost-effective way can be embraced. However, the effectiveness in terms of cost and quality in using the prefabricated components is being doubted by some stakeholders. It resulted in refusing the use IBS as a construction method for housing supply by some stakeholders. Therefore, this study was conducted to explore the effectiveness of prefabricated components used for better improvement in the future housing project. Thus, this paper scrutinizes the perspective on the effectiveness of utilizing the prefabricated components among the owners of housing projects through in depth interviews. A focused group discussion was conducted with five participants from the government institutions that are involved in the low-cost housing projects. Overall, the findings show that the use of IBS resulted in faster completion; however, the quality of the workmanship among the contractor-suppliers of the prefabricated components can always be disputed. In rural areas, the logistics cost of using IBS has been found to rise due to the spatial geographical location. The importance of this finding is it can be used as a guideline for the improvement on the effectiveness of utilizing the prefabricated component for future housing supply.

Keywords: *Prefabricated components; Low-cost housing; Rural housing; Cost effectiveness; Housing supply*

INTRODUCTION

The Malaysian government is continuously providing housing supply for the low-income groups as part of the national agenda. By realizing this mission, the construction industry plays a vital role and thus, the Construction Industry Development Board (CIDB) promotes the use of Industrialised Building System (IBS) which provide superior quality for the end users. The implementation of using the prefabricated components is not new in Malaysia. It started back in the 1960s with a pilot project on the construction of seven blocks of the 17-storey flats and four blocks of the four-storey flats comprising about 3,000 units of the low-cost flats and four-storey shop lots (Thanoon et al. 2003) at Jalan Pekeliling in Kuala Lumpur. In 2008, the government issued a circular which stated that any government projects including the housing projects which cost more than RM10 million should achieve 70% of the IBS score.

The benefits of the prefabrication technology are credible and the housing sector is the best market to apply this technology due to the repetitive nature of its products (Xu and Zhao,

2010). To date, several studies have shown that the main stakeholders, such as the developers and contractors, are the key actors who are reluctant to use the prefabricated components due to the cost issues (Baharuddin et al. 2016; Lou and Kamar, 2012; RI, 2018). Although the previous study by Thanoon et al. (2003) cited that the performance of IBS was competitive with the conventional construction method, Kadir et al.(2006) found out that the structural cost has showed an insignificant difference to the conventional methods. However, Kadir et al. (2006) also demonstrated that the labour cost was significantly lower compared to the conventional methods. More recent researches have shown more concerns on the logistic cost (Azman et al., 2013; Hadi et al., 2017; Kassim and Walid, 2013)of prefabricated components which resulted in high transportation costs (Hadi et al. 2017). Therefore, it is important to study the effectiveness of using prefabricated components to minimize the overrun cost as stated in Shehu et al. (2014) who claimed that 55% of the Malaysian's construction projects experienced cost overrun. This coincides with the statement of Rahim and Qureshi (2018) that in some cases, the implementation of the IBS method has exceeded the budget, targeted completion dates were not achieved, and the quality was always not up to the expectation.

In general, the government finances the cost of housing projects through the approved allocation in the Malaysian Plan (RMK) and the annual budget. The price of low-cost housing is controlled by the government. Since 1998, the low-cost house price per unit was between RM25,000 and RM42,000 for the target household group with the incomes between RM750 and RM1500 per month (Shuid, 2015). Shuid (2015) also stated that the cost of providing the public housing projects had risen with the government subsidizing more than 70% of them. Not only the housing for the low-income group is crucial, but the middle-income group's housing should also be a cause for concern. Thus, this preliminary study was conducted to explore the use of prefabricated components in the construction of the houses for the low-income group before conducting further research on the use of prefabricated components in the housing projects for the middle-income group. Furthermore, this study also investigates the issues concerning the low-cost housing projects which are in the rural areas where the number of IBS product manufacturers and distributors is small in certain states (Figure 1). Significantly, this study is crucial in breaking down the factors that should be taken into consideration in choosing the right IBS system to be implemented. It should be taken into account that the implementation of the IBS is emphasized not only for the government's housing projects, but also in the private housing projects. Hence, the effectiveness factors of analysing the IBS must be taken into consideration to improve the delivery of the housing project where the main focus is now directed to the provision of affordable housing. It is hoped that this study will provide the answers to the issues that are involved in the construction of low-cost houses so that an effective construction process can be achieved to ensure the attainment of the national agenda, which is to provide quality houses for the low and middle-income groups.

LITERATURE REVIEW

The population of Malaysia is arising each year. In 2018 alone, the population has grown to 31.7 million (DoSM, 2018a) and the Malaysian population is projected to increase in the year of 2040 by almost 41.5 million (DoSM, 2016). The increment is also expected to increase the demand for housing between the low and middle-income group. Hence, the efforts towards expanding the public housing supply should be strategized through the method of the prefabrication technology. The implementation of the prefabrication technology is not only

employed in Malaysia, but also has been adopted in most countries to solve the problem arising in the public housing supply. Thus, it is hoped that the prefabrication technology players will be more innovative and competitive in accommodating the demands of housing and later can profitably fulfil the national agenda of supplying the quality housing for the people.

However, the appointment and implementation of this technology throughout the construction process depends on the stakeholder's capacity and priority. This is due to the factors that should be considered in the execution of development in any housing projects. Those factors are the price, location and target group (KRI, 2015; Saleh et al. 2016; Samad et al. 2016). According to the Real Estate Housing Developers' Association (REHDA) Malaysia (RI, 2018) the housing price was supported by four main components that are the building and services cost, land dan infrastructure cost, profits, and others cost such as regulatory cost, professional fees, and etc. In order to reduce the building cost, IBS has been identified to be the contributor towards the cut down of the building cost, time-saving, and productivity enhancement. However, the study by Azman et al. (2013) has identified that the most frequent pre-selection criteria of using IBS were the costs, transportation and optimum distance, and land sites. The research carried out by Hadi et.al (2017) has found out that the problem in utilizing the IBS method in Sarawak was the accessibility of transportation. Improper infrastructure to ship the prefabricated product has contributed to the rising of overall construction cost. The location of the factory that is far from the construction site has created an ineffective distance that affect more on the transportation cost. With respect to that, the stakeholders should be wiser in deciding the most suitable construction process including choosing the right type of IBS used to match with the project's budget. The initial statistic obtained by CIDB in the year this study was executed (see figure 1) has found out that the number of IBS product manufacturer and distributors were centralized in the West and South of Peninsular Malaysia, namely in Selangor and Johor. Whilst the state that possessed the higher percentage of the low-income household group (B40) in Malaysia is Perak and Sarawak, with 12.5% and 11.4% respectively (DoSM, 2018b). The demands for the low-cost housing will increase in that particular area, but the IBS supply is low, and if the contractors wanted to hire the IBS manufacturer outside of the project location, the cost of transporting the prefabricated component will increase. Since the transportation cost in one of the critical factor that should be considered by the stakeholders, with the total number of only 15 IBS product manufacturers in that particular state which can be considered as low in supply. This little number will lead to the uncompetitive price and can be costly (Hadi et al., 2017). Even the premature market in achieving the economies of scale for cost reduction is also one of the preference factor that influenced the private sector to embark on the construction method within housing development using IBS (Chew et al, 2016; Mahalingam, 2017). Therefore, the spatial geographical location factor that is acceptable to the target group and the number of the IBS suppliers are expected to be the most significant factors related to the effectiveness of using IBS method for housing supply.

CIDB has classified six main types of IBS components that can be used in attaining the IBS score (see figure 2). Accordingly, it is crucial for the contractors to decide the right type of IBS components since the IBS score will be evaluated. This is due to the fact that the government projects should be closely monitored and assessed to achieve an IBS score of at least 70% and the IBS scoring will be evaluated in three parts (CIDB, 2010). Part 1 consists of the structural systems (max score is 50 points), Part 2 concerns the Wall Systems (max

score is 20 points) whilst part 3 consists of other simplified construction solutions (max score is 30). However, the data from the Implementation Coordination unit (ICU) of the Prime Minister office reported that only 24% of public projects valued 10 million and above have achieved an IBS score of 70% (Hadi et al., 2017; MIDA, 2016). Thus, this indicated that attaining the IBS score is one of the challenges faced by contractors in completing a public low-cost housing project. At the same time, the contractors too, are struggling to save the transportation cost.

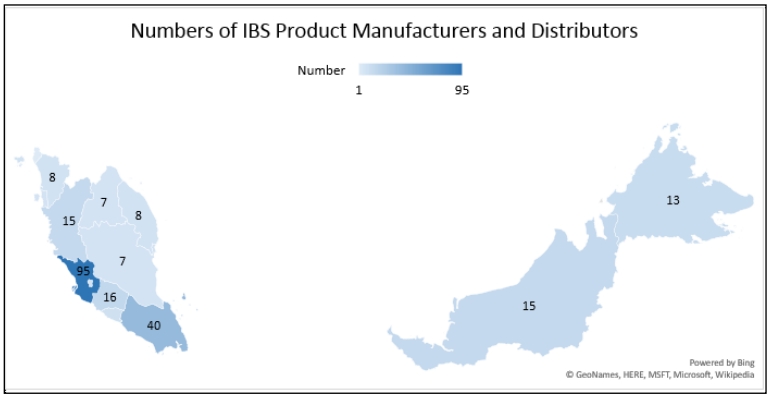

Figure 1. Numbers of IBS Product Manufacturers and Distributors as of July 2017 (CIDB, 2017)

Although the transportation cost will increase the total project cost has been discussed in some studies, (Azman et al., 2013; Hadi et al., 2017; Kassim & Walid, 2013) with regards to the implementation of the IBS, the capability of prefab in saving the time and cost still cannot be withhold by other researchers. Faghrinirejadfard et al. (2016) in their analysis using the Building Information Modelling (BIM) tools namely Revit Architecture and Naviswork have identified the reduction of 26% from the total construction cost can be attained by implementing the IBS in that particular housing projects. Furthermore, one case study conducted in New Zealand has showed that the use of prefab compared to conventional method resulted in 34% and 19% of average reduction in the completion of time and cost (Shahzad et al, 2015). These advantages have been promoted as an impetus to the housing supply in which the supply of houses in Malaysia is still insufficient according to the target group (Bank Negara Malaysia, 2016).

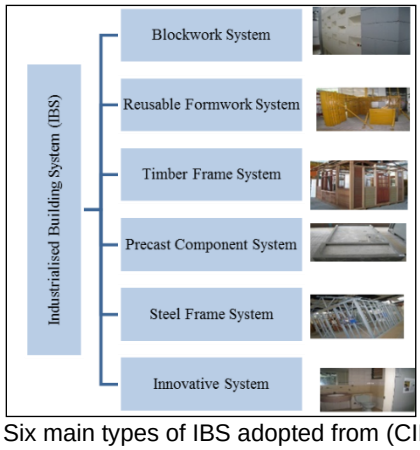

Figure 2. Six main types of IBS adopted from (CIDB, 2016)

However, there are more issues that are still in argument among researchers such as the payment method and procurement that can cause the project delivery failed to achieve the expectation of the IBS advantages (Bari et al, 2012; Jalil et al, 2015; and Nawi et al, 2014). A document analysis by Fateh (2017) in the standard comparison form of contract for Malaysia, UK, Switzerland, and Australia has found a room of improvement to tailor the IBS construction approach in Malaysian standard form of contracts. The interim payment method, on the off-site was not declared in the standard form which caused the contractor to pay up-front payment to the manufacturer before the prefabricated component can be manufactured. The total pay up front is huge and can cut short the cash flow of the contractor which is usually depending on the progress claim of work done. The suggestions on the enhancement of the Malaysian standard form are believed to improve the management of cash flow for the contractors whilst subsequently giving the impact on the overall progress of the project, that is, to achieve the objective of the project owner of completing the project efficiently.

Other than that, the complication in IBS installation has brought about the ineffective implementations throughout the overall project completion. The other problems, for instance the leakage and structural defect (Ismail et al, 2016) have been reported and led to the high maintenance cost (Rahman et al, 2015). The arising issue such as the leakage was caused by the flaws in the installation process and it has been given a negative impression to the private sectors before they started to adapt this method. This issue has evoked the negligence in meeting the need of the end users, who will be the occupant of the house. The effectiveness of the IBS installation in terms of overall quality of the project is also depending on the contractors' competency (Razak & Awang, 2014) and workmanship. However, Rashidi and Ibrahim (2017) also cited that improvement to increase the effectiveness using IBS is huge, considering the mass market opportunity for the IBS product, especially in the housing sector.

Although there are numerous studies discussing the issues of using IBS despite the fact of advantages using it by literature review (Jabar et al, 2013; Mohd Amin et al., 2017; and Rahim and Qureshi, 2018) and various studies discussed on the perspective of the contractors and manufacturer through interview method (Baharuddin et al., 2016; Nawi et al, 2014; Nawi et al, 2014; Razak and Awang, 2014; and Tamrin et al, 2016), but to date, there is no in-depth interview was conducted from the perspective of housing owners of that particular project, regarding the use of IBS. Thus, this study will fill in the gap in the previous research for the perspective of owner of low-cost housing project through in-depth interview since the demands of the housing for the low and middle-income group are high and continuously to grow each year.

RESEARCH METHODOLOGY

To analyse the perspective on the effectiveness of the IBS in the housing project for the targeted low-income group, the interview method has been adapted in this study. The method employed to analyse the primary data was the content analysis. A computer aided with the qualitative data software (CAQDAS) package called Atlas.ti 8 was used to identify the themes, patterns and trends (Saunders et al. 2009). This exploratory study was conducted by in-depth interviewing with five participants from government housing institutions to gather their opinions on the effectiveness of using prefabricated components for low-cost housing projects. All interviewees had between seven and 15 years of experience in the construction industry, including handling the low-cost housing projects. A focus group was formed to gain the insights on the issues involved in the low-cost housing using the prefabricated technology.

The data gathered from the interviews were transcribed and interpreted inductively with preliminary codes as shown in Figure 3 (Kempton and Syms, 2009). Several codes were merged and then reduced according to the themes to be highlighted, as suggested by Yusof et al. (2010).

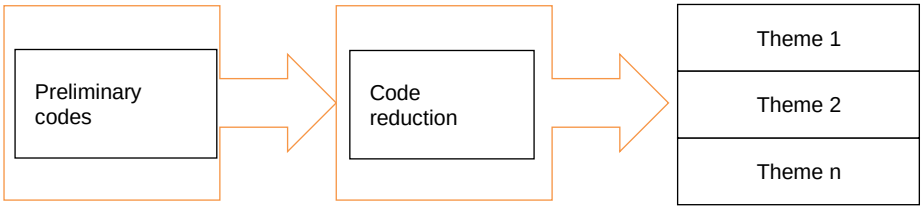

Figure 3. Code reduction/theme creation adopted from Kempton and Syms (2009)

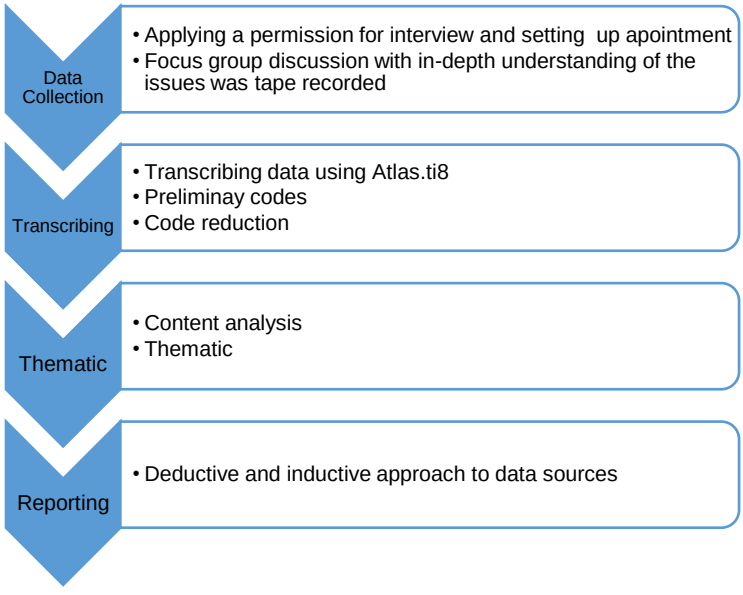

Figure 4. Summary of step for content analysis

The steps involved in the content analysis are summarized in Figure 4 and the overall six themes that emerged from the analysis are illustrated in Table 1.

Table 1. Themes, overview and indicative quotes

No	Theme name	Overview	Indicative quotes
1	Spatial geographical location for supplying prefabricated components in rural areas.	Participant highlighted that the effectiveness of the prefabricated supplier factory's location contributes to the high transportation cost of a low-cost housing project in rural areas or islands. (Details in discussion and findings section)	"The programme for people is out of the area. The method and issues are changing and many amendments were made mostly in design, in Rawang area where the locations of most factories are. The costing is not worth it. Should have the same demand. No collaboration. That is why IBS is not very effective. Design amendment. Out of range for supplier to supply."
2	Controlling prefabricated components prices and new procurement.	An agency controlling the price of IBS components should be set up and an IBS price schedule of rate should be established.	"There is no body or agency controlling the prefabricated components prices."

No	Theme name	Overview	Indicative quotes
3	Economies of scale	The mass production of housing could be reached by the economies of scale. However, the contract awarded for one project to one contractor was given to be fair to others. While the proposed IBS method was interchangeably changed by the contractor due to the factors of location and variation of orders by government institutions that trigger changes due to complaints received from previous low-cost housing occupants.	"There is a problem in supplying when using IBS. Some cases, we were giving EOT due to not enough machinery to produce the IBS material. To bring the technology to the site is a problem since the project cost is huge, about RM70M-80M. If the company is well established, like the private sector also use, it could be. The mass production will reduce the cost. There are no economies of scale. Like the project in Tanah Merah, Kelantan. They are using it in an isolated area. One project for one technology. The hypothesis is saying by using IBS can reduce cost, is not within."
4	Supplier attributes and the quality of the contractor's workmanship.	The IBS supplier only delivered the product without providing proper supervision and monitoring of installation on-site.	"For an example, they propose (company A) panel, and we didn't want the system because we received the complaints from the last customer that had lived in the house, but (company A)'s market is high. But we received complaints that the maintenance is high, the price will also rise, even though during construction. There is no monitoring problem during construction from supplier " "But the effectiveness of IBS is uncontrollable. There is nothing wrong with IBS, but the workmanship, educated person, supervisor on site that is uncontrollable".
5	Customer requirements	The end-user of low-cost housing purchaser complained about the difficulty of installing accessories such as curtain rails, grilles and etc.	"It should be complete with the railing, like using foam prefabricated type to drill for curtain railing, but cannot be done."
6	Fast completion	Participant agreed the IBS can provide fast completion.	"Till date there is no late issue of using IBS. IBS so far is OK.

FINDINGS AND DISCUSSION

Six themes emerged in analysing the factors that influenced the effectiveness of using IBS components in low-cost housing projects. The details are discussed in the following paragraphs.

Spatial Geographical Locations for Supplying the Prefabricated Components in the Rural Areas

The locations of low-cost public housing project nowadays are mostly situated in the rural areas due to the high demand from house purchasers in these areas. The interviewees stated that, currently, the low-cost housing projects are mostly located in the state of Kelantan. However, only seven out of 224 IBS product manufacturers and distributors are based in Kelantan (CIDB, 2017). In fact, the low-cost housing is highly requested in Sabah and Sarawak. Thus, the main challenge faced by the contractors in completing a housing project is the transportation cost in delivering and installing the components. The same transportation

challenge is also prominent in housing locations that are based on the islands. For example, the contractors in Labuan have to incur higher transportation costs compared to those who are constructing the projects on the main land. The interviewees claimed that some contractors changed the IBS method in order to achieve a 70% IBS score. This is because they have to work within the construction budget and find that the IBS components are reasonably fair to ensure an effective cost.

The use of IBS components for low-cost housing projects was compulsory in order to meet the directive in the government circular in 2008 of achieving a 70% IBS score. Through the interviews conducted, the interviewees did not fully agree with achieving the score due to the increase in the construction cost. The scenario became worse when the housing project using IBS was located in a rural area and the main challenge for the contractors is to bear the cost of transportation. Besides that, the interviewees also highlighted that some of the IBS components were not suitable for rural areas and were also not compatible due to the difference in the economy of scale for the area where the projects were implemented.

Economies of Scale

Economies of scale are defined as the increase in efficiency of production as the number of goods being produced increases. Typically, a company that achieves economies of scale lowers the average cost per unit through increased production since fixed costs are shared over an increased number of goods (Bari et al. 2012). A survey study by Bari et al. (2012) identified that project characteristics/IBS characteristics were related factors such as 'repeatability and standardisation', 'repeat of use design', 'moulds or construction technique from previous projects', 'fast-track job/ speed of construction' and 'economies of scale'. These are the most important factors that may influence the IBS construction cost. The study suggested the Project/IBS characteristics were significant when preparing costs and strategic decisions at the initial project stage.

When choosing the right type of IBS product, the stakeholders should look at the long-term lifecycle rather than the short-term. This can be done by choosing the fastest product installation to fulfil the needs of the low-income group and at the same time, ensure that they can afford to own a house. Some IBS products may not be reliable due to social acceptance. The key is that, even though IBS promises fast completion, the cost and maintenance may increase; thus the right selection of IBS product should be further studied in providing affordable housing since the government has to subsidize more than RM10,000 per housing unit. Shuid (2015) analysed that the government had subsidized between 20% and 75% of the selling price for every public housing unit. He suggested the government should return the responsibility to provide housing for the middle-income group to the private sector. Meanwhile, this sector keeps producing housing projects that offer higher-priced houses for the middle-income group. Both end-users and agency providers who are the stakeholders of the housing development should consider the win-win profits. It should be the condition in which the purchasers are able to afford the price of the house and the developers could still make a significant profit. This condition can be achieved when the cost of construction is reduced by employing the IBS. In order to achieve this in the private sector, the demand for IBS products should be high. Higher demand will encourage more suppliers, and eventually, the prices for the IBS components will be reduced due to the economies of scale (Chew et al. 2016).

Prefabricated Component Prices and Procurement

The right type of procurement or guideline for an IBS schedule price rate should be further studied (Nawi et al. 2014). The establishment of the right type of IBS procurement should be the same as the existence of the conventional schedule price rate. This can forbid the IBS suppliers from claiming higher prices than those that had been stipulated. An agency to control the IBS price should be set up to monitor the process of the IBS products.

Supplier Attributes and the Quality of Contractor Workmanship

The problems of prefabricated product assemblance and installation are often discussed (Jabar et al. 2013). This issue is related with the competency of the contractors (Jabar et al. 2013 and Razak and Awang, 2014). The supplier only provides the products and they are not accountable for the monitoring of products' installation. Generally, wrong or improper installation by contractors will often result in extra cost. This will affect the maintenance cost of a project. Cooperation and training among contractors who assemble the IBS products should be provided by suppliers (Baharuddin et al. 2016 and Nasrun et al. 2012). This will enhance the effectiveness of the delivery of low-cost housing to the purchasers.

Customer Requirements

Another issue on the implementation of the IBS is the public acceptance of the products. Some IBS products are highly durable, thus making it difficult for home owners to make small modifications to their house such as installing a curtain rail, hammering a nail or drilling a hole in the wall to install a pipe. This finding shows that customers' preferences should be taken into account when applying the IBS method. This findings also advocated research done by Wahi (2018) that construction material should be taken seriously for the future low cost housing project.

Fast Completion

Undeniably, the use of IBS can result in faster project completion (Kamaruddin et al. 2013 and Mydin et al. 2014). The prefabrication technology is able to fulfil the housing demands among the middle-income group. As reported by Bank Negara Malaysia (2016) estimated that about one million houses for the middle-income group would be completed within five years (2016-2020). By leveraging the appropriate prefabricated components while considering the spatial geographical housing location, the need for housing among the middle and low-income groups can be fulfilled.

CONCLUSION AND RECOMMENDATIONS

All in all, Malaysia required more affordable house units for the low and middle-income group considering the increased of population each year. There is a gap that should be improved by the stakeholders in implementing the use of prefabricated components to ensure the effectiveness in the future housing supply. This is relevant to the government's focus in providing allocation for the affordable houses. The use of prefabricated components which is fast in the completion of the housing project will facilitate the goals of providing more affordable houses for the low and middle-income group. However, the factors of effective

implementation discussed in this paper such as the spatial geographical location, economies of scale, prices and procurement, workmanship, and customer requirement should be taken into account to minimize the overall cost and further improve the project since the involvement of the private sector has given a huge impact on the housing supply . It can be concluded that IBS can provide faster completion in low-cost housing projects. However, several strategies when employing IBS should be carefully considered and implemented for the near future. Based on the interviews conducted and analysis done, the following recommendations are made:

1. This study investigates the use of prefabricated components which can accelerate the completion time with fewer workers on site. However, the selection of appropriate prefabricated component supply and cost/price criteria should be further considered by using tools such as BIM to support the decision-making process.
2. The case study method can provide rich data. This can be done through site visits in the selected regions that have high demand for low-cost housing. It will allow the data triangulation through interviews, site visits and document reviews. Eventually, this would enhance the validity of the research, especially in terms of the scope of public housing supply.
3. This study could be extended by focusing on the middle-income market since the current government housing provision system is focusing more on this group. The involvement of private sector to cater affordable market is a must, thus research into a business model which uses the prefabricated components for affordable housing supply should be further studied for this group.

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EXPERIMENTAL STUDY ON SHEAR STRENGTH OF COMPOSITE SLAB WITH STEEL FIBRE REINFORCED CONCRETE TOPPING

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Abstract

The conventional method of concrete composite slab construction uses steel fabric (SFA) as a secondary reinforcement in concrete topping. Nevertheless, there are various shortcomings of which most of industrial practitioners take it for granted. These include improper SFA installation that may cause a reduction to the concrete cover and longer time is needed to fix the adjacent meshes, as stronger connection is needed between the overlaps. In order to reduce problems associated with SFA, this study utilised steel fibre reinforced concrete (SFRC) in concrete topping to replace SFA as a secondary reinforcement. It is to be investigated about the shear strength of composite slab with a steel fibre of different proportion and length. Five concrete composite slabs were prepared, in which each varied in terms of steel fibre parameters, i.e. fibre aspect ratio (L/D = 80 and L/D = 60) and fibre volume fraction (V_f = 0.75% and V_f = 1.00%). The control specimen was also prepared for comparison purposes, where the concrete topping was reinforced with SFA. All composite slab specimens were tested for 28 days after casting and subjected to shear load. Each slab specimen undergone two different experimental setups by considering the left and right section. The test results have shown that SFRC composite slab can sustain a higher shear load as compared to the control. This improvement is in the range of 14% to 17% and 8% to 15% for SF33 and SF60, respectively. In addition, the study has also found that steel fibre with smaller aspect ratio in the concrete topping can sustain higher ultimate shear capacity as compared to the larger aspect ratio. To that, this research proved the benefits of SFRC in concrete topping in which it can reduce the problems associated with the use of SFA.

Keywords: *Steel fabric; Steel fibre reinforced concrete; Concrete topping; Composite slab*

INTRODUCTION

Composite slab is an element where precast slab and in-situ concrete topping work together to form an integral structural component (Kim S. Elliott., 1996; Izni Syahrizal Ibrahim., 2008; Noor Nabilah Sarbini., 2014). The on-site construction of composite slab is normally installed above the supporting beam. The reinforcing steel projecting from the supporting beam and in-situ concrete topping are used to link the beam and precast slab. This leads to the reinforcing steel and in-situ concrete topping being designed adequately to transfer the horizontal shear between the beam and precast slab. Furthermore, the top surface of the precast slab must also be taken into consideration before the in-situ concrete topping is applied in order to make a complete floor finish (Izni Syahrizal Ibrahim., 2008; Noor Nabilah Sarbini., 2014; Ibrahim, I. S et al., 2011; Sarbini, N. N et al., 2014; I. S. Ibrahim et al., 2016; Anoop Krishnan.K.M and Vra Saathappan, 2018). Normally for precast flooring construction, in-situ concrete topping is 40–100 mm in thickness and reinforced with steel fabric (SFA) are cast onto a precast slab. Steel fabric is a steel wire mesh that is formed as a joined grid with a specific spacing. Most of the time, the installation of steel fabric inside the slab is to prevent

an early micro crack development and control shrinkage. On the other hand, steel rebar is a reinforcement that is installed inside the element to make it functions as a tension device in reinforced concrete. These differentiate both materials with their respective functions. As plain concrete is weak in tensile, assistance from stronger material is needed to sustain the tensile stress, such as the installation of SFA in the concrete topping. This method is viewed as the best way to deal with the issue and is widely used until now.

While the use of SFA as a conventional method to reinforce concrete topping in composite slab construction has already been preserved, a question on why this method needs to be replaced arises. This is where the shortcomings of using SFA in conventional method construction occurred, especially in Malaysia (Noor Nabilah Sarbini., 2014; Krishnaveni Rangasamy., 2007; Malaysia Statistics., 2013). In practice, it is difficult to keep SFA in its place based on its design requirement especially in maintaining the concrete cover (Izni Syahrizal Ibrahim., 2008; Noor Nabilah Sarbini. 2014). This leads to various construction faults which are normally related to durability, corrosion, and fire rating requirements (Izni Syahrizal Ibrahim., 2008; Noor Nabilah Sarbini. 2014). The improper placement of mesh reinforcement and the presence of construction joints can lead to delamination, edge restraint, curvature and serviceability loss (I. S. Ibrahim et al., 2016). The installation of SFA also causes congestion at the intersection involving lapping of several meshes. This will lead to the reduction of concrete cover especially at the top surface of the concrete topping where it is exposed to severe environment conditions. At the same time, it will reduce the function of reinforced concrete topping to transfer the horizontal action that is induced in the composite slab.

Therefore, an alternative construction method or material which can be used to replace SFA is required and this includes the application of steel fibre in concrete topping which may overcome the disadvantages experienced from the installation of SFA. It is also worth to mention the advantage of using steel fibre reinforced concrete (SFRC) when it comes to cracking resistance as it possesses greater ductility in helping to increase impact and fatigue resistance (Kukreja, C. B et al., 1984; Mindess, S., 1994; Musmar, M., 2013; Sarbini, N. N., Ibrahim et al., 2012; Matsumoto, T. and Li, V. C. 1999; Pramod Kavade and Abhijit Warudkar, 2017; M. Kalaivani and S. Karthik, 2016). Furthermore, steel fibres improve the properties of concrete against static and dynamic load (Zollo, R. F. , 1997; Roslli Noor Mohamed 2009 ; RILEM TC 162-TDF , 2002; Roberts-Wollmann, C. L et al., 2004; Pramod Kavade and Abhijit Warudkar, 2017). The randomly distributed discreet fibres to reinforce plain concrete also provide three-dimensional resistance under the applied load and is effectively transferred within the developing cracks (Noor Nabilah Sarbini. , 2014; Sarbini, N. N., Ibrahim et al., 2014). Apart from that, the use of SFRC which is known for its performance in restraining shear stresses induced in the concrete element has been proven by previous researchers (Altun, F. et al., 2007; Banthia, N. et al., 2012; Ferrara, L. et al., 2010; Gao, J. et al., 1997; Goldfein, S. ,1965; Khaloo, A. R. and Kim, N. ,1996) . A study by S. Anandan *et al.* (2018) have shown that steel fibres can be suitably used to reduce the thickness of concrete elements. The effective dispersion of aligned fibres in slender concrete sections can enhance the matrix strengthening and provide better fracture properties. J Novák and A Kohoutková, (2017) have discovered how to ensure good toughness of a concrete composite before heating it with the combination of steel, as well as looking at synthetic fibres as a promising substitute. After heating, its residual mechanical behaviour, spalling resistance and ductility will be improved.

Most previous literature on composite slab focused less on the behaviour of such substitution method. This may due to the function of reinforcement in concrete topping that is; as a secondary reinforcement (Noor Nabilah Sarbini., 2014). However, there are few literature that have the similarity in focusing on the current study. Khaloo and Afshari (2005) have found that the existence of steel fibres in concrete slab can enhance the energy absorption based on the small-scale experimental test results. Furthermore, higher fibre reinforcing index, *RI* is likely to increase the energy absorption compared with the lower *RI* (*RI* = Fibre volume fraction, V_f × Fibre aspect ratio, $\left(\frac{L}{D}\right)$; where L is the fibre length and D is the fibre diameter). Steel fibre incorporation helps to soften a long deflection than a sudden brittle failure. SFRC has the ability to improve energy absorption and cracking behaviour (F. A. Rahman et al., 2017; Novák. J and Kohoutková. A, 2017).

On the other hand, Ibrahim *et al.* (2008) and Girhammar and Pajari (2008) have investigated the shear strength of precast hollow core slab with SFRC topping. However, the use of hollow core slab was affecting the fibre contribution investigation where the hollow section acted as the weakest point for the first crack to occur. Sarbini *et al.* (2014) and Mansour *et al.* (2015) have discovered that the use of steel fibres to reinforce concrete topping can benefit the whole composite slab structure Noor Nabilah Sarbini. , 2014; Mansour, F. R. *et al*, 2015). Anoop and Saathappan (2018) have studied that by using FRC topping, the flexural capacity has increased and the central deflection of FRC topping specimens was significantly reduced.

However, the replacement of SFA with SFRC needs detailed guidelines such as the suitable types of steel fibres, SFRC mix design, curing method, and casting process. SFRC's structural performance depends on factors such as fibre aspect ratio, fibre volume fraction, concrete strength, tensile strength and fibre orientation or fibre distribution in concrete, where researchers have carried out numerous studies on SF's mechanical strength properties in concrete structures. As stated in ACI 544, 3R-08, the percentage used for fibre volume fraction in SFRC should be within 0.5–1.5% because it is able to reduce the workability of concrete mixing and cause balling or matting if adding more fibre, which is extremely difficult to be separated by vibration (ACI ,2008; L. Soufeiani *et al*, 2016).

Therefore, this study focuses on investigating the shear strength of composite slab when replacing SFA with steel fibres in the concrete topping. The SFA will be fully replaced by steel fibres to study their effects and contributions. Two different types of steel fibres and two different fibre volume fractions are used in this research work and will be discussed onwards.

EXPERIMENTAL WORK

The composite slab specimen that was used in this research consisted of the precast slab underneath and concrete topping on the top. The precast slab was a prestressed concrete element, while the concrete topping was reinforced by the secondary reinforcement of either steel fabric or steel fibre. The design concrete strength for the precast slab and concrete topping was 60 N/mm^2 and 40 N/mm^2, respectively. The material composition for both elements were given in Table 1. The precast slab is 3300 mm long, 1200 mm wide, and 75 mm deep as shown schematically in Figure 1. It was prestressed pre-tensioned using four numbers of 12.9 mm nominal diameter helical wire with bottom cover of 30 mm. The top

surface of the precast slab was roughened using wire brush in the transverse direction. The parameters for the concrete topping were the types of steel fibre and fibre volume fractions, while the concrete topping depth was fixed at 75 mm. In this study, three different types of secondary reinforcement were used to reinforce the concrete topping.

The first type, abbreviated as SF60, was steel fibre (SF) having length of 60 mm and aspect ratio (L/D) of 80, while the second type, abbreviated as SF33, was 33 mm long with an aspect ratio (L/D) of 60. Figure 2 shows both SFs used in this study. Meanwhile, SFA which was the control specimen, was the third type of the secondary reinforcement. Detailed composite slab specimens were summarised in Table 2. Cube specimens (150 mm × 150 mm × 150 mm) were also prepared to determine the compressive strength at 28 days to ensure that the specimens complied with the design concrete strength.

Table 1. Concrete mix material compositions for 1 m^3 volume

Concrete Grade (N/mm^2)	Aggregates		Water (kg/m^3)	Cement (kg/m^3)
	Fine (kg/m^3)	Coarse (kg/m^3)		
60	822	927	150	480
40	762	1011	230	400

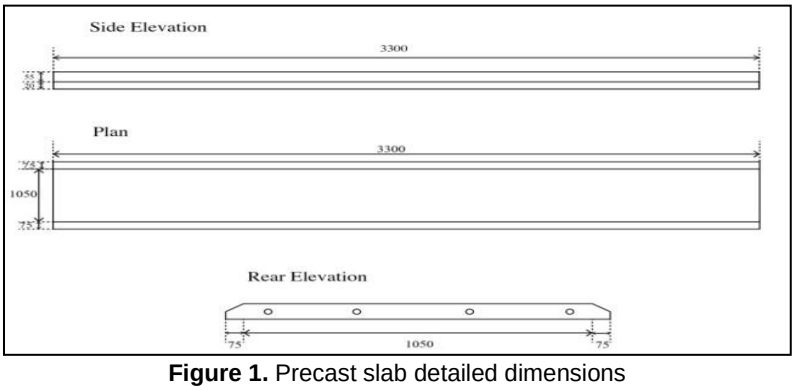
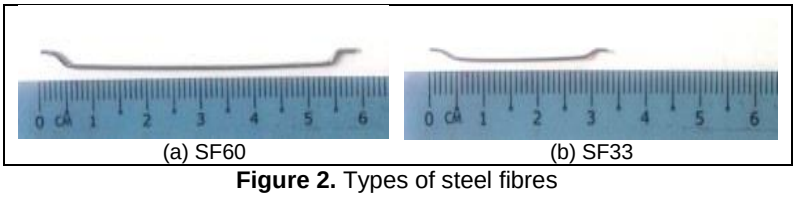


Figure 1. Precast slab detailed dimensions



(a) SF60 (b) SF33

Figure 2. Types of steel fibres

Table 2. Specimen name and detailed properties

Slab specimen abbreviation	Type of secondary reinforcement	Fibre volume fraction, V_f (%)
S1	SF60	0.75
S2	SF60	1.00
S3	SF33	0.75
S4	SF33	1.00
S5	SFA	-

The composite slab specimens were tested under shear load. Two different setups were adopted of which they were referred to as experimental setup 1 (ES1) and experimental setup 2 (ES2). One-point loading system was applied in both test setups. In ES1, the shear span-to-effective depth ratio, *a/d* was taken as 2.5. The actual testing arrangement was shown in

Figure 3, while the schematic diagram was shown in Figure 4. Meanwhile, ES2 was performed after one side of the specimen failed. Considering the disturbed region due to the formation of shear crack at failure, support 2 in ES2 was moved to a new position. The loading rate was maintained at 0.3 N/mm^2.s and continuously run until the specimen failed. The test was stopped when diagonal crack or sudden shear failure occurred in the shear span region.

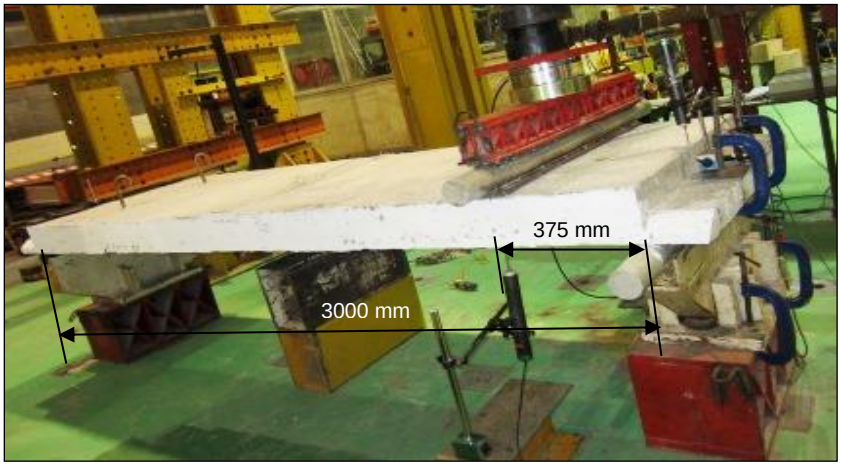


Figure 3. ES1 shear load test arrangement

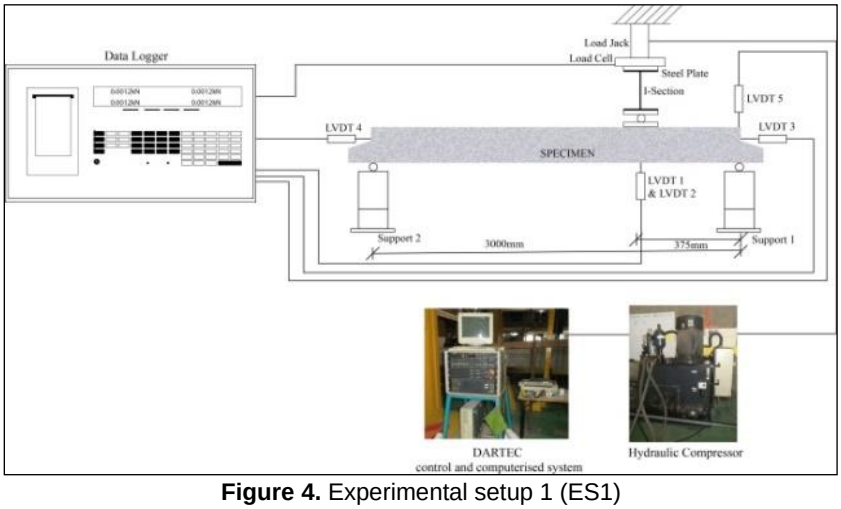


Figure 4. Experimental setup 1 (ES1)

RESULTS AND DISCUSSION

Compressive Strength

The concrete quality of the precast slab which was confirmed by the manufacturer has achieved the compressive strength of 60 N/mm^2 on Day 28. Meanwhile, the compressive strength for the concrete topping was tested on Days 7 and 28. The results were summarised in Figure 5 which has confirmed the design strength of 40 N/mm^2. Figure 5 shows the compressive strengths of steel fibre as secondary reinforcement or topping that were higher than steel fabric. The highest compressive strength was slab specimen S2 which was 60mm in length and 1% volume of steel fibre.

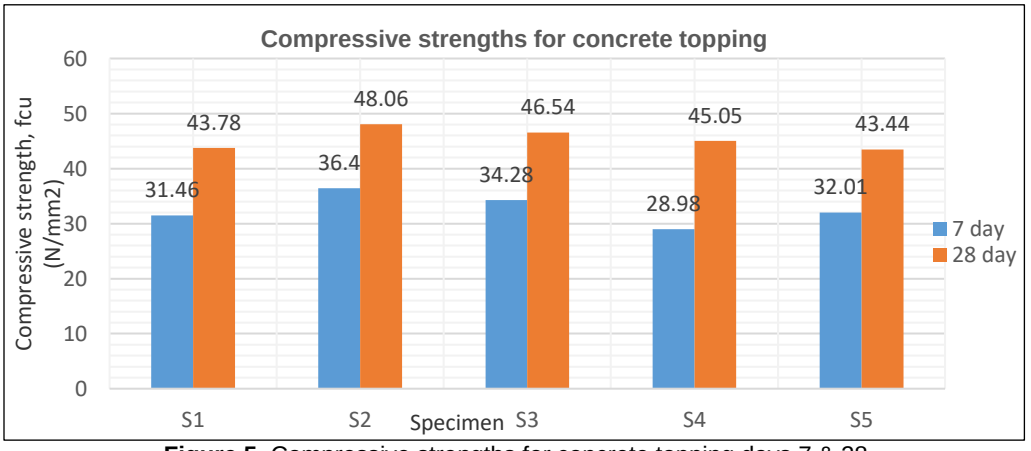


Figure 5. Compressive strengths for concrete topping days 7 & 28

Ultimate Shear Load

The design ultimate shear capacity of the composite slab specimen was 203 kN. The test results of the ultimate shear capacity and the corresponding maximum deflection of each composite slab specimens were summarised in Table 3. The ultimate shear capacity for specimen S1 was 213 kN (ES1) and 192.5 kN (ES2), while specimen S2 was 217 kN (ES1) and 237.5 kN (ES2). For specimen S3, the ultimate shear capacity for ES1 and ES2 were 195.5 kN and 250.1 kN respectively, and specimen S4 was 221.0 kN (ES1) and 237.5 kN (ES2). Meanwhile, S5 which was also the control specimen gave an ultimate shear capacity of 188.5 kN (ES1) and 219.0 kN (ES2). The ultimate shear capacity relationships for all specimens based on the two experimental setups were shown in Figure 6. The coefficient of variation, *COV* calculated using Equation 1 was determined for each specimen and the values were also given in Table 3.

$$COV = \frac{V_{SFRC}}{V_{CONTROL}} \qquad \text{Eqn. (1)}$$

Where:

V_{SFRC} = Ultimate shear capacity for specimen S1, S2, S3 and S4, kN

$V_{CONTROL}$ = Ultimate shear capacity for control specimen S5, kN

Table 3. Ultimate shear capacity and maximum deflection at failure for all specimens

Specimen	Experimental setup 1, ES1			Experimental setup 2, ES2		
	Ultimate shear capacity (kN)	Maximum deflection at failure (mm)	*COV*	Ultimate shear capacity (kN)	Maximum deflection at failure (mm)	*COV*
S1	213.0	14.53	1.13	**192.5	**8.34	**0.88
S2	217.0	18.10	1.15	237.5	19.60	1.08
S3	195.5	18.50	1.04	250.0	15.85	1.14
S4	221.0	15.51	1.17	237.5	14.31	1.08
S5	188.5	16.60	-	219.0	12.86	-

NOTE: **During the test for specimen S1 in the ES2, there is failure occurred to the steel plate which is used to transfer the line load. This causes reloading of specimen S1. Therefore, lower ultimate shear capacity is recorded.

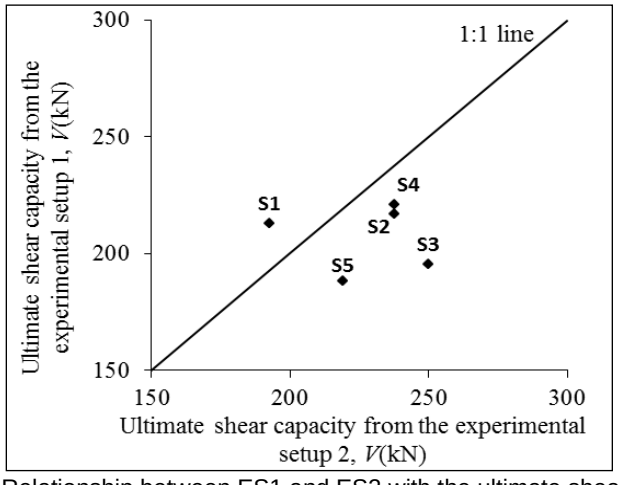


Figure 6. Relationship between ES1 and ES2 with the ultimate shear capacity

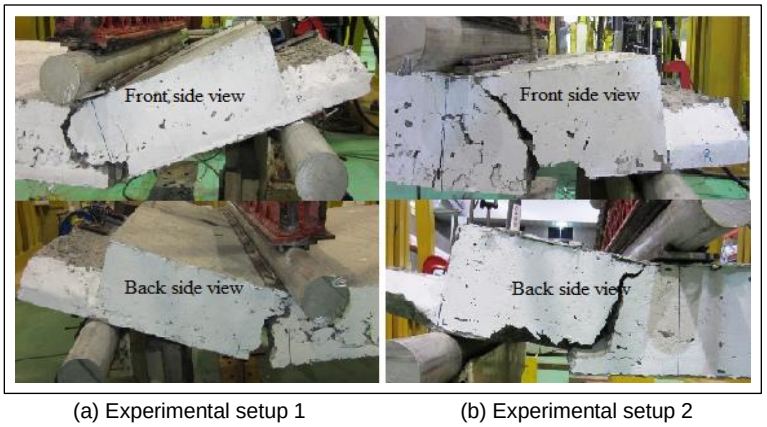
In ES1, all specimens reinforced with SFRC in the concrete topping showed higher ultimate shear capacity compared with the one using SFA. However, small enhancement on the ultimate shear capacity was shown by specimen S3, where the concrete topping was the one with SF33 steel fibre with V_f = 0.75%. Other S1, S2 and S4 specimens have shown large enhancement on the ultimate shear capacity when compared with the control where the *COV* was 1.13, 1.15 and 1.17 respectively. However, specimen S1 in ES2 showed the lowest ultimate shear capacity compared to the other specimens, including the control. This is further proven where *COV* = 0.88 as compared with the control specimen, S5. The lower ultimate shear capacity for specimen S1 in ES2 was attributed from the steel plate that was used to distribute the line load during the test, which then buckled before the specimen failed. After replacing the steel plate with the new ones, specimen S1 was re-tested. This may be the cause of the lower ultimate shear capacity since cracking had already occurred during the initial load test. For specimens S2 and S4 in ES2, the same enhancement on the ultimate shear capacity was recorded where the *COV* = 1.08. The highest increment on the ultimate shear capacity in ES2 was recorded for specimen S3 where the *COV* = 1.14. In general, the study proves that SFRC can be used as an alternative secondary reinforcement to replace SFA in the concrete topping for their enhancement on the ultimate shear capacity.

Failure Mechanism

The failure mechanism for each composite slab specimens was visibly observed due to shear. There was no interface failure between the precast slab and the concrete topping, where the crack penetrated through the compression zone of the concrete topping. This shows that there is minimal effect to the interfacial bond which may affect the performance of the composite slab. Figure 7 shows the control specimen, S5 exhibited shear failure where the crack initiated from the support and propagated towards the loading point. Shear failure was sudden and without any early signs. The same shear failure mode was also exhibited by other specimens such as S1, S2, S3 and S4. Upon entering the concrete topping, the crack slowly and gradually propagated until the formation of larger crack, in which later failed due to shear. Typical shear failure of the specimen with SFRC concrete topping was shown in Figure 8.

(a) Experimental setup 1 (b) Experimental setup 2

Figure 7. Failure mode for the control specimen S5



(a) Experimental setup 1 (b) Experimental setup 2

Figure 8. Failure mode for specimen S3

Shear Design Model

Eurocode 2 suggests that the ultimate shear capacity of reinforced concrete with the presence of longitudinal reinforcement but without shear reinforcement, which can be determined using Equation 2 given as follows [26]:

$$v_{Rd} = \left[C_{Rd,c} k (100 \rho_1 f_{ck})^{1/3} + k_1 \sigma_{cp}\right] \quad \text{Eqn. (2)}$$

where:

$C_{Rd,c}$ and k_1 are parameters referred to the National Annex. The recommended value is $\frac{0.18}{\gamma_c}$ and 0.15, respectively.

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0 \text{ with } d \text{ in mm}$$

$$\rho_l = \frac{A_s}{b_w d}$$

A_s is the area of longitudinal steel reinforcement, mm^2

f_{ck} is the characteristic compressive strength of concrete, N/mm^2

$\sigma_{cp} = \frac{N_{Ed}}{A_c}$, N/mm^2

N_{Ed} is the axial force, kN

A_c is the cross sectional area of the concrete, mm^2

Equation 2 is also complied with the one proposed by RILEM [27] where it considers the shear resistance of fibre reinforced concrete with the presence of longitudinal steel reinforcement. RILEM suggested that the addition of fibres may increase the shear strength of the provided reinforced concrete by introducing additional expression to the existing Equation 2. This additional expression is the shear supplement from steel fibres, v_{fd}. Therefore, the general equation for the design ultimate shear strength of composite slab with SFRC as concrete topping is given in Equation 3, with the shear supplement from steel fibre that can be calculated from Equation 4.

$$v_{Rd,c} = v_{Rd} + v_{fd} \quad \text{Eqn. (3)}$$

$$v_{fd} = Ak_f k\tau_{fd} \quad \text{Eqn. (4)}$$

where:

A is the parameter coefficient = 0.7 (RILEM proposed values based on bond and orientation factors)

k_f = 1.0 (for rectangular section)

$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$ with *d* in mm.

τ_{fd} is the design value of the increase in shear strength due to steel fibres, N/mm^2

Modular ratio, *m* is first used to transform the composite slab into homogeneous element. Therefore, the transformation can be considered by the properties of the plain concrete topping and precast slab. The ultimate limit state design is considered to derive the shear formula. Therefore, the modular ratio can be determined using the ratio between compressive strength of the concrete topping to the precast slab, as given in Equation 5. The new transformed section is now represented in Figure 9.

$$m = \frac{f_{cu,slab}}{f_{cu,topping}} \quad \text{Eqn. (5)}$$

where:

$f_{cu,slab}$ is the compressive strength of the precast slab, N/mm^2

$f_{cu,topping}$ is the compressive strength of the concrete topping, N/mm^2

Table 4 presents the values on the parameters for the proposed shear design model with the test results. The *COV* for each specimen shows an approximation of near to 1.00. This means that the proposed shear design model is able to resemble the actual shear condition in the experimental test. The relationship between the proposed shear design model and the test results are given in Figure 10. From the figure, the data tabulated is in close approximation with the 1:1 line. This concludes that the proposed shear formula model is suitable to predict the design ultimate shear strength of composite slab with SFRC topping.

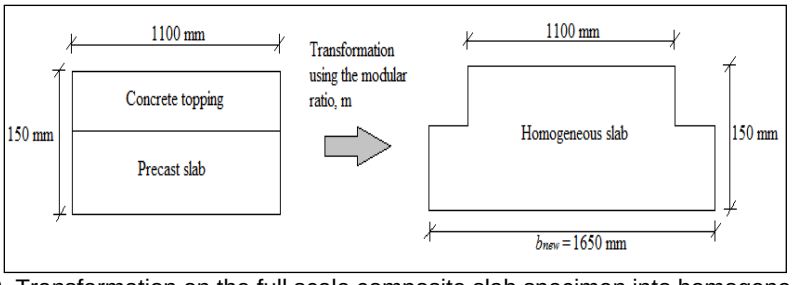


Figure 9. Transformation on the full scale composite slab specimen into homogeneous slab

Table 4. Comparison between the experimental test results and the proposed shear formula model on the ultimate shear strength

Specimen	v_{Rd}	τ_{fd}	v_{fd}	$v_{Rd,c}$	$V_{exp,ES1}$	$V_{exp,ES2}$	COV_{ES1}	COV_{ES2}
S1	1.08	0.34	0.47	1.55	1.70	1.54	0.91	1.01
S2	1.08	0.36	0.50	1.58	1.73	1.89	0.92	0.84
S3	1.08	0.36	0.50	1.56	1.56	1.99	1.00	0.78
S4	1.08	0.41	0.57	1.65	1.76	1.89	0.94	0.87

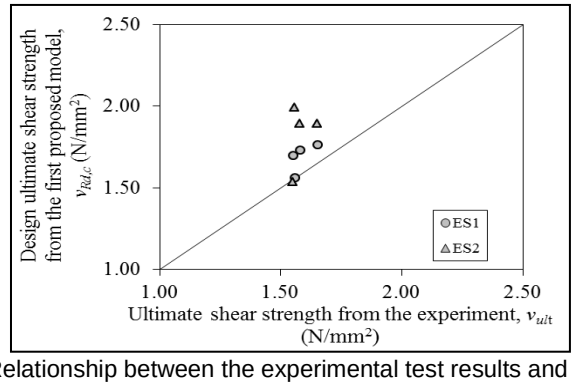


Figure 10. Relationship between the experimental test results and the proposed shear model for the ultimate shear strength

CONCLUSION

The test results have shown that the selection of shorter fibre (SF33) has increased the shear capacity by 14% at V_f = 0.75% and by 17% at V_f = 1.00%. Meanwhile, the longer 60 mm fibre, SF60 has increased the shear by 8% at V_f = 0.75% and by 15% at V_f = 1.00%. This

enhancement of shear capacity proves that steel fibres perform well in reinforcing the concrete topping, as the same to that of the conventional method using SFA. Furthermore, the proposed shear design model in this study is also found to provide good agreement with the test results, where the scatter of *COV*s is near to 1.00. Thus, the findings from this study shows a good indication of applying alternative construction method or material in the composite slab construction.

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ADOPTING BIG DATA TO FORECAST SUCCESS OF CONSTRUCTION PROJECTS: A REVIEW

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Abstract
Forecasting the success probability of a construction project is a critical activity in the ever expanding construction industry. The present trend of forecasting is focused on cost (budgeting) and time (scheduling) i.e. the two of three apex of iron triangle. However, increasing demands of stakeholders and generation of large amount of data, owing to the new information and communication system implemented, have made the researchers look at success beyond iron triangle and tools currently adopted for its measurement. This paper starts with an extensive literature review on project success criteria, and the need for forecasting project success with considerable accuracy. The paper investigates the concept of forecasting in various industries including construction, new challenges faced in forecasting, and the concept of Big Data. It tries to bridge the gap between the three aspects namely project success criteria, forecasting and tool required for the same. It then delves into Big Data in various industries and its potential to facilitate accurate forecast of the success of construction project, which has hitherto not been sufficiently addressed. The paper then looks at the possible challenges identified such as data veracity, connectivity, storage etc. and their solutions in the adoption of Big Data for the purpose. The paper concludes by suggesting further research in bridging of the gap in forecasting the project success and its benefits and suggests looking at Big Data as tool. A model to predict project success of construction project using Big Data is suggested as a future work.

Keywords: *Project Success; Forecasting; Prediction; Big Data; Construction*

INTRODUCTION

The size of construction industry has notable effect on the economy of a country (Ahmad et.al, 2016), with the government being the largest client. The construction projects, like infrastructure projects, have large financial stakes, especially public funds, and therefore the success of the project becomes critical. To ensure that a project is a success, it needs to be managed optimally. Deming and Drucker aptly illustrated that to manage something, it needs to be measurable (Mcafee and Brynjolfsson, 2012). However, the measure of the success of the process has remained a complex concept over many years (Ahadzie et.al., 2008). Furthermore, the success of a project is ascertained only after the project is completed. Forecasting the probability of success will help to inform the decision on whether or not a project should be funded or initiated. The concept of forecasting has been adopted in various fields like stock market, weather etc. with considerable success. The proliferation of information and communication technologies (ICT) and their adoption by the construction industry have led to the generation of large volumes of data, which is coined Big Data. Analyses of Big Data might shed light upon the relations between the various factors affecting the success of a project and hence facilitate more accurate forecast of the success of construction projects, than that is possible through the conventional approach. Big Data is seen as a possible future in digital age and an appropriate tool for forecasting. Big data has been adopted as tool for prediction in various industries and to an extent even in construction industry. However, these predictions are limited to forecasting the outcome of the events for

which Big Data has been used and not the project as whole. The gap of predicting the outcome of the project before the commence of the project with high level of accuracy considering all the success factors needs to be bridged and further research needs to be carried out in this direction.

The aim of the paper is to explore the potential for big data to be used as tool to forecast project success. The paper starts with the review on measures of project success adopted till date with the proposal that all the measures are post mortem and hence there is a need for forecasting and further proposes that big data be adopted as a tool for forecasting due to it relevance in the future. To this effect the paper presents some instances where adopting big data for forecasting in other fields have benefitted in saving resources. The paper then discusses the challenges faced in the adoption of big data and the ways to overcome them. The paper concludes by suggesting that predicting the success factor of a project before the commence of the project will enhance the stakeholder's ability to arrive at a more appropriate decision on the project so that resource wastage is limited. The paper suggests looking at big data as tool for this as Big data can process the volume of data.

MEASURE OF PROJECT SUCCESS

Measuring the success of a project is a key area in the field of construction project management (Toor and Ogunlana, 2009). The understanding of what defines a successful project remains a grey area (Chan, 2001) and it is even more complicated in construction industry (Ahadzie et.al., 2008). The two key questions in measurement of project success are: who determines the success of a project and what parameters determine a successful project (Lim and Mohammad, 1999). Researchers seem to have varied opinion regarding the critical success factors that governs the success of a construction project (Toor and Ogunlana, 2009).

The definition of success and its assessment varies when looked from different angles (Shenhar et.al, 1997). Each stakeholder defines success in their own terms and thus the ideal scenario of a project being a success for everybody is rarely achieved (Lim and Mohammad, 1999). Further complicating the issues is the unique nature of each project with each project having its own measure of success. Evaluating the success of a project is a key concern for every stakeholder. In 1960's, the measurement of project success was restricted to financial terms (Khosravi and Afshari, 2011; Toor and Ogunlana, 2009). The core parameters were further increased to three dimensions namely time, cost and quality known as the triple constraint or more popularly now known as Iron Triangle. These parameters were further re-iterated by various researchers as the most suitable method for measurement of project success. The iron triangle became popular and in most cases still the measure of project success due to ease of quantification. However, in the later years, the iron triangle being considered a short-term measure was deemed insufficient to measure a project success accurately (Al-Tmeemy et.al., 2011). The project success needs to be looked as a strategic concept aligning with both the short term and the long-term goal of the organisation (Al-Tmeemy et.al., 2011).

One of the earliest attempts to look beyond the basic parameters was proposed by Shenhar et.al (1997) suggesting that project success needed to be multi-dimensional. They identified four (4) dimensions to measure project success viz. project efficiency, impact on customer, direct business and organisational success, preparing for the future. Subsequently researchers

presented various models which looked at project success more holistically. Lim and Mohammed (1999), Chan (2001), Ahadzie et.al (2008), Toor and Ogunlana (2010), Patanakul et.al (2001), Khosravi and Afshari (2011) have done extensive research and presented models for project success criteria which are elaborate and look beyond the basic parameters.

However, all the above models measure the project success for a completed project and look at applying the benchmark for future improvement (Khosravi and Afshari, 2011). Forecasting the success of a project will help in arriving at an appropriate decision regarding the further progress of the project at any stage (Turner and Zolin, 2012).

FORECASTING

The need to know the future has always been a fascination, with earliest form of forecasting being the prediction of future events in one's life which continues even today (Armstrong, 2001). Over a period of time, organisations, both private as well as government, looked at forecasting to evaluate the effects of their decisions beforehand. There is a general thought all around that the uncertainties have increased (Letouze, 2012) and the decision makers need forecast to make some concrete decisions. A formal forecasting procedure helps in giving a clarity in decision making where there is uncertainty. Even though forecasting has had oppositions, with Peter Drucker (1973) terming it as a disreputable human activity (Armstrong, 2001), it has gained importance in recent years with formal methods of forecasting being proposed in various domains. Forecasting helps in planning for the future and making a judicious decision considering all the possible variables. In the present day, forecasting is being adopted extensively in fields such as finance, weather, energy, traffic to name a few.

Predicting the fate of the companies operating under financial duress has been a subject of research from the early 20th century with the formal documentation on bankruptcy dating back to 1930's (Almamy et.al., 2015). In 1968, Altman presented a z-score formula to predict bankruptcy using various parameter. In civil engineering, the Altman's z-score model has been adopted for early warning of financial crisis in real estate (Yi, 2012). Yi (2012) stated that having an accurate pre-warning analysis of a company's financial state at the right time helps in countering the market competition. Forecasting is extensively used in the prediction of the stock markets. Successful prediction of the stock market can yield major benefits for both individuals and companies by giving an indication of future value of a company's stock based on the various parameters.

Forecasting of weather and early warning of natural calamities like cyclone, tsunami etc. helps in preventing major damages to property and human life. The effect of prediction of weather and climate extends to the field of agriculture (Sivakumar, 2006). Forecasting helps the people involved in agriculture sector to either prepare for adversities or take advantage of expected favourable conditions (Hansen, 2002). With renewable energy gaining importance in recent years, the predictions on weather conditions is very useful in generation of energy. Predicting the wind speed accurately is very important in generating wind energy efficiently and power generation can be considerably increased (Monfared et.al, 2008). Modern day transportation adopts forecasting extensively in planning of journeys and traffic density. The growing volume of traffic has increased the demand for accurate prediction of real time travel conditions (Kamarianakis, 2012).

The field of construction project management has made some progress in predicting the outcome of projects with reasonable accuracy. Turner and Zolin (2012) presented a model which looked at real time monitoring and future perception of the project success by suggesting leading performance indicators. Their model identified nine (9) scales which can be used to forecast the project success perceptions of stakeholders. The study by Ling and Liu (2004) looked at predicting performance of design and build projects in Singapore. Their model, which used artificial neural network predicted six (6) performance parameters of project success of design and build projects. Ling et.al (2008) constructed five (5) models to predict project performances of foreign Architectural, Engineering and Construction firms in China. They suggested adoption of multi-linear regression model which had a reasonable accuracy. The model presented by Wang et.al (2012) looked at predicting construction cost and schedule using artificial neural network. The model had an 80% accuracy on sample projects adopted.

As compared to hundred (100) years ago, when forecasting was considered more an art rather than science (Lynch, 2008), today various tools and methods are being adopted to forecast events. Some of the tools and methods used for forecasting are Delphi technique, extrapolation method, rule-based forecasting adopting expert system (Armstrong, 2001), artificial neural networks (Zhang et.al, 1998), fuzzy logic (Monfared et.al, 2008) to name a few. However, with the volume of data increasing rapidly and existing methods falling short in terms of volume of data processed, the new methods are being explored to improve accuracy. In recent years, Big Data as a field has emerged to provide solution for the large sets of data which are being generated. Big Data is projected as the future and has great potential for its application especially in forecasting.

BIG DATA

The present age is termed as the digital age (Letouze, 2012) and in the last thirty (30) years, digitization has become a major part of our day to day life. The analogue devices are being replaced by digital devices which generate a large amount of data (Reinsel et.al, 2017). A report presented at world economic forum held in Switzerland in 2012 declared data as the new class of asset much like gold, silver etc. (Lohr, 2012). However, majority of the data is unstructured and raw (Boyd and Crawford, 2011) accounting for 70 – 80% of all data generated (Khan et.al, 2014). The origin of the term "Big Data" is ambiguous (Diebold, 2000), however, earliest recording of the term Big Data is largely credited to John Mashey, who in 1998 explained the term Big Data in his presentation titled "Big Data and the next wave of infrastress" (Fan and Bifet, 2012). The term big in itself is abstract and quantifying what constitutes big has been pondered over the years. There are various definitions of Big Data. It is generally agreed that it signifies very large information which requires something special to be processed. The definition presented by De Mauro et.al, (2016) sums up the important characteristics of Big Data. According to them,"Big Data is the information asset characterised by such a high volume, velocity and variety to require specific technology and analytical methods for its transformation into value" (De Mauro, 2016).

Characteristics of Big Data

Big Data is characterised by three (3) V factors or attributes namely Volume, Variety and Velocity (Bilal et.al. 2016). Few researchers add another V namely value to the three (3) V's.

Fan and Bifet (Diebold, 2000) added another two (2) V's to the existing three (3) namely variability and value to the existing three thus making it five (5) V's. Some researchers attribute the fourth V to veracity. The requirements or definition of the three (3) V's or five (5) V's can also have slight variations according to the domain in which Big Data is being adopted (Yu and Guo, 2016).

Life cycle of Big Data

The life cycle of Big Data consists of various stages as shown in Fig 1 (Khan et.al, 2014). The life cycle begins from the generation of raw data which is generated from various sources, collected in different forms such as text, images etc. through various methods. Once the data is captured and filtered as required, the next step is the data analysis. The two main objectives of data analysis are to understand the relationships between the data and how the processed can accurately forecast future events (Khan et.al, 2014). Some of the methods of data analysis are data mining algorithms, cluster analysis, correlation analysis, statistical analysis and regression analysis (Khan et.al, 2014). The next step, the storing of data and processed information, which does pose a problem if the volume is large. Storing of data in a hard drive is not feasible is the data set is large. The solution to storing Big Data is the network storage namely cloud, with adequate provision for access and security. A distributed storage system is adopted to facilitate efficient storing, processing and accessing. The part of sharing, publishing, securing and retrieving and reusing of data forms an extension of data storage. The data stored should provide value to the user and it is important that the data is authenticated. The retrieving and reusing of data should be carried out on a platform which is compatible to all the tools used by various people.

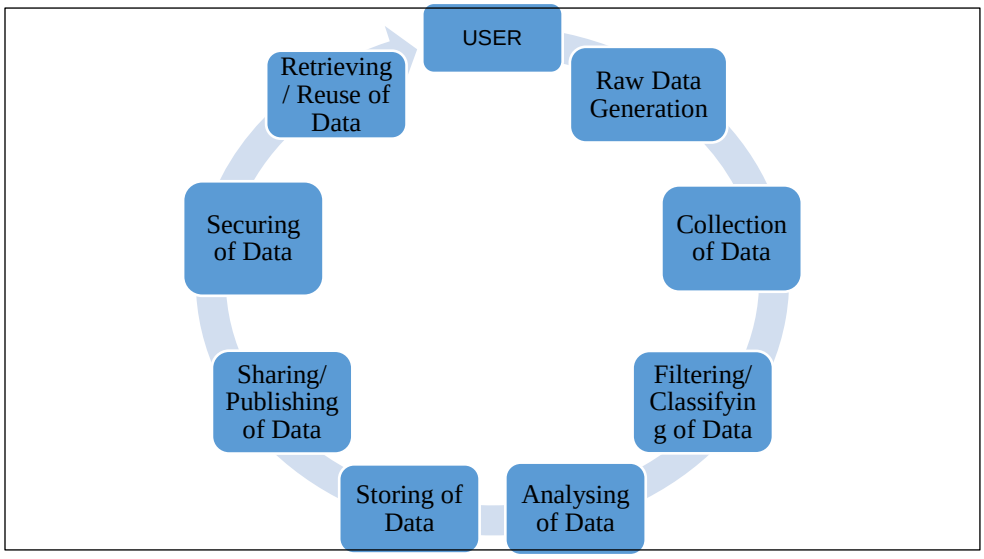

Figure 1. Figure showing life cycle of Big Data (Source: Khan et.al, 2014)

APPLICATION OF BIG DATA

The technological advancement and the advent of new devices has facilitated the capture and storing of large data sets and process them quickly (Fan and Bifet, 2012). This has prompted various organisations to apply Big Data in their domain. The Domains that have

implemented Big Data in different ways include Government, Telecomm, Sports, Infrastructure, Retail, Construction & Real estate, Health Care, Education, Banking, Manufacturing, Insurance to name a few.

In the health care industry, electronic medical record facilitates the access of medical data anywhere by physicians and patients and further empowers the patients to be actively involved in their health related matters. Big Data is also used to integrate medical data with the other social determinants like income, social status, daily habits of individuals etc. and help assimilate information without personal interview (Murdoch and Detsky, 2013). The data generated from intelligent monitoring and recording system (IMRS) in monitoring traffic systems benefits in efficient traffic management and also helps in prevention of crime (Xia et.al., 2016). In the field of energy, smart energy meters have facilitated the capture of large data especially relating to consumption of energy. The key area where Big Data is adopted in the domain of energy is the management of peak electrical loads (Zhou et.al., 2016). Generation of renewable energy combines Big Data and weather and climate patterns across time and space (Zhou et.al., 2016). Retail industry harnesses the data generated to analyse the behaviour of their customers and further integrate the available data from other sources to promote marketing (Lohr, 2012). Finance industry has grown by volumes in recent years and there are number of companies encompassed in this sector namely banking, stock broking, insurance, investment funds including consumer finance, credit cards to name a few. Application of Big Data in finance sector is helpful in e-commerce, marketing of financial products, portfolio management and real time analysis of the stock market (Fang and Zhang, 2016).

By far the most comprehensive application of Big Data comes in creating smart cities which combines the data of various aspects of a city and present them in a form so that everybody can visualise and analyse the information (Kitchin, 2014). Some cities like London provide real time data of weather, level of air pollution, public transport availability and movements, water body levels, electricity demand, stock market status, trends in social media, look at traffic camera feeds, and even the happiness level to their citizens. More and more cities are moving towards being smart and intelligent and the role of Big Data is only going to increase in future.

Application of Big Data in construction

The construction industry, due to its sheer size, generates large volumes of data albeit heterogeneous and it is expected to increase enormously (Bilal et.al., 2016). Apart from the normal avenues, a large amount of data is being generated by testing and monitoring systems. Generation of such volumes of data is forcing the industry to look into application of Big Data as possible solution for complex engineering problems (Alavy and Gandomi, 2017). Even though the construction industry is relatively late to catch up on the application of Big Data to harness its advantage, a considerable amount of work has been done in the past 2 – 3 years. Table 1 shows the list of relevant works carried out by various researchers in the field of construction.

Table 1. Table showing various works on application of Big Data in construction

SNo	Author	Year	Research
1	Lu et.al	2015	Benchmarking construction waste management performance using Big Data
2	Han and Golparvar-Fard	2016	The potential of big visual data used in conjunction with building information modelling (BIM) for Construction Performance Analytics
3	Zhan et.al	2017	Bayesian mixture model to estimate short-term average urban link travel times using large-scale trip-based data with partial information.
4	Tseranidis et al.	2017	Data-driven approximation algorithms, often called surrogate modelling, in the stage design of civil structures.
5	Catbas and Malekzadeh	2017	A machine learning-based algorithm for processing massive data collected from the mechanical components of movable bridges.
6	Riveiro et al.	2017	A new method for fully automated point cloud segmentation of masonry arch bridges.
7	Nejad et al.	2017	Aimed at optimal arrangement of surveyed pavement inspection units (SIUs) for cost reduction, minimization of inspection errors and accuracy improvement of pavement network analysis.

For the design of structures to implementation of projects, monitoring of progress and quality, the researchers have proposed the use of Big Data. The design of large structures today need to account for many factors such as aesthetics, stability, energy efficiency etc. Redesigning of structures during the construction stage or otherwise cause delays which in turn can be translated to waste of resources. The nD modelling in BIM has provided an opportunity to evaluate construction performance in real-time (Han and Golparvar-Fard, 2017). The adoption of BIM in a construction project has improved the overall productivity by around 25% (Han and Golparvar-Fard, 2017) and use of Big Data can further enhance the figure. Tseranidis et.al (2017) look at the application of Big Data in the design stage itself to achieve optimisation. Their paper looks at minimising human element in design iterations. Considerable work is being done on creating models for monitoring and further maintenance of existing bridges. Catbas and Malekzadeh, (2017) very specifically look at creating a model for monitoring and further maintenance of movable bridges thus increasing their service life. Riveirio et.al (2017) presented a model to monitor structural health of masonry arch bridges. Their model provided data for further operations of the bridges in a much simpler way.

Application of Big Data in Forecasting

The process of prediction using large data is gaining ground and methods are being evaluated and proposed to quantify parameters of human behaviour (George et.al., 2014). Predictive analysis uncovers patterns and relationships in data and can be adopted in any discipline (Gandomi and Haider 2015). The main purpose of prediction is to get a good out of sample prediction (Varian, 2014). However the traditional methods of analysis looked at small set of data and more often than not, the researchers found it difficult to generalize the result and further research had to be conducted to get a more accurate result. Big Data, by its sheer volume has a higher probability of accuracy as it has a higher volume of data set. Although the use of Big Data in forecasting is very recent, the researchers are realising the importance and power of harnessing the data and its impact on economics (Chase, 2013).

The transportation sector has adopted Big Data for forecasting extensively for generating the flow of traffic. For the road users, it helps in making better travel decisions (Lv et.al., 2015). The best example are the apps like Google Map and Waze which provide the traffic density and travel duration. It also helps the government agencies in making decisions to

improve efficiency of traffic operations and also improve environment by reducing carbon emissions. The early knowledge of air quality will help people in their decision of travel plans and the government in their process of creating policies for sustainability (Zheng et.al., 2015). The model proposed by Zheng et.al (2015) can forecast the reading of air quality at a specific monitoring station over next 48 hours with a reasonable accuracy.

In the field of finance, Big Data has been adopted for forecasting in stock market in the short term prediction of share prices. Diebold (2000) advocated the use of Big Data to measure macroeconomics in real time to ensure a closer to accurate result in forecasting. With the increasing uncertainties in economic world, Big Data helps in reducing the gap in the accuracy of forecasting economic trends (Gandomi and Haider 2015). In times of an economic crisis, rapid pace of information flow can help both the government and people to make quick decisions (Askitas and Zimmermann, 2009).

"Forecasting energy consumption in the presence of different events, will assist venue operators to estimate energy cost of future events and it will enable them to include energy cost in the facility usage fee" (Grolinger et.al., 2015). Grolinger et.al (2015) have suggested the effect of Big Data in analysing the energy use and potential avenues for savings. They have further suggested the used of Big Data to educate the real estate buyers on energy usage and conservation. In Retail industry Big Data has been adopted to predict the behaviour of their customers and their trends in future purchases especially from internet activities of users. For instance, people posting news about an upcoming event in their life, like a wedding, are immediately notified by the retailers on the promotions and special offers related to the wedding purchases.

BIG DATA TO FORECAST PROJECT SUCCESS IN CONSTRUCTION- POSSIBILITIES AND CHALLENGES

The exponential growth of construction industry has created a potential of generating large amount of data. However the size of the data, even though fragmented, is very large and synthesizing this volume of data requires special tools and processes. Big data, being an emerging field can present a solution for collating and processing such large data. Other domains have adopted Big Data and have reaped the benefits of forecasting using Big Data especially in terms of monetary gains. Forecasting has helped companies reduce expenses, as in the case of Saint Gobain, UK, where a saving of £165,000 was achieved in its electricity bills (Marmaras et al., 2017).

Similarly, in construction, big data can be adopted to create models that can forecast project success. Measuring the probability of success and its prior knowledge at an early stage can help the stakeholders decide on the project. A decision to drop a project can be taken if the forecast shows a lower probability of success (Turner and Zolin, 2012). A model could be developed which includes the project success criteria of all the stakeholders involved in an extensive way. The model could specify the probable success percentage for each stakeholder under various distinct parameters thus presenting a clearer picture on the expected probability of success and facilitate further comparison to the final outcome of success. Each stakeholder, be it architect, contractor, promoter or end user, have different criteria of success and to include all the parameters will involve an enormous amount of data. The existing models are limited in the inclusion of project success criteria and the tools adopted for the model are

limited in the volume and speed of data they can process. The concept of Big Data is being suggested for such a venture, as the data involved is exhaustive and at present Big Data has the capability to handle such data with speed and accuracy.

Even though the concept of data analysis has been adopted in construction industry, Big Data is still very new. As is the case with other tools, construction industry is slow to adopt Big Data technology (Bilal et.al., 2016). The successful implementation of Big Data technology in various aspects of construction industry still pose a challenge (Alavy and Gandomi, 2017). Some of the possible challenges relate to data storage, data security, data quality, cost implications, Internet connectivity etc. Solutions are being explored to overcome the drawbacks, for instance cloud computing is being looked as an option for large data storage and processing.

The size of the data does pose a problem in storage of data. The local computers are insufficient to store and process the volume of Big Data. Using cloud to store Big Data is a solution presented for the above problem. Storing data on cloud can help researchers harness the power of cloud-computing as well as the tools available (Marx.,2013). However cloud-computing has its own challenges. Storing of data in cloud means that the data is handled by an external agency. The external agency should not only have the infrastructure to maintain the present data and their processing but also be in a position to scale up at a rapid pace. Further the distant service provider may have issues in terms of power outages, crash of software tools and other disruptions.

The security issues relating to data storage is a concern (Bilal et.al., 2016). The internet usage being a new phenomenon, there is no fool proof method of safe guarding data. To overcome the challenge posed by security of data there are various measures are being adopted. Tools are being developed which provide access control, prevent denial of service and intrusion to name a few. However, in terms of cyber security, there is still a long way to go.

Another challenge is to provide uniform platform for everybody to use. The challenges comes both in terms of different organisations as well as the tool used for subsequent steps in workflow. The diversity should be taken into account while developing and adopting the tools as well as platforms (Marx, 2013). Further, the process of digitisation of data is a more recent trend. The older data is either available in conventional format (hard copy) or digitized scanned copies. Though there exists a large volume of data across regions and across time, most of the data do not present a meaningful interpretation in their present stored format. For instance, scanned copies of drawings could provide large data but the data needs to be extracted for a significant understanding or the billing information could be in different format for different organisations or projects. A substantial effort is required to have all the data on a uniform platform before they can present a value, a key characteristic of Big Data.

CONCLUSIONS

All industries are becoming big, whether it is competition, size of projects, or resources involved in a project and thus any success or failure will have great impact on the resources especially finance. The present scenario of economic downturn presents a great opportunity to look at new models which will give an accurate prediction of the end result of a project.

This paper looked at the existing methods of measuring project success and found that in most cases the assessment is an afterthought. Further, the few models forecasting project success are limited in terms of parameters assessed, tools used, types of projects and region where the project is executed. These models do not provide a complete picture on prediction of project success and hence the accuracy is limited. Thus, the need arises to create a model to include all the parameters of project success from the viewpoint of all the stakeholders involved int the project. To create such a model, the technology adopted should have the ability to process large amount of data with speed and accuracy. The rise of Big Data as a discipline has presented an opportunity to use the large amount of data, generated so far over the years and across the world, to create models for more accurate forecasting. Even though there are limitations on the adoption of big data like data veracity, storage etc., constant technological improvements are presenting methods to overcome these challenges. The adoption of big data for forecasting a project success at the conceptualisation stage can revolutionise the construction industry. This can make way for a majority of the completed projects to be termed as success from the point of view of all stakeholders involved rather than limiting the achievements to a select few.

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BUILDING INFORMATION MODELLING INTEGRATED PROJECT DELIVERY SYSTEM IN MALAYSIA

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Abstract
Construction industry is categorized as the largest industry in the society. In order to succeed the projects, efficient construction project management is needed to mitigate the problems of uncertainty, high inefficient, high wastage, excessive overtime and rework constantly exist in construction industry. Thus, Building Information Modelling (BIM) consistently in offering a new platform of decision support system in the design decision and knowledge that dispersed among the projects team's members in the construction projects process. Therefore, it is significant to understand and implement BIM into Integrated Project Delivery (IPD) to provide better construction management solutions to the industry. This research will identify the principles of IPD in Malaysia followed by examining the implementation level of IPD in Malaysian construction industry as well as evaluate the BIM integration in Integration Project Delivery. In this study, three (3) phases of research methodology had been adopted: initial discussion and literature Review; data collection and analysis and conclusion. Based on the discussion it can be concluded that 18 principles of IPD except fiscal transparency and shared financial risk and reward were the most contribution towards BIM adoption. Throughout the improvement of overall construction projects in Malaysia, the GDP of national economic is able to be influenced directly.

Keywords: *Building Information Modelling (BIM); Integrated Project Delivery (IPD); Construction industry*

INTRODUCTION

Construction industry transforms numerous resources into constructed physical infrastructure needed for social economic growth which contribute to the increase of global economy. However, the industry is a fragmented and dynamic sector with projects based nature (Hoezen, Reymen, & Dewulf, 2006). As stated by Federal Transit Administration, (2012), construction project management is a method to coordinate and manage the construction projects life cycle fulfilling the clients requirement. However, characteristic of the work tasks interdependency is one of the difficulties in construction project management. This is due to most of the contributors are relatively isolated but in some way depends upon the others. The industry culture in changing sets of contractual relationship frequently had contribute the issues of conflicts, lack of respect and trust among the specialists and stakeholders involved in the reality construction projects (Hoezen et al., 2006). Herewith, project integration is essentially in ensuring project success. The integration among project team enable participants to achieve open source of information, early contribution of experts and manage risk collectively based on the level of integration. Nevertheless, projects integration does not occur automatically. Lack of collaboration, poor communication, inconsistent share vision and unsuitable project stakeholders' participation are the main challenges that failed to form team integration (Izam et.al., 2013). Through the various business impacts in the globalization, construction industry has to improve in terms of innovation in the management system and integration method as an essential to sustain in continues advancement of the industry trend (Guérin, 2012). Therefore, Integrated Project

Delivery (IPD) is introduced to serve as an integration philosophy and delivery method to address the project integrated. To support the IPD in Building Information Modelling (BIM), a Terrell discussion upon the IPD collaboration concepts were practically analyze. BIM provide an essential technology and communication tool in the Integrated Project Delivery (IPD) which enables the collaboration in construction projects and resulted in better performances. In fact, IPD is also known as advance project delivery procurement developed to better carry out the BIM functions in construction projects. The involvement of IPD through BIM is able to collaborate, integrated and allows all project participants for better integration in the entire Life Cycle Project of construction (American Institute of Architects, 2007).

Principles of Integrated Project Delivery (IPD)

The whole principle of IPD build up through the integration of people and system into a theory able to maximize the efficiency throughout the whole life cycle. Mitropoulos and Tatum, 2000, in the research of integration mechanisms, the project integration mechanisms and the level of collaboration had been divided into three groups: contractual, organisational or structural named by (Ashcraft, 2013) and technological. Based on literature reviews, IPD methodology is built on 21 principles. In this study, IPD principles had been classified into four (4) categories to better distinguish the function and application of the principles in IPD projects as Table 1.

Table 1. The Organisation of Questionnaire Survey

Principles	Elements	Sources
Contractual Principles / Legal Principles	Multi-party contract agreement	El Asmar et al. (2013); Kenig et al. (2010)
	Early involvement of key participants	Ghassemi & Becerik, (2011); Gerber & Kent (2010)
	Shared financial risk and reward / mutual benefits	Cohen (2010), Thomsen (2009); AIA (2007)
	Jointly developed and validated project goals and objectives	Ashcraft (2013); Kenig et al. (2010)
	Liability waivers among key participants	Sive (2009); Ciotti & Pasakarnis (2011)
	Fiscal transparency (Open book)	Thomsen (2009)
	Intensified early planning	Ciotti & Pasakarnis (2011); AIA (2007)
Behavioural Principles	Mutual respect and trust	Ibrahim (2011); Kenig et al. (2010)
	Willing to collaborate	Kenig et al. (2010)
	Open communication	Ibrahim (2011); Kenig et al. (2010)
	No blame culture	Baiden (2006)
	Organisation and leadership	AIA (2007); Ashcraft, (2013)
	Unrestricted shared information	Baiden (2006); Ibrahim, (2011)
Structural Principles	Lean principle of design, construction and operation	Kenig et al. (2010); Cohen (2010)
	Co-location of team	Baiden (2006); Cohen (2010)
	Team flexibility	Thomsen (2009); Baiden (2006)
	Operate without boundaries	Ibrahim (2011); Baiden (2006)
	Collaborative innovation	AIA (2007); Baiden, (2006)
	Collaborative decision-making and control	Ashcraft (2013); Ghassemi & Becerik-Gerber (2011).
Technological Principles	Appropriate technology: Building Information Modelling (BIM)	Cohen (2010); Kenig et al. (2010)

RESEARCH METHODOLOGY AND PROCEDURES

Data Collection and Analysis

The research described in this paper aims was to achieve multiple objectives and an ultimate aim was to set up the possibility of BIM in Integrated Project Delivery (IPD). The main research methods adopted for this study was comprised two components which are a literature review and a detailed quantitative questionnaire survey in the research design and data collection. The research is conducted in two (2) stages. During the first stage, the study starts with preliminary study to identify the objective, problem statement and significant of study. Then, the literature review is carrying out by searching through potential source of academic databases such as thesis, book, dissertation and conferences paper. In second stage, the quantitative questionnaire survey research methods adopted to generate information from large samples. In the third stage, the collected responses are then analysed in order to examine the implementation level of IPD in Malaysia construction practice. In the final stage, the evaluation of BIM integration in IPD is being access.

Questionnaire Survey

The questionnaire survey was divided into four main sections as described in the following to achieve the objectives of this research:

Section 1: Background information – to obtain information for the general of the respondents and their organization such as organization information, job position, experiences, BIM knowledge level and type of project involvement.
Section 2: Investigation of various factors Matrix of Principles of IPD in Malaysia
Section 3: Implementation Level of IPD in Malaysian Construction Industry.

Respondents to rate their levels of agreement on the factors through a 5-point Likert scale: from 1 = strongly disagree to 5 = strongly agree. Meanwhile, a set of criteria is used for identifying and selecting the professionals for the questionnaire survey, and all these included:

1. Respondent with the extensive experience BIM in IPD projects;
2. Respondent who has implemented BIM in current or previous construction projects;
3. Respondent who has the perceptions and knowledge of BIM on the implementation practices in IPD

Statistical analysis

Responses from the professionals were analyzed by using statistical tools in SPSS software. Cronbach's Alpha is considered as the most suitable test to measure the

internal consistency and the reliability of a test score for a survey's sample (Roland & Cooil, 1994). It is used to accesses the questionnaire and check the internal consistency of the responses (Bryman, 2001). Cronbach's Alpha value ranges from 1 to 0, the value larger 0.7 indicates is high reliability and the acceptable value range is from 0.35 to 0.7 (Field, 2009 & Aje, 2017) Mean value analysis technique is a preferred tool for analyzing data collected by questionnaire surveys. Y. Wu et al. (2018), Ke et al. (2010) & T. O. Olawumi and Daniel W.M. Chan (2018) employed the mean value to rank the critical factors. The higher the mean value, the higher the rank and vice versa. The mean value (MV) for each factor is calculated by the equation of:

$$\text{Mean Value} = \frac{\sum x}{n}$$

Where, $\sum x$ = Total Frequency of x
n = Total of respondents

Standard variation (SD) is used to consider when two or more factors have the same mean value in the results of scoring. The factor has a smaller SD value is ranked higher within a set of factors with same mean value. However, if the SD value is same among the factors of same mean value, the factors will remain as same rank (Olatunji et al., 2017).

RESULT AND DISCUSSION

Demographic information

The data of the questionnaire surveys were made up of the respondents from the AEC industries. They were architects, civil and structural engineers, mechanical and electrical engineers, quantitative surveyors, contractors, developers and local authorities. In the data collection, consultant from the civil and structural engineers had the highest percentage in participating this study which was 29%. 19% of the respondents were the second highest among all the respondents and they were contractor. On the contrast, there was only 2% of the developers involved in this study.

After analyzing the collected data, most of the respondents which recorded as 38% were came from the categories of 0 to 5 years working experience. On the other hand, working experiences from 20 to 25 years and 25 to 30 years had the same lowest participating percentage which were only 3%. Besides, most of the participants were came from the civil and structural engineers with the working experiences from 0 to 5 years and 10 to 15 years with the amount of 10 % of the respondents for the two categories. The least participating category was developer and they were came from the working experience from 20 to 25 years. Table 2 below shows the working experiences against profession of respondents. It clearly shows that the involvement of different participants from AEC industries and their working experiences.

Table 2. Working Experiences from Different Profession of Respondents

Profession / Working Experience (years)	Architect (%)	Civil and Structural Engineer (%)	Mechanical and Electrical Engineer (%)	Quantitative Surveyor (%)	Contractor (%)	Developer (%)	Local Authority (%)	Total (%)
0 - <5	7	10	2	7	5	0	7	38
5 - <10	3	7	3	2	2	0	5	22
10 - <15	0	10	2	2	3	0	3	21
15 - <20	2	2	0	0	2	0	2	7
20 - <25	0	0	0	0	2	2	0	3
25 - <30	0	0	0	0	3	0	0	3
> 30	0	0	3	0	2	0	0	5
Total (%)	12	29	10	10	19	2	17	100

Principles of Integrated Project Delivery (IPD) In Malaysia

In general, twenty (20) elements to build up the IPD system were adopted from the study. IPD system is indeed a system that integrates all peoples, tools and processes into a system to decrease waste as well as improve efficiency throughout design, fabrication and construction process. Besides, all these elements are actually related to each other and there is no any information regarding the principles of IPD in Malaysia as captured in Table 3. Therefore, finding out the most contributed principles that operate in Malaysia is essential. The elements are analysed through the factor analysis.

Table 3. Factor Matrix of Principles of IPD in Malaysia

Principles of Integrated Project Delivery (IPD)	Factor Loading Spacing
Appropriate Technology: Building Information Modelling (BIM)	0.886
Collaborative Decision-Making and Control	0.870
Jointly Developed and Validated Project Goals and Objectives	0.858
Unrestricted Shared Information	0.841
No Blame Culture	0.825
Operate Without Boundaries	0.808
Liability Waivers among Key Participants	0.782
Team Flexibility	0.773
Intensified Early Planning	0.770
Collaborative Innovation	0.769
Willing to Collaborate	0.745
Mutual Respect and Trust	0.736
Multi-Party Contract Agreement	0.717
Open Communication	0.666
Early Involvement of Key Participants	0.631
Co-Location of Team	0.570
ean Principle of Design, Construction, and Operation	0.519
Financial Transparency	
Shared Financial Risk and Reward	

Based on Table 3, there exists 18 principles that can be identified as the contributory factors to the principles of IPD in Malaysia as another 2 principles had been removed after the performance of factor analysis.

Implementation Level of IPD in Malaysian Construction Industry

The implementation of IPD in Malaysian Construction Industry is important as to identify the level of implementation in different elements on how well the project team integrated (NASFA *et al.,* 2010). With this kind of information, determination of the implementation level of IPD in Malaysia construction industries can be done by classifying those principles (Table 4).

Table 4. Guide for Level of IPD Integration

	Level 1	**Level 2**	**Level 3**	**Level 4**
Level of integration	Lowest			
Delivery method	IPD as Philosophy	IPD as Philosophy	IPD as Delivery Method	IPD as Delivery Method
Known as	Lean Delivery	IPD-ish, IPD-Lite, IPD like, Integrated practice	Multi-party contracting, "Pure" IPD, Relational contracting, Lean Project Delivery System	"Actual IPD"
Nature of Agreement	Transactional	Transactional	Relational	Relational
Key Characteristics	No contractual Language requiring Collaboration Willing to Collaborate Mutual respect and trust	Some contractual Bonded collaboration Early involvement of key participants Co-location of team Intensified early planning / intensified design Lean Principles of design, construction and operation	Multi-party contract / Single Purpose Entity Collaboration decision making and control BIM used by project participants	Multi-party contract / Single Purpose Entity Collaboration decision making and control Liability Waivers Shared financial risks and rewards Fiscal transparency Jointly developed and validated project goals and objectives Shared BIM model Team Flexibility
Highly Desirable Limited	Limited risk shared No blame culture Open Communication	Shared risk and rewards/Mutual benefits (no contractual bond) BIM used by project participants Less assign liability Unrestricted shared information Fiscal transparency (no contractual bond)	Liability Waivers Operation without boundaries Shared financial risks and rewards Fiscal transparency Jointly developed and validated project goals and objectives	

Level 1	Level 2	Level 3	Level 4
	Jointly developed and validated project goals and objectives (no contractual bond) Collaborative innovation	Shared BIM model Organisation and Leadership Team Flexibility	

From the analysis, most of the respondents or Malaysian construction industries do not implement financial transparency and shared financial risk and reward. It already shows that the Level 4 implementation can be eliminated as the key characteristics require fiscal or financial transparency. In Malaysian construction industries, the implementation level of IPD is Level 3. This is due to the reason of all the key characteristics, multi-party contract, collaboration decision making and control as well as BIM used by project participants have been implemented. The reason of changing the delivery method and nature of agreement are due to it is now not just an idea but achieves the aim of occurrence of IPD (NASFA et al., 2010).

BIM Integration in Integration Project Delivery (IPD)

From the study, there are a lot of benefits of BIM as shown in Table 5. Therefore, evaluating the benefits of BIM in IPD system in Malaysia is necessary to give related information to the communities. The following will be analysed through factor analysis.

Table 5. Factor Matrix of BIM Integration in IPD

BIM Integration in Integrated Project Delivery (IPD)	Factor Loading
Use Current Situation of Data to Inform Executing Equipment (Regulate)	0.906
Take Off Quantity (Quantify)	0.875
Illustrate A 3D Model for Better Visualization (Visualize)	0.844
Track Status of Materials from Manufacture, Arrival at Site, and The Installation (Qualify)	0.842
Predict Future Performance of Material (Forecast)	0.815
Store Various Data (Document)	0.791
Store Data to Operate Executing Equipment (Control)	0.708
Collect Current Information with The Aid of Other Equipment (Capture)	
Monitor "Live" Status at Site with Aid of Mobile-Application (Monitor)	
Determine The Needed and Suitable Material (Prescribe)	
Determine The Optimum Location of Equipment (Arrange)	
Determine The Optimum Amount of Equipment (Size)	
Clash Detection (Coordinate)	
Determining The Suitability of Chosen Build Material to Specific Code (Validate)	
Ease The Drawing When There Is Changes (Draw)	
Manufacture Materials Based on Stored Data (Fabrication)	
Combining Different Segments (Assemble)	

After running the analysis, there only exists 7 contributory variables to BIM integration in IPD. They are use current situation of data to inform executing equipment, take off quantity, illustrate a 3D Model for better visualization, track status of materials from manufacture,

arrival at site, and the installation, predict future performance of material, store various data and store data to operate executing equipment.

CONCLUSION

In general, 18 principles of IPD except fiscal transparency and shared financial risk and reward has contributed the most. Besides that, suggestion on the additional level 4 which categorizing the implementation of IPD were been discussed. This includes, Level 1 and Level 2 which act as philosophy while Level 3 and Level 4 are as delivery method. Later in the discussion, 18 benefits where identified using BIM and 7 functions of BIM that significantly contribute to IPD has been highlighted. This includes regulate, quantify, visualize, qualify, forecast, document as well as control. Among these 7 functions, Malaysian construction industries agree that regulation contribution the most which will reflect the whole process on the legal. Hence, from the overall study, BIM does give impact towards the whole IPD system.

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BUILDING INFORMATION MODELLING (BIM) STAGE 2 IMPLEMENTATION STRATEGY FOR THE CONSTRUCTION INDUSTRY IN MALAYSIA

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Abstract
Building Information Modelling (BIM) within the Malaysian construction industry continue to thrive under the Construction Industry Transformation Programme (CITP) 2016 to 2020. Embracing new technology and modern construction, such as information and communications technology (ICT), as the future direction will drive the industry toward an improved performance and continued global competitiveness. By 2020, construction industry players that are engaged in government projects worth over 100 million will be required to achieve a minimum of 40% implementation rate of Stage 2 BIM maturity. This paper aims to assess the status of BIM adoption in Malaysia to ensure that the development of strategy can be used as an overarching framework for the implementation scheme. Survey was conducted in 2016 among construction industry players in Malaysia and generated a sample of 570 responses. The findings revealed that the percentage of BIM adopters (17%) in Malaysia is extremely low. In this survey, several challenges that hinder the adoption of BIM in Malaysia was analysed. It is expected that the findings from this study will recommend BIM stage 2 implementation strategy for the construction industry in Malaysia.

Keywords: *Building Information Modelling; BIM adoption; BIM implementation strategy*

INTRODUCTION

The Construction Industry Development Board (CIDB) Malaysia continues to transform the construction industry into a modern, highly productive and sustainable under the Construction Industry Transformation Programme (CITP) 2016 to 2020. It was stated that the Malaysian construction industry is required to achieve the implementation of stage 2 BIM maturity by 2020, in which a minimum of 40% implementation rate of public projects valued at RM 100 million and above shall implement the corresponding approaches and processes (CIDB Malaysia, 2015). Embracing new technology and modern construction, such as BIM is seen as the future direction for improving productivity of the industry.

Current rapid shift towards new dimension of the fourth industrial revolution or 'Industry 4.0' will require the industry to prepare for the technological and cultural changes into digital construction. Industry 4.0 is mainly driven by digitalization and the future of construction will soon be characterized by connected system of sensor, intelligent machines, mobile devices and new software applications. Integration of 'big data' created by technology embedded in Industry 4.0 is important for the construction industry to boost productivity, manage complexity, reduce project delays and cost overruns, and enhance safety and quality (Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016).

BIM is a metaphor for digital construction and the role of BIM is pivotal as fundamental to create intelligent data throughout the project life cycle. In the era of digital empowerment, construction industry must reimagine the business models and change the work process to stay competitive. The technological revolution starts with enhanced process and management

through BIM. BIM in Malaysia is defined "Modelling technology and associated set of process to produce, communicate, analyse and use of digital information models throughout construction project life-cycle" (CIDB Malaysia, 2016). Figure 1 define what was meant by BIM stage and the associated characteristics of each BIM model applied to the intended deliverable.

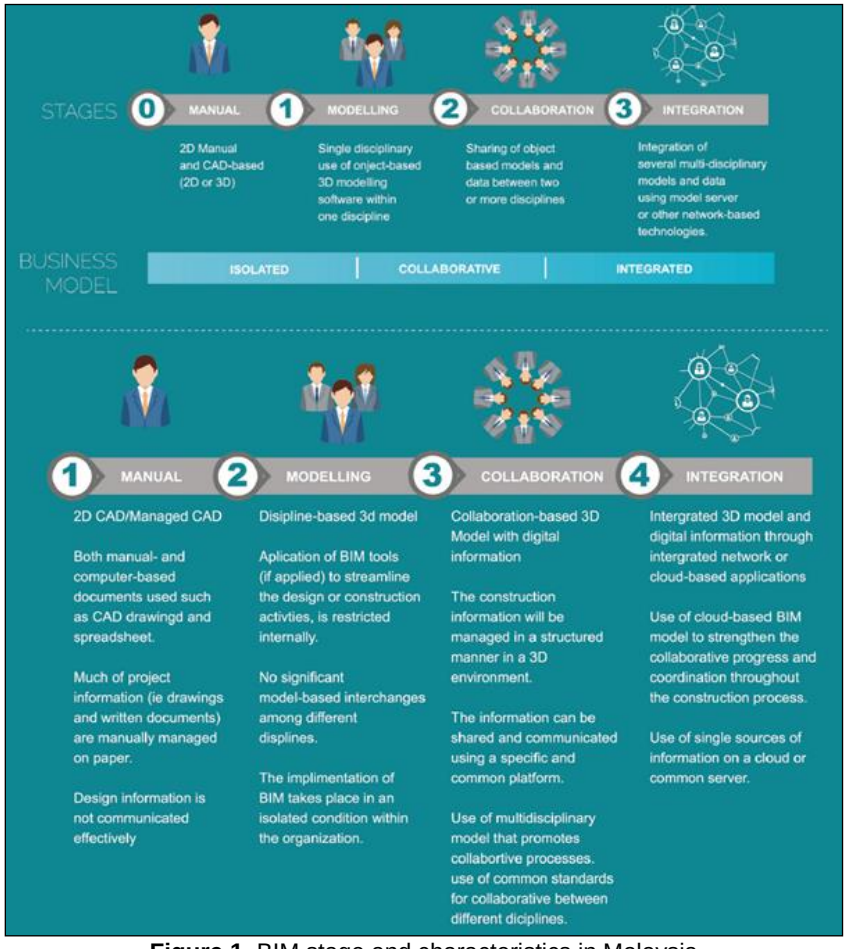

Figure 1. BIM stage and characteristics in Malaysia

This study was motivated by the current level of uncertainty that to what extent BIM is implemented in Malaysia. A number of studies have been conducted to identify challenges faced by the Malaysian construction industry in implementing BIM. The result shows the majority of construction industry players see BIM as 'disruptive technology' and they are reluctant to change the established traditional process (Zahrizan, Ali, Haron, Marshall-ponting, & Abd, 2013). The need for the industry to embrace change is highlighted in CITP, however there are challenges that make the adoption of BIM much slower than anticipated.

To date, there is no specific baseline that can be used to benchmark the adoption level of BIM in Malaysia. This study describes applied research to generate an instrument for benchmarking BIM adoption in Malaysia. The study aims to provide insight into the current BIM adoption in Malaysia, as well as to establish BIM adoption strategy which is vital to ensure the direction of BIM continues to thrive as described in the CITP.

Assessing BIM adoption in Malaysia

Based from the Bew-Richards BIM Maturity model and Succar model perspective, the construction industry in Malaysia can be categorised between stage 1 and 2 (Imoudu Enegbuma, Godwin Aliagha, & Nita Ali, 2014). But according to study conducted by Zahrizan et al., (2013), BIM level in the Malaysian construction industry is between Level 0 and 1. Even though many researchers have discussed the level of BIM implementation in Malaysia, the basis on determining the level of BIM is not being assessed using appropriate BIM performance measurement.

To justify level of BIM implementation in Malaysia, assessment through complementary BIM tools, workflows and protocols are required. Such complex implementation is not instantaneous but passes through recursive periods of implementation readiness, capability acquisition, and performance maturity (Succar et al., 2015). BIM implementation consist of activities taken by an organizational unit to prepare for, deploy or improve it products and processes. Considering BIM in Malaysia is still in infancy stage, assessing the status of BIM adoption in Malaysia is important to ensure that comprehensive strategy can be developed as an overarching framework for the implementation scheme.

Prioritization of strategic initiatives for Malaysia BIM roadmap

The findings provide by assessing the status of BIM adoption in Malaysia will lay the foundation for the future development of BIM implementation scheme. BIM implementation is introduced with three-phased approach separating an organisation's readiness to adopt, capability to perform and its performance maturity. In an attempt to develop a strategy for implementation plan, this paper analyses the readiness of Malaysian construction industry to adopt BIM with respect to the (1) people, (2) process, and (3) technology. Gu & London (2010) suggest that there are varying levels of adoption and therefore the need for comprehensive BIM roadmap to facilitate BIM adoption in Malaysia.

Despite the substantial pressure from government, BIM adoption in Malaysia still faces challenges due to several challenges. Failure to address organisational challenges may result in loss of productivity from BIM adoption. Dealing with resistance to change, BIM adoption results in many different types of opportunities and challenges compared to traditional ways of working in the industry, and many studies have been carried out to reveal them (Talebi, 2014).

RESEARCH METHODOLOGY

A survey was conducted among the construction industry players in Malaysia. This survey is conducted to gauge the level of BIM adoption in the Malaysian construction industry. The data collection process lasted four months and generated a sample of 570 responses. The methods used for data collection included online survey, interviews (by telephone and in-person), conferences, and seminars. The target groups of respondents comprised stakeholders in the construction industry (i.e., architects, engineers, surveyors, contractors, developers, and government officials, among others). The responses reflected the process of BIM progress in Malaysia and the necessity of dispassionate reporting of the actual conditions.

The questionnaire was divided into five sections as follows: (1) General respondent background; (2) BIM resources; (3) BIM in organisation; (4) Challenges for BIM implementation; and (5) direction of BIM in organisation.

FINDINGS AND DISCUSSIONS

BIM Adoption in Malaysia

The findings from this survey indicate a widespread awareness of BIM among the Malaysian construction industry, and 84% (refer Figure 2) of the responses are willing to adopt the implementation of BIM. Although the survey shows extensive awareness and willingness of the industry to change for BIM, the percentage of BIM adopters (17%) is extremely low. The considerably low rate of BIM uptake in Malaysia underscores the significance of the diffusion of BIM within the construction organization to understand the barriers and drivers of BIM adoption in Malaysia.

BIM diffusion is referred as the rate of BIM tools and workflows are adopted across markets (Succar & Kassem, 2015b). In this paper, we also recommend the strategy for organization to signifies the planning and preparation activities preceding adoption of BIM.

BIM Awareness and Readiness

Awareness of BIM must arise through organizations at an early stage for the rapid adoption of BIM in Malaysia. Based from this survey, the required knowledge on BIM is still minimal despite the awareness on BIM of the construction industry players. According to responses, their organization failed to provide staff members with trainings on BIM tools and workflows. Lack of knowledge and skills among staff members in organization will hinder the implementation of BIM due to the process and technological changes within the organizations.

Readiness will determine the tendency of organization to adopt BIM. Readiness mainly depends on contexts, situations, and individuals involved in the implementation. Readiness can be expressed as the level of preparation, potential to participate, or capability to innovate (Succar & Kassem, 2015a). The readiness levels of BIM among the players in the Malaysian construction industry are still low based on the following findings of the survey (refer Figure 2): 41% of the organization lack clear policies that support the implementation of BIM, 72% of the organization lack allocations for any financial incentive for using BIM, 64% percent of the organization failed to invest in BIM training, and 67% percent of the organization failed to invest in BIM hardware and software.

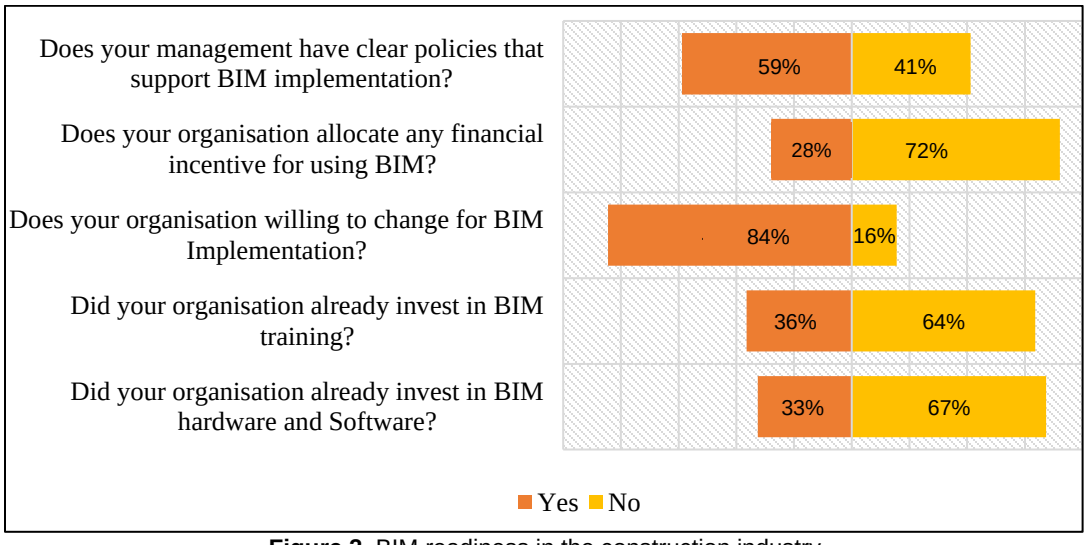

Figure 2. BIM readiness in the construction industry

BIM Adoption Rate

Figure 3 shows architects are the leading adopters of BIM in Malaysia at 42% and followed by engineers at 21%. This result highlights that BIM is mainly used among professionals at the design stage, thereby further showing that the current BIM practice in Malaysia is only predominantly focusing on the interests of architects and designers. This survey also determined that contractors (13%) and quantity surveyors (12%) have begun applying BIM. Small and large organizations at 29% were the optimum sizes of organization that adopt BIM.

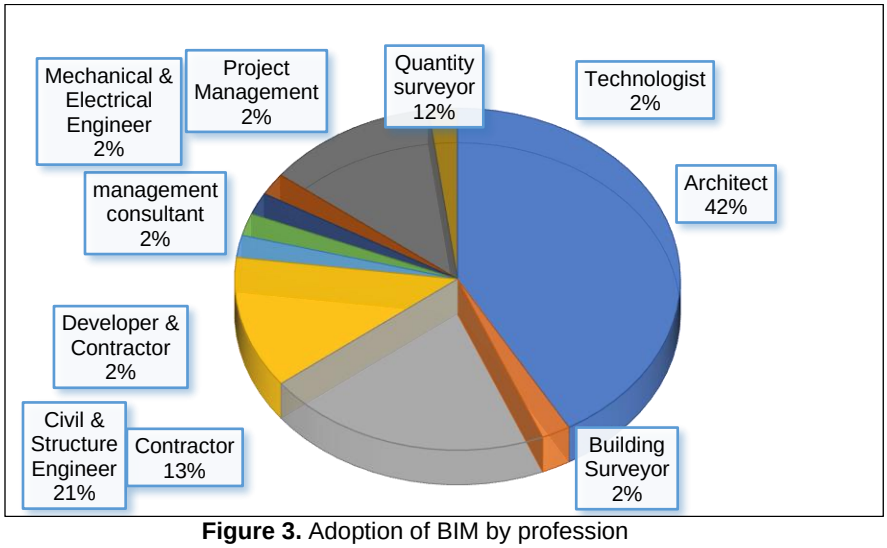

Figure 3. Adoption of BIM by profession

Challenges to the implementation of BIM

The ability to understand the challenges of adopting BIM is considered a foundation to predict the adoption process because such capability provides constructive strategies to

mitigate the challenges. Table 1 presents several challenges that surround the adoption of BIM in Malaysia. The results show that high cost of technology, high training cost, lack of knowledge on BIM, high cost of software, and insufficient availability of BIM trainings are the critical challenges that hinder the adoption of BIM in Malaysia. To articulate the strategic BIM adoption, the challenges are divided into three categories, namely, people, process, and technology.

Table 1. Challenges to the implementation of BIM

Factor	Mean	Rank	Category
High cost of technology	4.09	1	Technology
High training cost	4.06	2	Technology
Lack of knowledge on BIM	4.05	3	People
High cost of software	4.04	4	Technology
Insufficient availability of BIM trainings	3.83	5	People
Lack of time for experimentation and implementation in fast-paced projects	3.79	6	Process
Lack of references to assist in implementing BIM	3.76	7	Process
Lack of awareness of BIM benefits	3.66	8	People
Lack of time to implement	3.60	9	Process
Lack of competency among team members in using BIM	3.59	10	People
Existing hardware incapable of running basic BIM software	3.51	11	Technology
Reluctance to initiate new workflows for the implementation of BIM	3.44	12	People
Lack of direction of BIM in the industry	3.37	13	Process
Inadequate familiarity with the use of BIM	3.35	14	Process
No BIM requirement/ mandate exists in the industry	3.33	15	Process
BIM software is complicated to use	3.31	16	Technology
Resistance to change for new technology	3.24	17	People
Assumption that conventional methods are better than new processes	3.07	18	Process

The cost of implementation was recognized as one of the barriers to BIM implementation. The Malaysia Productivity Corporation (MPC) reported that many construction organizations were unprepared to invest in new technologies and human resource trainings on a large-scale basis because they were uncertain of the immediate future growth (Malaysia Productivity Corporation, 2012). The perceived sources of high cost, such as technology, training, and software, were deemed factors that hinder the implementation of BIM within construction organizations.

The limited number of BIM professionals who are competent and capable of implementing BIM, which is regarded as resistance based on the "human factor," are the other factors that limit the adoption of BIM in an organization. This phenomenon occurs when the industry is unequipped with a set of BIM knowledge. Organizations should develop the capability of people with a set of skills and knowledge of BIM. Most organizations are concerned that the learning curve in adopting BIM could affect their respective businesses. In addition, the lack of references to assist in implementing BIM tends to extend the period of the learning curve. The availability of references will empower organizations with sources of information that will aid them during the learning process.

Strategy for Organization to Adopt BIM

BIM involves an integrated process between human competency and technology to produce, process, manage and collaborate the high-performance digital construction information. This provides the opportunity for the organisations to enhance their decision-making process by acquiring the reliable information and promotes data-centric solution at the early stage of construction process.

The BIM adoption process involves several change management processes to support the skill upgrading and technology adoption. However, the change management process does not need to be drastic. The process can be in stages, depending on the organisation's capability and competency.

To institutionalise BIM in the organisation, it involves an initial investment in term of cost and time. Thus, the gain optimal benefits from the investment, the organisations must acquire right strategy to support BIM execution process.

Technology (Software and Hardware requirement)

BIM is not about software, but the organizations' need to employ the software to support BIM process. There are different types available BIM-related software in the market. Based on the availability, the organization need to acquire the software according to the deliverable from BIM uses and the organization's capability of investment.

To support the BIM process, the organizations' need to acquire or upgrade their hardware. Initially, the organizations' can use the existing hardware that comply with the basic requirements (specification) of BIM software. However, at the advance BIM implementation stages, it is recommended that some of the existing hardware to be assessed and upgraded with high-performance graphics capabilities to enhance the productivity and efficiency.

People

BIM does not work by itself - people make it work. Therefore, engaging and nurturing the individual with BIM competency is critical during the BIM adoption process. BIM requires the individual that have sound experience in construction know-how matters with equipped with the BIM methodology knowledge. Its involves skill upgrading process which comprises practical learning process on wide range of subject, courses and training option that related to BIM methodology.

Either the organization initiates the training or seminar in house or sent their staff to the outside training provider, there are few knowledge that the organization's must establish during the BIM adoption process. At the initial stage, the organizations' must acquire the personnel that have sufficient knowledge on the BIM process. Based on that knowledge, the organizations' must able to acknowledge what benefits BIM can bring to the organizations' and how BIM will be implemented. At strategic level, the organizations must have some personnel to prepare and manage the execution plan for organization to adopt BIM.

Process

Successful of BIM implementation is more than just getting the technology in place. The deployment of BIM in organizations involves considerable transformation operation process, depending on the organizations' requirement and needs. Thus, the pace of adoption process may differ from one organizations to another. In some cases, it is need the customization process.

The process to implement BIM involves activities to manage the large pool of resources. Therefore, the organization should have a strategy and plan to support the execution process. Since the orientation of BIM process is based on data-centric solution, the organization need to establish a process protocol as a customized document to standardize the operation and management the data. The protocol should consist of guidelines on the method to execute the BIM process. The protocol then become a reference document on the process work throughout the design and construction process.

CONCLUSION

BIM fundamentally require some changes to an organization depending on their objective for using BIM. Adapting new ways of working is complex but change management process need to be strategize in stages based on the organization's capability and competency. In general, three central tenets organization need to consider is people, process and technology. BIM software is important to support BIM process. Currently, there are different type available BIM-related software. However, the organization need to acquire only specific software according to what they want to achieve in the project. Understand the organization's knowledge and skill gaps are important for BIM adoption. Basic knowledge on BIM will ensure the understanding on BIM process and assist in the steep learning curve for BIM adoption.

In summary, the transition phase towards BIM needs to be monitored and facilitated to ensure that the benefit of BIM can be maximised in our construction industry. The limited resources to assist the BIM implementation will adversely affect the implementation pace in Malaysia. That is, if a well-planned and properly implemented strategy of BIM adoption is in place, then such adoption can be achieved within a short period.

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THE INFLUENCE OF HOUSING TYPES AND PRICE ON ABANDONED HOUSING PROJECTS IN MALAYSIA

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Abstract
Housing construction is one of the most important economic activities in Malaysia and taken seriously by the government. However, the housing project in Malaysia still faces the abandoned issue due to several problems. Abandoned housing projects happen across the globe, and is an issue that gives negative effects to the stakeholders of those projects. This study was conducted to study one of the factors which is the influence of housing types and price on housing abandonment in Malaysia, specifically in Peninsular Malaysia. This paper also reviewed the other factors that contribute to this matter such as improper market study, mismanagement, financial problem, land and legal disputes, lack of project risk assessment, inapplicable government policy, incompetent workers, lack of enforcement and inconsistent monitoring by the authorities. Together, the economic analysis was presented to analyse the impact of housing project abandonment to the economy of the country. This paper will contribute to the body of knowledge in terms of abandoned buildings in Malaysia.

Keywords: C*onstruction; Abandoned project; Housing*

INTRODUCTION

The United Nations (UN) estimates the current population of Malaysia in 2018 is 32,055,660 and it is equivalent to 0.42% of the total world population. This estimation shows that there are high demands for better quality homes as shelter for the nation, more efficient buildings as well as urban infrastructures in Malaysia. In 2015, during the UN general assembly, Malaysia's 6th prime minister assured that Malaysia will embrace the 2030 Agenda for sustainable development and its implementation. One of the sustainable development goals is providing safe, affordable and upgrading the unhealthy home areas. It shows that, the need for the construction industry is higher in order to fulfil the ambition of sustainable development in Malaysia.

In the beginning of 2018, the Department of Statistics Malaysia reported that the construction sector has an average growth rate of 5.9% of construction work done and it recorded about RM 37.1 billion in value. Figure 1 shows the contribution of construction work done in 2018; the construction of residential building contributes about 26.6% from the total construction work done. The activities of construction are being dominated by the private sector with 60.9% share and the remaining 39.1% shared by the public sector.

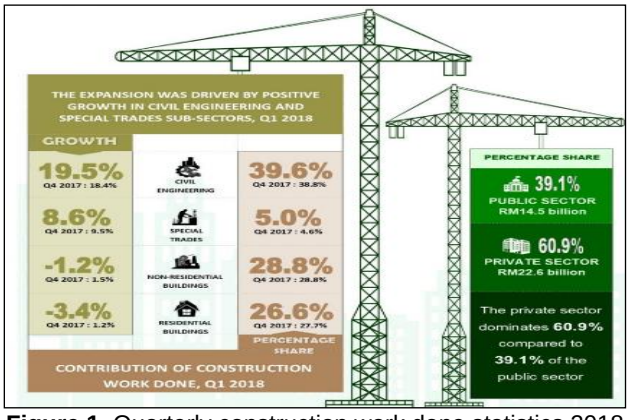

Figure 1. Quarterly construction work done statistics 2018
(Source: Department of Statistic Malaysia)

The construction industry makes up an important part of the Malaysian economy due to the amount of industries linked to it and the number of people it employs. It is considered as one of the most substantial economic drivers for Malaysia. However, not all of the construction activities ended up with a successful development or completed on time (Ariffin et. al, 2018). This matter will affect many institutions such as the developer, contractor, buyer, government bodies and the funder for the project.

The problem regarding the abandoned building issue in Malaysia is still unsettled until today. Thus, this paper will study the factors contributing to the abandoned housing projects, especially on the influence of types of housing demand. Moreover, this paper also overviews other factors and the impact of abandoned housing projects.

LITERATURE REVIEW

Types of Houses in Malaysia

A house is a home, building or structure that functions as a habitat for humans or other creatures. The term house includes many kinds of dwellings, ranging from rudimentary huts of nomadic tribes to complex structures composed of many systems. Apart from being affordable, the aspect of comfort is also important. Housing becomes an important part of daily life, can help residents address the struggle to maintain their economic livelihood, take shelter from the threats of a changing climate, the challenges of urban violence, and the inequities of governance (Vale, et.al, 2014).

Malaysia has various types of housing such as cluster, condominium, detached, semi-detached, terrace, townhouse, low-cost, flat and low-cost flat. Figure 2 shows the summary of housing supply by type in Malaysia at the end of 2018. The number of population has a relationship with the demand of housing, where it can be seen that Selangor had a higher demand of housing compared to other states due to the higher population, followed by Johor and Perak. The figure indicates that the terraced house was the prominent housing type, followed by the condominium type of house and others. (Abdul Rahim & Hariza, 2012) found that terrace house was the most affordable and famous housing alternatives for Malaysians.

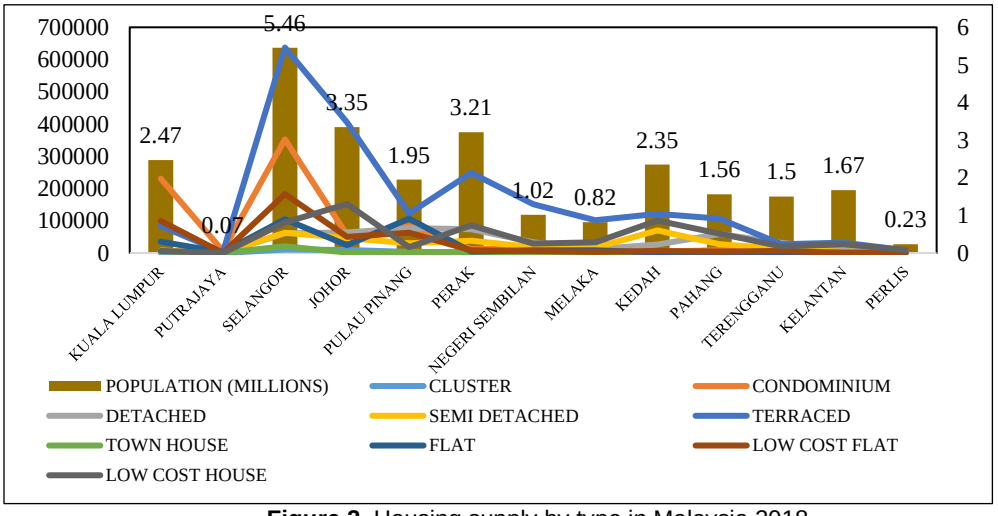

Figure 2. Housing supply by type in Malaysia 2018
(Source: Valuation and Property Services Department of Malaysia)

The Malaysian House Price Index (MHPI) at the end of 2017 increased by 5.8% as reported by The National Property Information Centre (NAPIC). During quarter 3 of 2017, the average house price in Malaysia was set at RM 404,835. NAPIC also reported that Melaka recorded the highest annual increase with the house price rise of 5.4%. In Q3 2017, the most expensive housing in Malaysia was in Kuala Lumpur with the average price RM 785,327 and the cheapest housing at the average of RM 164,300 was in Kelantan. Table 1 shows the median price of property types of the states in Malaysia. It is noted that the price range is different, even when the type of houses is the same for every state. The table also indicates that urban states have a higher price of houses compared to rural areas.

Along with the success of housing construction in Malaysia as stated above, the existence of abandoned housing projects is still inevitable. The increase in house prices has boosted the property sector and also attracted many new developments for residential building. The growth of the Malaysian housing sector has been underpinned by the interface between three forces; growing population, high rates of urbanisation and a growing economy (Ramlan H & Zahari E.E, 2016). Figure 3 shows the abandoned housing project by types in Malaysia quarterly in 2018. 270 projects for the landed housing type were abandoned, followed by 49 projects for strata high-rise and 7 projects for strata landed. The landed type house was in a group of terraced, cluster, detached, semi-detached and low cost houses.

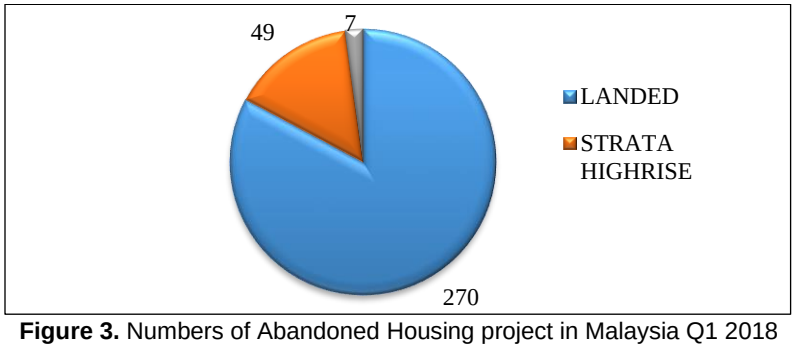

Figure 3. Numbers of Abandoned Housing project in Malaysia Q1 2018
(Source: National Housing Department)

Table 1. Residential Median Price by Type for Every State in Malaysia Q1 2018

	Kuala Lumpur	Putrajaya	Labuan	Selangor	Johor	Pulau Pinang	Perak	N.Sembilan
Cluster	RM25,500	ND	ND	RM720,000	RM848,000	RM166,458	RM453,400	RM90,000
Condominium	RM618,500	RM260,000	ND	RM324,000	RM320,000	RM485,000	RM368,000	RM137,500
Detached	RM3,600,000	RM6,000,000	RM477,500	RM493,000	RM255,000	RM450,000	RM140,000	RM340,000
Semi detached	RM1,560,000	RM1,350,000	RM535,000	RM835,000	RM508,000	RM690,000	RM348,800	RM360,000
Terraced	RM1,250,000	RM706,000	RM350,000	RM450,000	RM368,000	RM365,000	RM230,000	RM260,000
Town house	RM787,000	ND		RM370,000	RM275,000	RM510,000	RM510,000	RM70,000
Flat	RM215,500	ND	RM165,000	RM145,000	RM90,000	RM285,000	RM175,000	RM95,000
Low Cost Flat	RM156,000	RM247,000	ND	RM100,000	RM65,000	RM95,000	RM64,000	RM49,500
Low Cost House	RM280,000	ND	ND	RM190,000	RM78,000	RM160,000	RM114,000	RM80,000
	Kedah	**Pahang**	**Terengganu**	**Kelantan**	**Perlis**	**Sabah**	**Sarawak**	**Melaka**
Cluster	RM125,000	RM64,000	RM270,000	RM70,000	RM125,000	RM190,000	RM242,000	RM320,000
Condominium	RM190,000	RM320,000	RM322,500	RM350,000	ND	RM287,500	RM350,000	RM180,000
Detached	RM326,000	RM95,500	RM160,000	RM295,000	RM390,000	RM398,500	RM238,000	RM167,000
Semi detached	RM292,000	RM330,000	RM315,000	RM290,000	RM348,000	RM665,000	RM620,000	RM360,000
Terraced	RM170,000	RM238,800	RM225,000	RM180,000	RM230,000	RM350,000	RM340,000	RM194,000
Town house	ND	ND	ND	ND	ND	RM680,000	RM65,000	RM70,000
Flat	ND	RM76,000	RM160,000	ND	ND	RM190,000	RM115,000	RM125,000
Low Cost Flat	RM50,000	RM64,500	RM56,000	RM57,000	ND	RM145,000	RM65,000	RM45,000
Low Cost House	RM105,000	RM112,000	RM73,000	RM58,000	RM88,500	RM200,000	RM142,500	RM80,000

(Source: Valuation and Property Services Department of Malaysia)

Factors of Abandoned Housing Projects

The Ministry of Urban Wellbeing, Housing and Local Government (MHLG) defines that an abandoned project is when the project is uncompleted within or later than the delivery date as stated in the sale and purchase agreement and no significant activity happens at the construction site for six (6) continuous months, or petition for winding up has been registered in the High Court under section 218 of the Companies Act 1965 (Dahlan, 2008). In addition, during the inspection done by the MHLG body (monitoring and enforcement division), if found that the developer is unable to finish the project as per schedule and the project has continuously stopped working for more than six months, the project is thus considered abandoned.

Abandoned projects gave an adverse impact to Malaysia as a country with regards to the economic and environmental aspects (Abdul Hadi et. al, 2014; Woka, P., & Miebaka, A. 2014). Table 2 presents the breakdown of abandoned housing projects in 2017 from MHLG In the context of Peninsular Malaysia. The table illustrates that out of 3365 total housing projects, 254 of them were abandoned. From the Table 2, the highest percentage of abandoned housing projects was recorded in Negeri Sembilan which was 15%, followed by Kelantan at 13%.

Table 2. Abandoned Housing Projects by State 2017

State	No of Total Project	No of Abandoned Project	% of Abandoned Project to The Total of Project
Johor	561	44	7.84%
Kedah	198	14	7.07%
Kelantan	142	19	13.38%
Melaka	116	8	6.90%
N. Sembilan	162	25	15.43%
Pahang	349	17	4.87%
Perak	357	18	5.04%
Perlis	23	0	0%
Pulau Pinang	206	14	6.80%
Selangor	881	82	9.31%
Terengganu	116	4	3.45%
WP Kuala Lumpur	254	9	3.45%
Total	3365	254	7.51%

(Source: Abandoned Project Rehabilitation Division, National Housing Department 2017)

Many factors contribute to the matter of abandoned housing projects. Failure in managing the market signal is also the reason for abandoned housing projects (Khalid, 2010). Oversupplying house will cause the problem of low demand of sale, so developers unwilling to accept the total loss will abandon the project. A lack of proper feasibility study and inaccurate market search may also cause inaccurate market demands for the housing type. Moreover, the developers' behaviour is another factor that abandoned housing projects occurred. Developers focused on only making a profit will abandon unprofitable projects rather than completing them.

Besides market study, as mentioned in a previous study by Ibrahim (2006), lack of experience and skills in handling projects in the construction industry by the main contractor may lead to mismanagement on site. Khalid (2010), Abdul-Rahman et al. (2016) and Nagamany (2016) also agreed that improper management of the team that controls the time and expenses of the project will lead to an abandoned project.

In addition to the above management problems, abandoned housing projects are also caused by the condition/law for operating any development for a private developer that has been set by the government which is sometimes inapplicable (Dahlan, 2008; Khalid, 2010). For example, the government put the requirement to the private developer to contribute 30% of low-cost house for every development. Khalid (2010) found that the developer tends to abandon the low-cost housing instead of waiting for a purchaser or invest using their own money for the project until the project is completed.

Dahlan (2008) also added that bank institution is able to misdeed their power to the debtors since there is no legal provision regulating loan and repayment of the loan. Same as the other authors, he also admitted that the mismanagement, conflict and insufficient coordination between developers and authority are some of the causes of abandoned housing projects.

The cause of all the above factors is actually the financial constraint faced by the developer due to the inadequate financial management that leads to the abandoned housing projects (Ariffin et al., 2018). The statement was supported by other authors (Razak D.A et.al, 2015; Mumin M.H 2016) and MHLG. MHLG also agreed that inadequate funds by the developer can lead to abandoned housing projects.

The government has already taken many initiatives to prevent this matter such as introducing the build-then-sell concept (BTS) (Zairul, M.N, & Ibrahim, 2004), amending the Act regulation and introducing the public-private partnership (PPP) between the government and the private developer; nonetheless, abandoned housing projects still occurred (Dahlan, 2008; Abdul Rahman, 2016). With mentioned causes and effects as above, another important factor contributing to the project abandonment is housing types and price. Thus, the main objective of this paper is to study the influence of housing types and price on abandoned housing projects.

METHODOLOGY

Firstly, in order to find out the type of housing in Malaysia and the actual scenario of abandoned housing project factors, an extensive literature review has been carried out. The data of type of housing supplied and the price for each type in every state were collected from NAPIC. From the literature review study, the factors contributing to the abandoned housing projects were gathered.

Secondly, the general effects of housing abandonment were analysed by conducting a questionnaire with 100 respondents from the community surrounding abandoned housing projects. The questionnaires were distributed evenly and analysed by using the Relative Importance Index (R.I.I.) technique based on the work of Chai et. al (2015). The data obtained from the questionnaire was analysed using the average index method and the multiple-choice questions were made based on the Likert's Scale for five ordinal measures of agreement. The Relative Importance Index (RII) is as Equation 1;

$$R.I.I. = [(5n5+ 4n4 + 3n3 +2n2 + n1) /5N] \quad (1)$$

Where;

n5 = Strongly Agree (SA),
n4 = Agree (A),
n3 = Unsure (US),
n2 = Disagree (DA),
n1 = Strongly Disagree (SDA),
and N = number of respondents.

RESULTS AND DISCUSSION

Abandoned housing projects based on price and types

Besides housing projects, finished housing buildings that were unsold are also considered as abandoned (Abdul Hadi, 2015). Besides the unfavourable location, the price and type of housing are some of the factors of unsold houses (Thean, 2018). The large number of unsold properties is due to the mismatch between the prices of new launches and households' affordability (Cheah et. al, 2017).

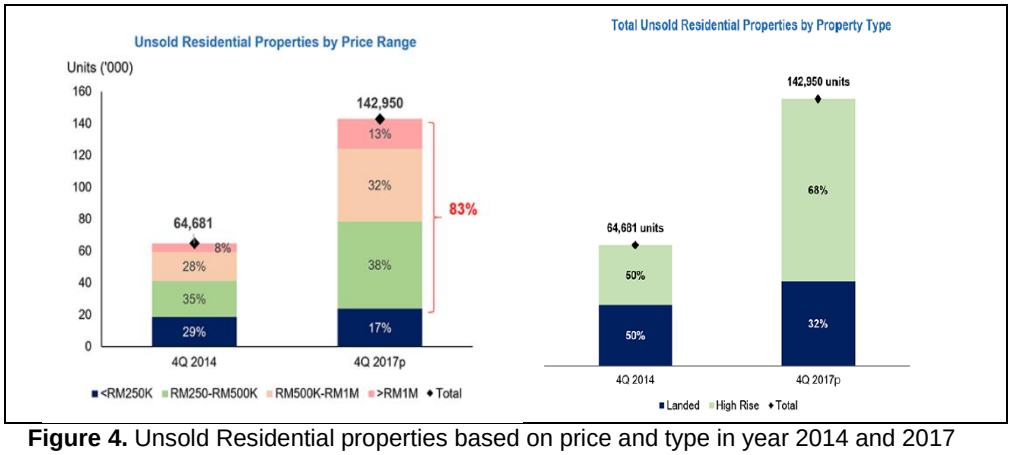

Figure 4. Unsold Residential properties based on price and type in year 2014 and 2017 (Source: National Property Information Centre)

Affordable housing is 30% of the household income (Bujang, 2017). People are considering other expenses before deciding to buy a house, where more than 30% of income spent on housing is considered as a burden. Figure 4 shows the number of unsold properties based on the current price in 2017. Due to the high prices of housing in Malaysia, people choose to rent instead of buying their own house to decrease their household burden (Olanrewanju & Tan, 2017), thus causing unsold housing in Malaysia to increase.

The housing type selection is affected by the socioeconomic status, age, building location, parenting young children or not and gender (Gifford R, 2007). Figure 4 indicates that the high-rise housing type is the property that has the biggest unsold rate compared to landed house. Most of the people in Malaysia choose to live in landed houses instead of high-rise houses (Oliver et.al, 2016). Some of the reasons are high-rise houses have many disadvantages compared to landed houses; for instance, high-rise houses need to pay management and

maintenance fees, have smaller spaces, and limitations and rules that need to be considered (Mohd Ridza, 2015; (Chia et. al., 2016).

The Malaysian House Price Index (MHPI) in the fourth quarter of 2017 has increased by 5.8% from year 2014 as reported by the National Property Information Centre (NAPIC). The comparison between years 2014 to 2017 was made due to the implementation of 6% government service tax (GST) in Malaysia. From there, it can be seen that the residential properties with the range of RM 250,000 to RM 500,000 constituted to the majority of unsold properties. Besides, the residential properties with the price of more than RM 1 million were constructed by year 2017 but unfortunately, the unit of unsold properties was huge. From here, it can be seen that the price of the property kept increasing but there were limited buyers of the property due to the uprising price. Moreover, the high-rise building contributed to the great amount of unsold properties recorded in year 2017 at 68%.

Figure 5 shows the status of the abandoned housing projects in Peninsular Malaysia from 2008 to 2017. The figure consists of the numbers of existing abandoned housing projects in the planning stage to be rehabilitated, new projects under the rehabilitation stage and the completed projects that have been restored. In year 2008, the estimation of total abandoned housing projects was 396 projects. 270 projects were in the planning to be rehabilitated while 126 projects had been completely revived by the authorities. On the other hand, in year 2017, the number of completed projects increased to 192. From this figure, it can be said that by year 2008 to 2017, the problem regarding abandoned housing projects was still unsolved and had become a burden to the government due to the negative impact given by this matter. With the government's initiative to revive these projects until they are completed, the number of completed projects from the abandoned ones can be decreased, but bearing in mind that the cost of reviving the building is huge and can sometimes be more than the allocated capital cost (Ariffin et. al, 2018).

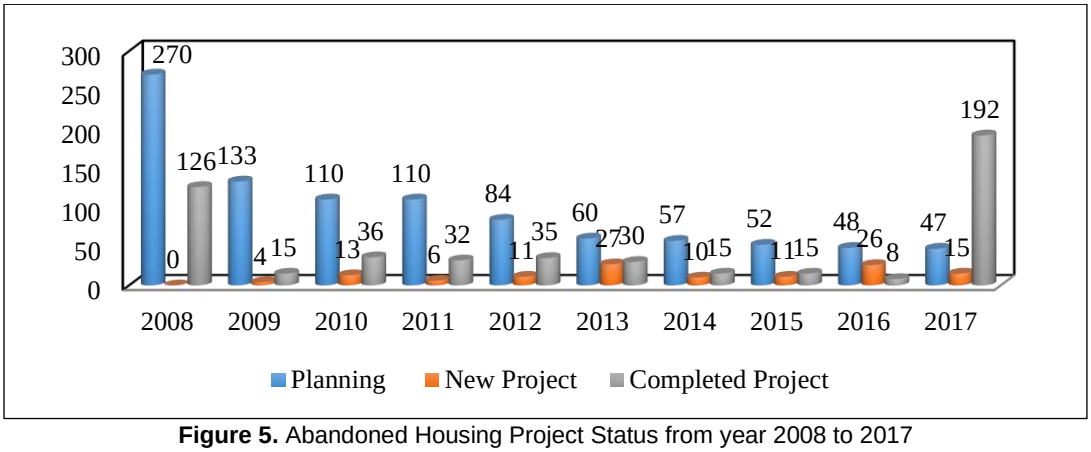

Figure 5. Abandoned Housing Project Status from year 2008 to 2017
(Source: Abandoned Project Rehabilitation Division, National Housing Department)

Effects of housing building abandonment

Based on Figure 6, 41% agreed that the abandoned housing projects affected their surroundings. The location of the project may be near their residential area so this is quite disturbing for them. Some of the sites could become the place for drug addicts or the place

for crimes to occur. Some communities could invade into the project site, damaging and prowling most materials predestined to be used for development and construction.

The abandoned housing project area will badly affect the surrounding area. Vale et. al (2014) found that these abandoned places gave shelter to negative activities such as gambling, drug use, gangsters, and vagrants. The residents who lived near the abandoned housing projects felt unsafe due to the existence of unknown people staying illegally there. The author also added that the residents nearby experienced stealing and robbery incidents. Besides, abandoned housing projects will lead to the existence of dangerous animals such as snakes, rats, mosquitos and flies (Vale et. al, 2014). The problems relating to illegal garbage dumping also happened in abandoned housing projects as reported by Dahlan (2007).

All of the impacts above will indirectly affect the country itself in terms of economic growth for the construction industry, not to mention the increase of unemployment, thus giving a bad reputation in which no one intends to invest in a problematic country. Vale (2014) added that the socio-economic and environmental impact would cause a bad image to the tourism sector and reduce the number of tourists coming to our country.

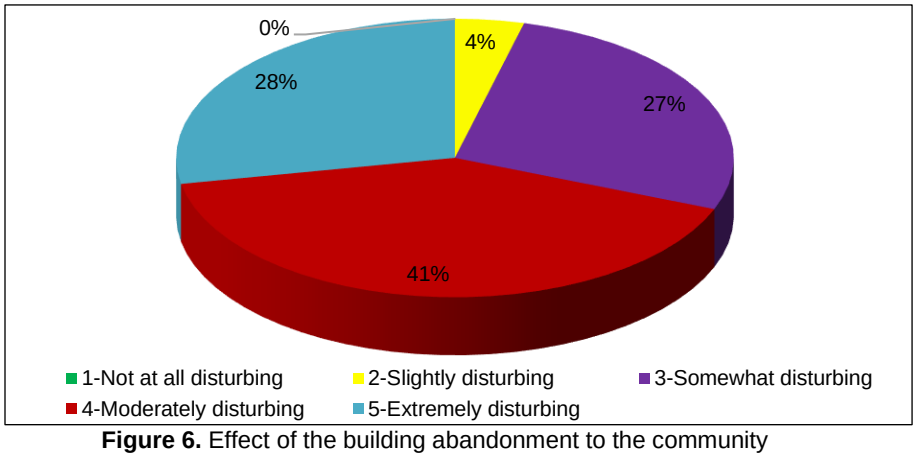

Figure 6. Effect of the building abandonment to the community

CONCLUSION

Based on the findings and literature review of the present study, the housing type and selling price are some of the factors contributing to abandoned housing projects. Purchasers are still considering on whether to buy high-rise houses due to several factors. Moreover, the price of housing in Malaysia is still unaffordable for middle income households, so the housing demand versus affordability is low. In regards to the findings, the stakeholders involved need to find the initiative and alternative to encounter the problem. On the other hand, by realising the impacts of abandoned housing projects, it will make the stakeholders more cautious the next time they intend to invest in the development industry.

ACKNOWLEDGMENTS

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APPLICATION OF HIGH STRENGTH REINFORCING BARS AND FIBROUS CONCRETE IN EARTHQUAKE-RESISTANT STRUCTURE ELEMENTS

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Abstract
The use of high strength reinforcing bars has becoming an interesting and cost-efficient option in construction industry recently. However, their application is still limited due to their low deformability which may induce a brittle collapse in the structures. Also, longer anchorage length is needed to transfer stress from reinforcing bars to the surrounding concrete. This paper focuses on investigating the influence of high-strength reinforcing bars on the behavior of structural elements, and the effect of fibrous concrete to compensate the negative effect of high-strength reinforcing bars. Five half-scaled specimens of interior joints, divided into 3 groups, casted using plain or fibrous concrete and reinforced with conventional 420 MPa or high strength reinforcing bar of 520 MPa. First group consisted of a specimen with conventional reinforcing bars and plain concrete, whereas the second group consisted of two specimens with high-strength reinforcing bars and plain concrete. The last group is similar to the second, with the addition of polypropylene fibre into concrete matrix. Loading protocol of all test specimens is defined according to ACI 374.2-13. The structural behaviors, such as dissipated energy, bond between reinforcing bars and surrounding concrete, and stiffness degradation of the five specimens were evaluated and compared.

Keywords: *Cyclic loading; High-strength reinforcing steel; Beam-column joint; Polypropylene fibre reinforced concrete; Bond*

INTRODUCTION

In construction industry, demand for sustainable and cost-saving materials is constantly increasing. The search of efficient use of materials is driving decades of work in the field of building materials by many researchers. Finding a higher strength and better material behaviors allows practitioners to overcome many problems that may arise during design and construction, or even improve the structural behaviors. One of the interesting products is the utilization of high strength reinforcing bars in construction. The use of reinforcing bars with higher strength is known to be advantageous, such as alleviating the congestion of reinforcing bars in several regions of elements, the weight of materials used, and the size of structural elements. Those advantages are leading to the reduction of budget in purchasing, handling, and storing of materials, as well as the reduction of environmental impact by using a smaller quantity of raw resources.

Currently, construction industry in Indonesia is predominated by the use of reinforcing bars with yield strength of 420 MPa. Reinforcing bars used in high seismic activity region must satisfy the requirement stated in clause 21.1.5 of SNI 2847-2013, which refers to ASTM A706M Grade 60 (420 MPa) and ASTM A615 Grade 40 (280 MPa) and Grade 60. Higher strength of reinforcing bars only allowed in confinement ties, which is up to 700 MPa in yield strength. Those minimum requirements are intended to ensure the desired behavior of structures designed with this code can be achieved.

The substitution of conventional with higher strength reinforcing bars becomes an interesting topic recently in Indonesia. Reinforcing bars with yield strength of 520 MPa considered to be a good option which will supersedes those of conventional 420 MPa. Nevertheless, high strength reinforcing bars is notoriously has some drawbacks. Seismic behavior of materials, i.e. ductility and energy dissipation capacity of materials are lower in excess of yield strength. Also, increasing the yield strength of reinforcing bars embedded in concrete resulting in a greater development length, i.e. the length needed to transfer yield tensile strain to the surrounding concrete. As a consequence, structural elements such as beam-column joints, need to increase the size to accommodate longer development length.

Indonesia is located at seismically active region, surrounded by three earth plates, i.e. Eurasian, Pacific, and Indo-Australian. Hence, the behavior of structures under seismic loads must be taken as an important aspect in the design phase. Any modification causing potential decrease in seismic behavior must be justified in order to ensure that the seismic behavior of structure is still acceptable. Many researchers conducted studies of yield strength enhancement in structural elements in recent decades. Rautenberg et.al. found that the substitution of Grade 60 to Grade 120 reinforcing bars drops the energy dissipation capacity of column specimens. Similar result was obtained by Nagai and Ottani, that studies the substitution of Grade 60 to Grade 97 MPa reinforcing bars in beam element.

Material technology for concrete construction has rapidly advancing in the recent decades. The search of concrete materials with advanced technology is developing alternatives with improved properties and behavior of material. One of those alternatives is fibre-reinforced concrete, which could improve the behavior of material as reported by some researchers. Those fibres come in many types and shapes, whether natural or polymer, and straight or hooked. Common types of fibre that used as reinforcement in concrete matrix are steel and polypropylene fibres. Studies conducted by many researchers (e.g. Ramakrishnan et.al., Wafa et.al., and Jie et.al.) found that the post peak behavior, ductility and energy dissipation capacity of structural elements shows an improvement by adding a number of fibre into concrete matrix. For the material level, the effects of the addition of fibre to compression strength of concrete varies between one to another research due to the difference in basic concrete mix, air content, etc. Some research report an enhancement of compression strength, while other research shows a reduction. Huang et.al. reported that a better bond performance is achieved by fibre reinforced concrete specimens. However, the application of fibre reinforced concrete, particularly for polypropylene fibre, in structural elements is still limited due to the lack of research.

The objective of this research is to study the effect of reinforcing bars substitution, from ASTM A706M Grade 60 (420 MPa) to higher yield strength of 520 MPa. Furthermore, this research also study the possibility of using polypropylene fibre reinforced concrete in order to compensate the negative effects of the reinforcing bar substitution. This research is focusing in the behavior of interior beam column joint, while the change of stiffness, energy dissipation, and ductility is evaluated.

EXPERIMENTAL PROGRAM

Test Specimens

Five interior beam-column joint scaled in half were tested in this study. All of the specimens subjected to reversed lateral cyclic displacement. Those five specimens divided into three groups based on the materials used. First group consisted of one specimen, casted with plain concrete and reinforced longitudinally with 16mm, 420 MPa reinforcing bars. This specimen is defined as control specimen, which represent the current materials used in the construction industry in Indonesia. To study the substitution of high strength reinforcing bars, the second group consisted of 2 specimens which are casted with plain concrete and reinforced by 500 MPa reinforcing bars. One specimen is reinforced longitudinally with 16 mm, while the other with 19 mm reinforcing bars. The last group also consisted of 2 specimens reinforced by 500 MPa reinforcing bars with reinforcement configuration identical to that of the second group, but with the addition of polypropylene fibre into concrete matrix. Polypropylene fibre was added into concrete mixes of the third group at volume fraction of 0.5% per m^3. The specification can be seen in Table 1.

Table 1. Specification for each interior beam-column joint specimens

Group	Specimen	Longitudinal Reinf.		PP Fibre
		Yield Str. (MPa)	Diameter (mm)	
1	D16-400N	400	16	0%
2	D16-500N	500	16	0%
	D19-500N		19	0%
3	D16-500F	500	16	0.50%
	D19-500F		19	0.50%

Reinforcing Bars

Specimens of this study are reinforced by reinforcing bars which have different yield strength. Reinforcing bars with yield strength of 400 MPa were used as longitudinal and transversal reinforcement in the first group of specimens, which is defined as control specimen. While, specimens in the second and third group were reinforced by reinforcing bars with yield strength of 500 MPa. The mechanical properties of reinforcing bars were obtained from the testing of 2 sets of rebar specimens, which have diameters of 16mm and 19mm, and nominal yield strength of 400 and 500 MPa. The test was conducted according to ASTM 370.

Table 2. Result of monotonic tensile test of reinforcing bars

Material	Sectional Area (mm^2)	Yield Str. (MPa)	Tensile Str. (MPa)	Young Modulus (Gpa)	Ductility
D16	201.06	434.1	577.4	198.1	42.372
	201.06	485.2	630.9	207.9	31.741
D19	283.53	503.9	674.9	195.7	27.442

From the table above, it is evident that reinforcing bars with yield strength of 500 MPa have less ductility than that of conventional 400 MPa reinforcing bars. The ductility of higher strength reinforcing bars is 13.9% to 25.1% less than conventional ones.

Concrete

All specimens were casted with 30 MPa concrete, with the difference of fibre usage in the concrete matrix. First and second group specimens were casted with plain concrete, and the third group were casted with fibrous concrete. Polypropylene fibre was added to concrete matrix at 0.5% volume fraction per m^3. Concrete compressive test specimens were tested in the age of 7, 14, 28, and 52 days.

Table 3. Average compression strength of specimens at 28 days

Material	Compression Strength (MPa)	Strain		Ductility	
		εc	εu	μ	Average
F'c 30 Mpa	32.27	0.004	0.008	2.076	2.045
	33.45	0.005	0.009	2.022	
	34.53	0.004	0.008	2.036	
F'c 30 Mpa PPF	32.10	0.003	0.028	9.160	8.625
	32.03	0.003	0.024	8.089	

From the table above, the addition of fibre into concrete matrix lower the ultimate compressive strength. The addition in volume fraction of 0.5% reduce the compressive strength up to 6.8% that of plain concrete specimens. While, the addition of fibre significantly increase the material ductility. Maximum strain of concrete increased up to 272%, and the ductility of material increased from 2.045 for plain concrete to 8.625 for fibrous concrete.

Design of Specimens

Interior beam-column joint specimens used in this paper are designed as Special Moment Resisting Frame, according to SNI 2847-2013 clause 21.5. Each specimen is consisted of a 350x350mm column and two 150x250 beams. Beams of specimens were reinforced transversally with D10-55mm reinforcing bars, with yield strength identical to that of longitudinal reinforcement. As shear reinforcement of column, D10 reinforcing bars were spaced uniformly at 80mm from top to bottom support.

All D16 specimens, i.e. D16-400N, D16-500N, and D16-500F, were reinforced identically for both column and beams. Columns of those specimens were reinforced longitudinally with 8-D16 bars with reinforcing ratio of 1.31%. Different amount of steel bars was used for top and bottom longitudinal reinforcement of beams. Top layer of beam section was reinforced by 3-D16 bars or 1.6% reinforcement ratio, while bottom layer was reinforced by 2-D16 bars or 1.1% reinforcement ratio.

Specimens using D19 reinforcing bars, i.e. D19-500N and D19-500F slightly differ from D16 specimens. Columns of both specimens were reinforced longitudinally with 8-D19 bars, giving reinforcement ratio of 1.85%. While, both beams were reinforced symmetrically between top and bottom layer with 2-D19 reinforcing bars, or 1.51% reinforcement ratio. Reinforcement configurations of all specimens are illustrated in Figure 1.

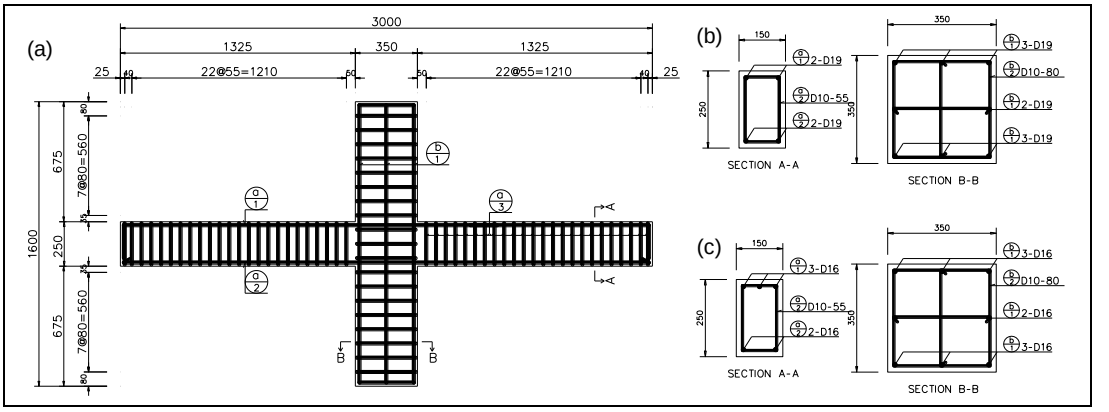

Figure 1. Reinforcement detail of all specimens, (a) elevation view of specimen's reinforcing bars, (b) beam and column section for D19-500N and D19-500F specimens, (c) beam and column section for D16-400N, D16-500N, and D16-500F specimens

Test Instrumentation

Measurement of the behavior of specimens under reversed cyclic loads were taken by a total of 26 channels. Instrumentation of the specimens focused mainly on the joint region and along plastic hinge region of beams. Drift of the column was measured by four Linear Variable Displacement Transformer (LVDT) along the height of specimen. Rotation and shear deformation of plastic hinge region was measured by a total of 8 LVDT, as illustrated in Figure 2.

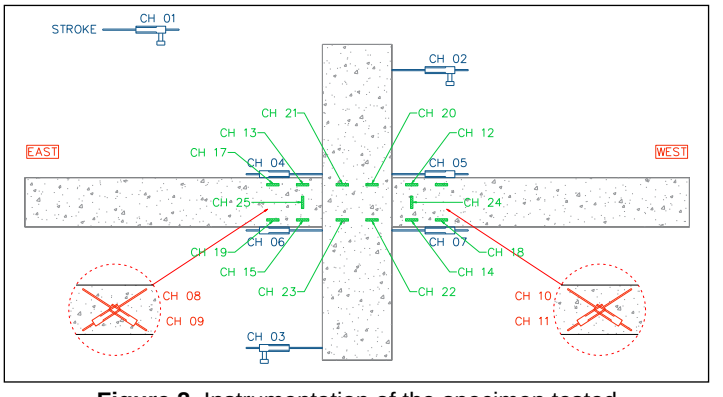

Figure 2. Instrumentation of the specimen tested

In the joint region, 14 strain gauges were used for measuring longitudinal and transversal reinforcement. Four strain gauges were placed inside the joint to obtain the bond behavior in this region, and the rest were placed in plastic hinge region of the beam. A total of 8 strain gauges were attached to longitudinal reinforcement, and 2 strain gauges measuring the transverse reinforcement strain. Measurement of force applied was taken by the internal load cell of the actuator. Measurement taken by LVDT, strain gauges, and load cell were sent to data logger to be stored at computer. Reading of all channels was taken every 4 seconds approximately.

In addition to the utilization of LVDTs and strain gauges, several observation of the specimen's behavior were done manually. Crack propagation of the specimens were plotted and documented at every peak, followed by measurement of crack width using feeler gauge. Important events, such as first crack and spalling of concrete cover were recorded through the test.

Test Setup and Loading Protocol

Both end columns were restrained as pin, while both of the beams end were restrained to vertical movement, and released to lateral and rotational movement. This test setup was designed to reproduce the lateral behavior of beam column joint in real moment frames structure. Lateral load then applied to the top pin of column, displacement-controlled, using 100 kN DARTEC Loading Frame. The test setup and loading history of the specimens are shown in Figure 3 respectively.

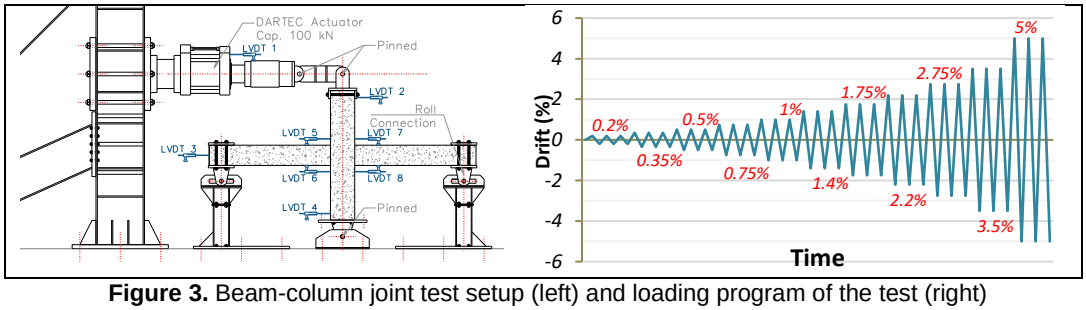

Figure 3. Beam-column joint test setup (left) and loading program of the test (right)

All specimens subjected to displacement controlled, reversed cyclical load according to ACI 374.2. The tests were conducted in absence of axial load on column in order to obtain conservative result. Lateral loading of the specimens consisted of 11 increasing drift level ranging from 0.2% to 5%. Rate of loading was increased every 2 drift levels, ranging from 0.025 at the beginning of the test, to 0.25 mm/s at the 11th drift level. Each of those cycles was repeated 3 times before advancing to the next drift level. Each drift level was increasing in the magnitude of 1.25 to 1.5.

RESULTS AND DISCUSSION

A total of 66 cycles were subjected to each specimen with increasing drift ratio up to 5%. No failure has occurred to all specimens despite damaged heavily at the end of loading. No cover spalling was observed to happen in the specimens with fibrous concrete. Also, it should be noted although the first crack of all specimens occurred at the same drift level, cracks formed in both fibrous concrete specimens were much less in length compared to specimens with plain concrete, suggested that fibrous concrete has higher tensile strength over plain concrete.

Backbone Curves

Since the substitution of conventional 400 MPa to 500 MPa reinforcing bars is not compensated by the reduction of area, such substitution gives a significant improvement in lateral load capacity, measured 35.15% higher. The addition of polypropylene fibre into

concrete matrix yields only a slight improvement in peak lateral load. For D16-500F specimens, the peak lateral loads increase up to 8.2% and 4.5% for positive and negative loading direction respectively. For D19-500F specimens an increase of 5.65% was measured for positive loading direction, while a slight reduction was measured for negative loading direction. Such reduction could be due to an offset of force measured by the load cell, i.e. shift towards negative value of force initiated from the beginning of the test.

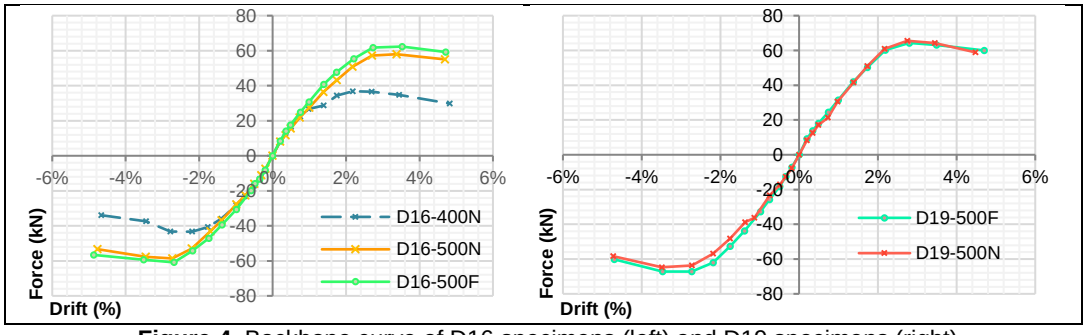

Figure 4. Backbone curve of D16 specimens (left) and D19 specimens (right)

Dissipated Energy

Due to significant difference in force and displacement, scaling for force and displacement is needed to make the hysteretic curves of all specimens comparable. Scaling of those curves is defined in ACI 374.2-13 using significant yield point. Initial stiffness of the backbone curve is defined as secant slope between (0,0) and the point when backbone curve have 0.75 of the maximum lateral strength. The yield displacement then defined from the intersection of initial stiffness with horizontal line of peak lateral load. Positive and negative direction of loading can be scaled separately due to possibility of difference in both directions. Comparison of significant yield point and normalized dissipated energy of each specimen is given in Table , while dissipated energy of each drift level is compared in Figure 5.

Significant yield point of the specimens is shifted towards a higher value of displacement by the change of yield strength of reinforcing bars. The addition of polypropylene fibre can shift the significant yield point to a lower value of yield displacement, thus increasing the initial stiffness of fibrous specimens. With those points, all of the hysteretic curves can be scaled and compared.

No noticeable difference was found in normalized dissipated energy between the specimens of conventional and high strength reinforcing bar. Difference in the yield displacement ratio of D16-400N and D16-500N specimens is due to difference in significant yield displacement, around 28 mm and 41 mm respectively. A higher dissipated energy capacity was achieved in two fibrous concrete specimens, D16-500F and D19-500F. Specimens with fibrous concrete dissipates 24.5% and 27.5% more energy than specimens with plain concrete, for D16 and D19 specimens respectively.

Table 4. Significant yield points of each specimen

Specimens	Significant Yield			
	(+) dir.		(-) dir.	
	Displ. (mm)	Force (kN)	Displ. (mm)	Force (kN)
D16-400N	28.048	36.843	28.825	43.346
D16-500N	41.749	57.991	41.198	58.621
D16-500F	39.948	62.355	39.473	60.856
D19-500N	39.447	65.555	41.925	64.704
D19-500F	38.947	64.325	39.237	67.172

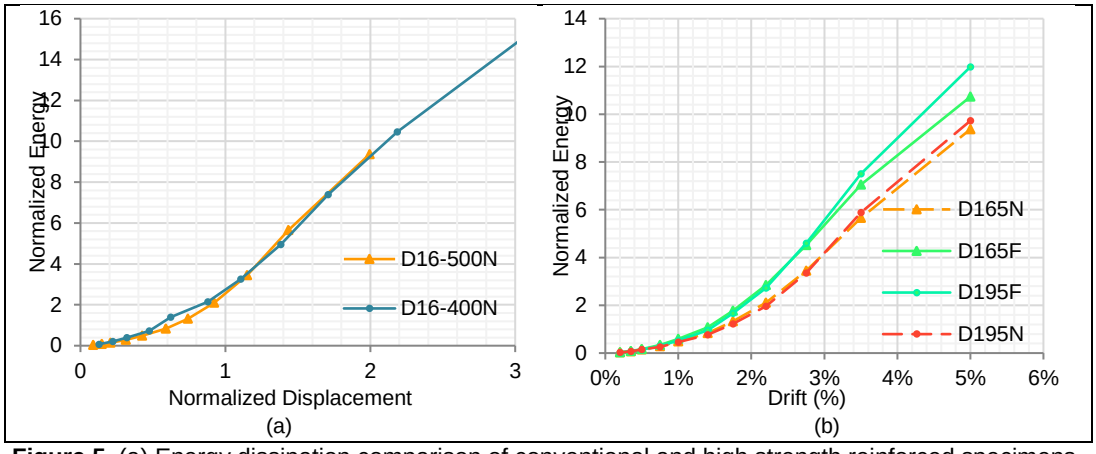

Figure 5. (a) Energy dissipation comparison of conventional and high strength reinforced specimens, (b) energy dissipation comparison of plain and fibrous concrete specimens

Peak-to Peak Stiffness

From the backbone curve, difference in the rate of stiffness degradation by all specimens can be evaluated. This degradation can be due to bond loss between concrete and rebar, concrete cracking and spalling, etc. Peak-to-peak stiffness is defined as the slope of line that connecting two peak points (i.e. positive and negative loading direction) in the same cycle.

Peak-to-peak stiffness is improved in both fibrous concrete specimens. This improvement is observed to occur throughout the testing, although the magnitude of improvement varies along the test. For D16 specimens, the addition of polypropylene fibre enhances the initial stiffness by 7.8%, whereas an enhancement of 3.2% achieved by D19-500F specimen compared to that of specimens with plain concrete. Those initial stiffness is calculated from first cycle in the first drift level of the tests, i.e. at 0.2% drift level. At the end of loading, improvement of stiffness in fibrous concrete specimens is 5.6% and 2.7% over the stiffness of plain concrete specimens, for D16 and D19 specimens respectively. The comparison graph shown below suggested that the addition of concrete fibre is significantly enhancing the stiffness of specimens, notably in the elastic range loading. While for higher drift ratio the addition of fibre into concrete matrix increase the stiffness in a lower magnitude. Degradation of peak-to-peak stiffness of the specimens is illustrated in Figure 6.

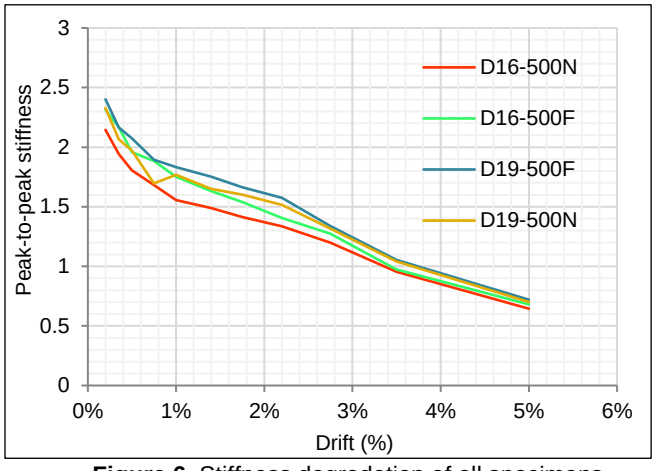

Figure 6. Stiffness degradation of all specimens

Crack Analysis

The pattern of cracks forming on the beam-column specimens was documented throughout the testing. The pattern of cracks formed in plastic hinge region of the specimens is shown in the Figure 8. Specimens with fibrous concrete show more dispersed cracks formed in the beams relative to specimens with plain concrete. Moreover, no spalling was observed to take place in the plastic hinge region for fibrous concrete until the end of the test. The number and average spacing of the cracks on each specimen is quantified in Figure 7.

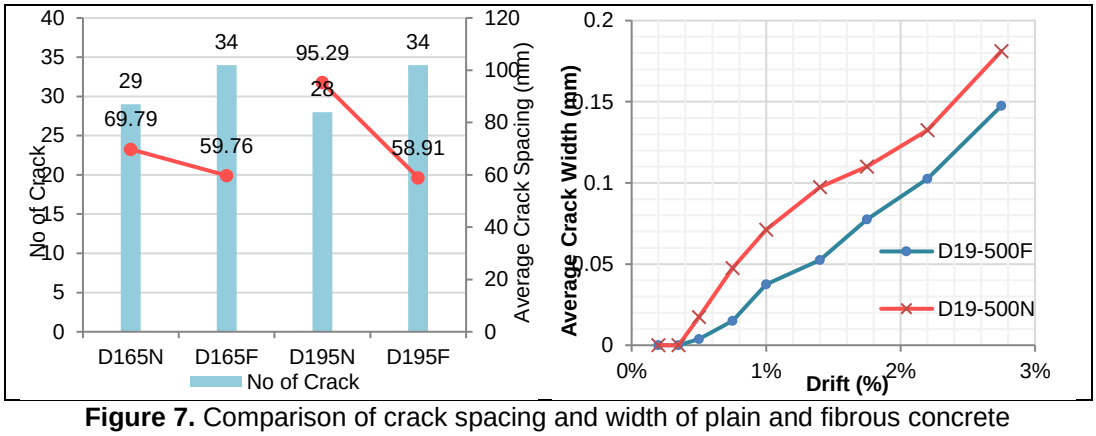

Figure 7. Comparison of crack spacing and width of plain and fibrous concrete

Specimens with the addition of fibre were forming a higher number of cracks along the beam. The increase in number of cracks means the reduction of crack's spacing. The number of cracks formed in fibrous specimens is 17.2% and 21.4% higher for D16-500F and D19-500F specimens, compared to the number of cracks formed in specimens with plain concrete. The reduction in average crack spacing is 14.4% for D16-500F specimen, and 61.76% for D19-500F specimen.

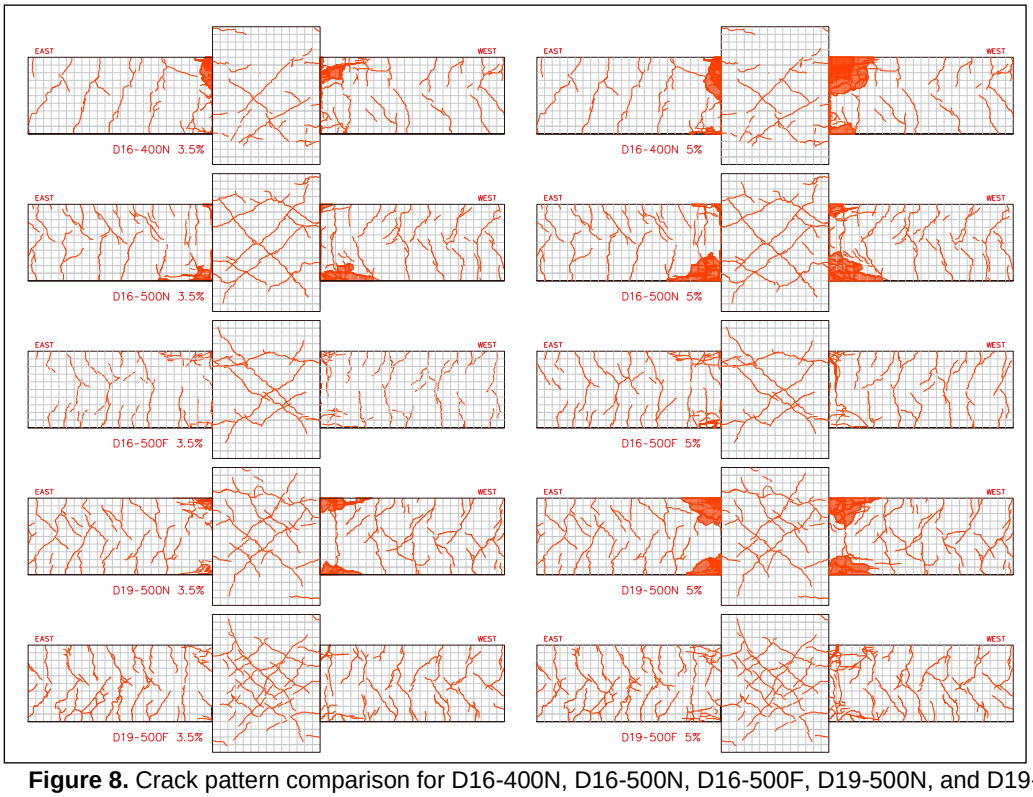

Figure 8. Crack pattern comparison for D16-400N, D16-500N, D16-500F, D19-500N, and D19-500F specimens at 3.5% and 5% drift ratio

In addition to number and crack spacing, the width of cracks was also measured throughout the testing at several locations. Eight cracks were measured in each specimen at every reversal of the loading. The result of crack width, shows that the smaller cracks were formed in fibrous specimens. Average width of the cracks formed in fibrous specimen is 18.62% smaller at the end of loading, or at 5% drift level. The comparison graph of crack width also suggested that the most significant reduction of crack width is at the elastic range loading.

Displacement Ductility

Displacement ductility (μ) was determined as the ratio of the lateral deflection when the specimens fulfilled all three acceptance criteria for moment frames to the significant yield point. The significant yield points were calculated by the equal area method as explained above. The displacement ductility values show that specimens with lower reinforcing strength have higher minimum ductility than both specimens with high strength reinforcing bar, although the difference is not significant.

Table 5. Comparison of minimum ductility for all specimens

Specimens	Yield Lateral Deflection (mm)		Ult. Lateral Deflection (mm)		Minimum Ductility	
	Positive	Negative	Positive	Negative	Positive	Negative
D16-400N	28.83	28.05	82.80	85.65	2.872	3.054
D16-500N	41.20	41.75	84.72	83.34	2.056	1.996
D16-500F	39.47	39.95	86.61	83.67	2.194	2.094
D19-500N	41.93	39.45	83.91	79.62	2.001	2.018
D19-500F	39.24	38.95	83.34	83.46	2.124	2.143

CONCLUSIONS

This test is consisted of five half-scaled specimens, casted with plain and fibrous concrete with volumetric ratio of 0.5%. All specimens subjected to identical cyclic loading to make a comparative study. Interpretation of the data obtained from the testing is as follow:

- Specimen reinforced by conventional reinforcing bars (D16-400N) has larger normalized energy dissipation, compared to that of high strength specimens. Yet the difference is insignificant. While both of fibrous specimens dissipated a higher energy than the specimens with plain concrete. The enhancement of energy dissipation is ranging from 24.5% to 27.5%.
- Specimens with high strength reinforcing bars tend to have a lower ductility. The decrease in minimum ductility is ranging from 23.61% to 34.63%.
- Specimens with the addition of polypropylene fibre have an increased maximum resisted lateral force, ranging from 4.5% to 8.4%. No spalling observed in the fibrous specimens.
- Stiffness of the specimens was increased with the addition of fibre into concrete mixes. Initial stiffness of fibrous specimens is 7.8% higher, and at the end of loading, peak-to-peak stiffness of fibrous specimens is 5.6% higher than specimens with plain concrete is. The most significant enhancement in stiffness is inside the elastic range.
- From the comparison of cracks formed on the beams, specimens with fibrous concrete have a larger number of cracks forming, and a reduced average spacing between cracks. Crack width is also reduced with the addition of fibre into concrete matrix and no concrete spalling.

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APPLICATION OF BAMBOO FIBRE COMPOSITE IN STRUCTURAL STRENGTHENING

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Abstract
Fibre reinforced polymer (FRP) is the most commonly used for structural strengthening, however, it requires high energy consumption to manufacture and non-environmental friendly. Alternatively, natural fibres such as bamboo, which has a high tensile strength characteristics may be used. However, limited study on the use of bamboo fibre as external structural strengthening is available. This paper presents the application of bamboo fibre vinyl-ester composite plate (BFVCP) for the strengthening of reinforced concrete (RC) beams. In this study, fibre volume fraction ranging from 0% to 40% were considered. The effect of volume fraction on the flexural and tensile strength of the composite plate was evaluated through mechanical test. The structural behaviour of RC beams was tested to failure using a four-point bending. BFVCP were applied externally in the beam's mid-span of the bottom soffit to study the structural strengthening in flexure. Results showed that the highest tensile strength of the specimen was obtained using the fibre volume fraction of 40%. Strengthening of RC beam using BFVCP successfully re-gained about 2% of the original beam structural capacity, when applied to the weakened beam in flexure along the tension zone. Strengthening by BFVCP has diverted the vertical cracks at the mid-span to the edge of the plate. Result from this study shows that BFVCP may be used for weakened beam external strengthening.

Keywords: *Bamboo fibre; Composite; RC beams; Strengthening; Vinyl-ester*

INTRODUCTION

Natural fibre composites made from agricultural plants such as kenaf, jute, sisal, mengkuang and bamboo are gaining attention in structural application recently (Tong et al. 2017). They are used as an alternative to the commonly used external strengthening material such as the fibre reinforced polymer (FRP) (Ali et al., 2016). Although FRP offers many advantages such as high tensile strength and lightweight, however, the drawbacks such as high cost and impact to the environment during production opened an avenue to the use of natural fibre composites (Chin et al., 2012; Chin et al., 2016). Natural fibre derived from kenaf (Abdul Rahman, 2011), jute (Alam et al., 2015), pineapple leaves (Chin et al., 2018), mengkuang leaves (Chin et al., 2018) were used as composite plate for strengthening of reinforced concrete (RC) beams, but none on bamboo fibre composite. Most of the studies employed bamboo as reinforcement in structural elements (Tan et al., 2017) but limited study on the use of bamboo fibre (Tong et al., 2018) especially as composite material for external structural strengthening (Lim 2017).

Strengthening of RC beams are usually conducted either in the weak location, such as in flexure and shear zone of the beam. Sen and Jagannatha Reddy (2013) investigated the use of natural jute fibre textile reinforced composite system for flexural strengthening of RC beams. Hafizah et al. (2014) studied kenaf fibre reinforced polymer composites for strengthening RC beams in flexure with 50% fibre volume fraction. The length of composite used in this study was 1400 mm along the tension zone (within the support). The size of the composites was

100 mm × 6 mm × 1400 mm. Findings showed that the strength of kenaf fibre composites gradually increased with increasing fibre volume fraction, while kenaf-epoxy composite exhibited the highest Young's modulus at 50% fibre volume fraction. Apart from that, sisal fibre composites and sisal fibre rods were also utilized for flexural strengthening of RC beams by Khan et al. (2016). Two different strengthening configurations were adopted which include sisal fibre composites and sisal fibre rods. They reported that sisal fibre rod is more effective than the composites. The ultimate load of the RC beams increased 65% with sisal FRP rods compared to the un-strengthened beams (Khan et al., 2016). Kenaf fibre hybrid composite plates were tested for potential application in shear strengthening of RC beams by Alam et al. (2016). The composite plates were fabricated using kenaf and carbon fibre with 5 different mixes. They found that carbon addition enhanced the tensile strength of the plates. The hybrid composite plate with 10% carbon content gives 130% higher tensile strength compared to those without carbon content. From the aforementioned past studies, it was noticed that kenaf, jute and sisal fibres were given much attention for structural strengthening. However, there was a limited study on bamboo fibre for structural strengthening. Hence, in this work, bamboo fibre was mixed with vinyl-ester to form a polymer composite RC beams strengthening in flexure. The mechanical properties such as flexural strength and tensile strength is evaluated. The structural behaviour of beam strengthened by bamboo fibre vinyl-ester composite plate (BFVCP) are also studied.

METHODOLOGY

Preparation of Bamboo Fibre

Bamboo Semantan (*Gigantochloa scortechinii*) obtained from Raub, Pahang is used in this study. The freshly harvested bamboo was dried and soaked with 10% of sodium hydroxide for about 48 hours in order to obtain a suitable bamboo fibre (Tong et al., 2017). The bamboo strip is roll milled to obtain monofilaments. The fibre has a density of 0.890 g/cm^3. The bamboo node may reduce the mechanical properties of the composite plate, thus the fibre was cut into a length of 450 mm to avoid the node. The extracted fibres were then washed with distilled water to remove the impurities on the surface of the fibre until the pH value was neutralized into the optimum range of pH 5 to 6. Subsequently, the fibres were dried in an oven with a temperature of 60 °C for 24 hours, before placing in a desiccator before further use.

Polymer Matrix

Vinyl-ester resin was used as a binder in this study with a density of 1.05 g/cm^3. Cobalt accelerator and methyl ethyl ketone peroxides (MEKP) hardener were mixed gently with vinyl-ester during the fabrication of the composite plate. The mix ratio of vinyl-ester to MEKP and cobalt used was 100: 2: 0.1. The mixing procedure must be carried out in sequence, firstly by blending vinyl ester and cobalt under intense stirring for 5 minutes, followed by the MEKP addition and stirring for another 5 minutes.

Fabrication of BFVCP

In the present study, hand lay-up method was adopted for composite fabrication at room temperature. Stainless steel moulds were used to cast the BFRCP plates. Five different fibre

volume ratios of BFRCP including 0%, 10%, 20%, 30% and 40% were fabricated. Various sizes of BFRCP were fabricated and tested. For the flexural test, the BFRCP with a dimension of 12.7 × 127 mm, and 4 mm thick plate was used, whereas for tensile test, a dimension of 25 × 250 mm, and a thickness of 3 mm was prepared. The plate strengthening at soffit of flexural zone of RC beam has a dimension of 120 × 450 mm, with thickness of 10 mm.

The mould releasing agent (honey wax) was applied to the mould and Teflon paper was put underneath the bottom part of the mould to avoid adhesion between the composite plate and the mould. The vinyl ester resin and the bamboo fibres were arranged across the mould uniformly and layer sequentially. At first, a thin layer of vinyl ester was poured into the steel mould, followed by a layer of unidirectional bamboo fibres. After that, the second layer of resin was poured on the previous surface of bamboo fibres for interfacial bonding. Subsequently, another layer of bamboo fibres was then placed over on the previous layer. These steps were repeated until the thickness of the plate considered in this study was obtained. The final step of the fabrication was compression of the composite plate after the required thickness of the plate had been achieved. The fabricated BFRCP were cured at room temperature for 24 hours before post-cured in oven with the temperature of 110 °C for about 4 hours and kept in a desiccator for 24 hours.

Reinforced Concrete Beam

The test comprises of three RC beams which includes a solid beam as control beam (CB), RC beam for strengthening with bamboo fibre vinyl-ester composite plate (VSSB) and beam without strengthening with bamboo fibre vinyl-ester composite plate (VUSB), respectively. In this study, all the beams were in the dimension of 120 × 300 mm with a length of 1500 mm. All the beams were reinforced with two steel rods of 10 mm diameter at both the tension and compression zones. Shear link using 6 mm diameter steel rod with spacing of 100 mm center to center were placed on the full length of the solid beam. The shear link was omitted in the flexure zone to evaluate the effectiveness of the BFVCP. Ready-mixed concrete of grade 30 MPa was used in this study. Figure 1 shows a schematic diagram of the reinforcement arrangement without a shear link in the mid-span of the beam. All the beams were tested to failure using a four-point bending.

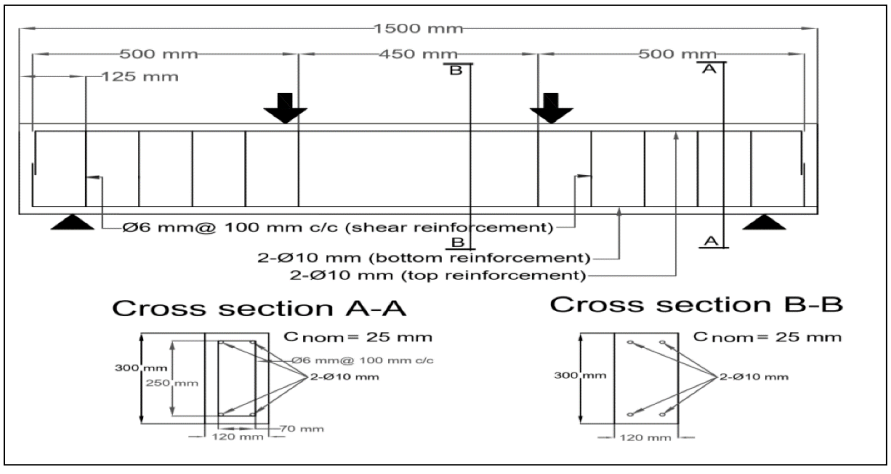

Figure 1. Schematic diagram of RC beam with omitted shear link in the mid-span

Mechanical Properties Tests

The flexural strength test was conducted using a Universal Testing Machine (UTM) with the capacity of 5 kN. The composite samples were prepared in accordance to standard ASTMD790-03 with fibre ratio ranging from 0% to 40% in order to determine the most effective fibre loading of bamboo fibre reinforced composite plate (BFRCP). The size of composite plates for flexural test were in the dimension of 127 × 12.7 mm, and 4 mm thick. The flexural test was performed via three-point loading where the load imposed to the mid-span of the samples until failure. Similarly, tensile strength test of the composite plate samples was conducted using a 5 kN UTM. The composite samples were prepared in accordance to ASTM D3039 with fibre ratio ranging from 0% to 40%. The fibre to volume ratio that gave the strongest sample was chosen to prepare the strengthening plate for RC beam. The composites were in a dimension of 250 × 25 mm, and thickness of 3 mm. A uniaxial load was applied at the ends of the composite with a test speed of 5 mm/min.

RESULTS AND DISCUSSION

Flexural Strength of BFVCP

The flexural strength provides an information about the bending strength of the bamboo composite material. The flexural test is needed to evaluate the strengthening potential that may be gained from the BFVCP application. Table 1 summarizes the result of ultimate flexural strength and peak load for different volume fractions of BFVCP under three-point loading test. It was found that, a neat vinyl ester plate (0% fibre) has the lowest ultimate flexural strength. The sample with fibre volume fractions ranging from 10% to 40% showed significant improvement of flexural strength of 104.7%, 140.2%, 240.4% and 271.6%, respectively, compared to the neat vinyl-ester plate. The result proves that bamboo fibre increases the flexural strength of the vinyl-ester plate. The strength of pure vinyl-ester plate is quite low (37.9 N/mm^2), because the polymer atom on its own has a limited flexural strength. Addition of bamboo fibre provides a strengthening reinforcement to the vinyl-ester polymer due to the bonding between the polymer and bamboo fibre microstructure. The flexural strength was observed to increase proportionally with the fibre volume fraction added in a manner similar to those reported by Hafizah et al. (2014) for the case of polymer-kenaf fibre composite. The extent of strengthening by the bamboo fibre is unknown, because in this work the flexural strength keeps increasing with increasing fibre load. However, most of the practical natural fibre composite application often uses the ratio of about 10% to 40%, therefore in this work the test is limited to 40% fibre loading. Moreover, at a higher fibre loading, the outer layer of the fibre will be exposed to moisture absorption, hence may cause a deterioration of the fibre for a long-term use.

Table 1. Flexural strength of BFVCP

Fibre volume fraction	Peak Load (N)	Ultimate Flexural strength (N/mm^2)
0	120.6	37.9
0.1	246.6	77.6
0.2	289.7	91.1
0.3	411.3	129.1
0.4	475.7	141.0

Tensile Strength of BFVCP

Figure 2 shows the comparison of tensile strength in terms of stress vs. strain for various fibre volume fractions. It was found that the sample with fibre addition has a significantly higher tensile strength than the neat polymer. The BFVCP containing 40% fibre gave the highest tensile strength (990 MPa). The result from the test performed in this work shows the tensile strength increases with the fibre loading, but the extent of the strengthening effect is unknown. As mentioned earlier, the most practical fibre loading for polymer composite application ranging from 20% to 40%. Moreover, composite with more than 60% fibre content tend to be brittle (Ngo et al., 2014), hence not suitable as strengthening material. Therefore, in this work the test is limited to 40% fibre loading and further test was made using the mix with strongest flexural and tensile strength, i.e. 40% fibre.

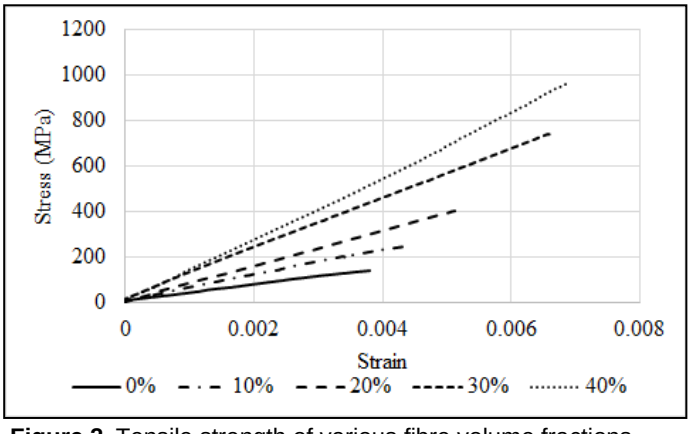

Figure 2. Tensile strength of various fibre volume fractions

Strengthening of RC Beams with BFVCP in Flexure

The effect of BFVCP on structural strengthening was studied by comparing the strength of a control beam (CB) to that of weakened beam, i.e. with shear link omitted in the flexural zone, denoted as unstrengthened solid beam (VUSB) as well as RC beam strengthened with BFVCP (VSSB). The BFVCP was placed in the flexural zone at the bottom soffit of the beam. All the beams were tested to failure under four-point loading. Table 2 summarizes the results of ultimate load from the four-point loading test. Figure 3 shows the comparison of load-deflection curves between the control beam, beams strengthened with BFVCP and without strengthening, respectively. It was found that the omission of a shear link in the midspan of the beam VUSB showed a reduction in the load-carrying capacity, about 13.0% compared to the control beam, CB. Meanwhile, beam VSSB has shown slight re-gained in the beam capacity to approximately 2.0%, compared to the un-strengthened beam in flexure (VUSB). However, strengthening with BFVCP was unable to restore the original beam capacity of the control beam. Earlier, Hafizah et al. (2014) requires about 90% of the length of the beam bonded at the tension zone in their study on kenaf fibre polymer composite, in order to re-gain most of the beam capacity. In the case of bamboo fibre, it is not possible to fabricate a plate that covers almost the entire length of the beam because each bamboo culm is limited to about 450 mm. Hence, it was not possible to achieve a full anchorage length along the tension zone of the beam with BFVCP due to the length limitation of the fibre.

Table 2. Ultimate load of various beam specimens

Beam	Ultimate Load (kN)	Strengthening Percentage (%)	Strengthening Ratio
CB	151.9	-	
VUSB	132.1	-13 (compared to CB)	0.87
VSSB	134.9	+2 (compared to VUSB) -11.2 (compared to CB)	1.02

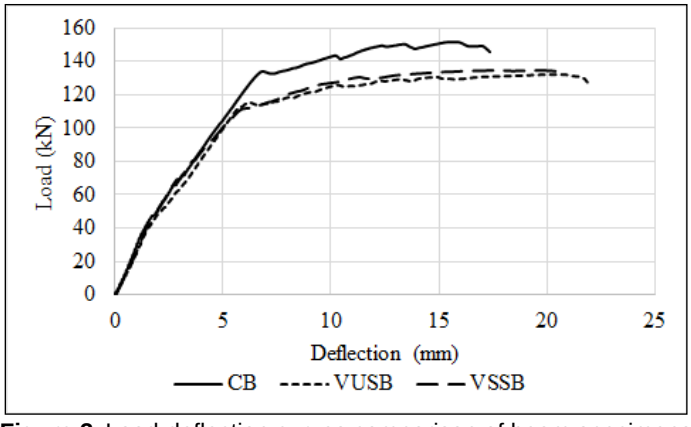

Figure 3. Load-deflection curves comparison of beam specimens

In terms of crack pattern, vertical cracks were formed along the tension zone in the mid-span of the control beam (CB) as shown in Figure 4. On the other hand, Figure 5 shows the crack pattern of VUSB. More visible vertical cracks were seen in the mid-span of the beam due to the absence of shear link. Figure 6 shows the crack pattern of VSSB. A large visible vertical crack was formed at the edge of the BFVC plate. This signifies that strengthening using BFVCP managed to divert the vertical cracks by resisting the tensile stresses in the mid-span to the end of the plate. All the beams failed in bending.

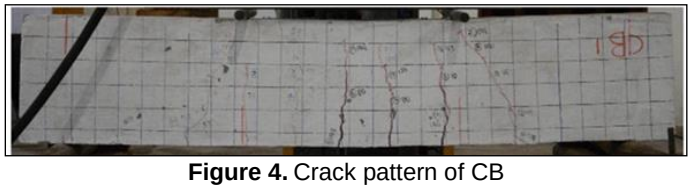

Figure 4. Crack pattern of CB

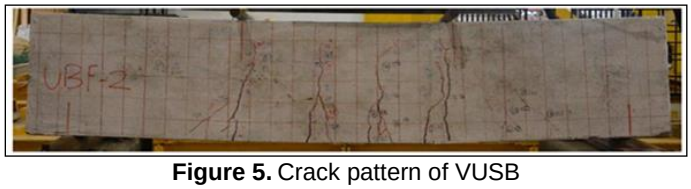

Figure 5. Crack pattern of VUSB

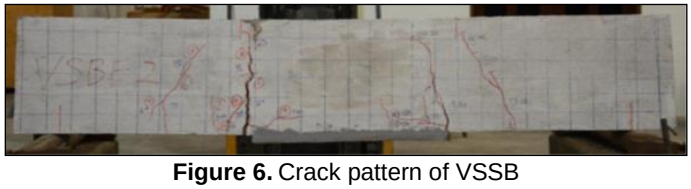

Figure 6. Crack pattern of VSSB

CONCLUSIONS

Based on the results obtained, 40% fibre volume fraction gives the highest tensile and flexural strength compared to other fibre loading. Strengthening of RC beam in flexure using BFVCP increases the load-carrying capacity of the beam without the shear link in the midspan (VUSB) by 2%. The drawback of this study is due to the short bamboo fibre length (450 mm due to bamboo culm), which causes insufficient of anchorage length bonded along the tension zone of the beam. Consequently, a limited improvement in the beam structural capacity was achieved.

ACKNOWLEDGEMENT

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COMPARISON OF BIAXIAL TENSILE BEHAVIOUR OF PLAIN AND STEEL FIBRE REINFORCED CONCRETE (SFRC) WITH DIFFERENT TESTING TECHNIQUES

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Abstract

Most concrete biaxial behaviour investigations are focused on biaxial compression due to the complexity of biaxial test set up. This paper is aimed to construct a simple and economic biaxial testing frame for conducting a biaxial tensile test on plain concrete and steel fibre reinforced concrete (SFRC). It is also aimed to compare the biaxial tensile behaviour of the current study with the previous research by using different testing techniques under an equal stress ratio. Lever arm principle is applied in the proposed biaxial test set up. For SFRC, hooked-end type steel fibre with fibre volumetric fractions 0%, 0.5%, 1.0% and 1.5% are used. Uniaxial tensile strength of plain concrete is greater than biaxial tensile strength in SFRC. For plain concrete, the opposite result is obtained. The biaxial tensile strength is insignificantly affected by the increment of fibre volumetric fraction but the post-cracking behaviour of concrete is enhanced with the inclusion of steel fibre, which is in agreement with previous findings. The comparison shows that the proposed biaxial testing technique proposed is suitable to conduct biaxial tensile test.

Keywords: *Biaxial tension; Behaviour; Plain concrete; SFRC; Testing techniques*

INTRODUCTION

Steel Fibre Reinforced Concrete (SFRC) is introduced since the 19th century due to its efficiency in crack bridging and ability to enhance the toughness of concrete structure. With the addition of steel fibre, concrete structures experience a more ductile failure than the catastrophic failure in normal concrete. In recent years, research on multiaxial loadings of concrete structures are gaining attention because most of the concrete structures experience multiaxial loading, such as beam-column connections, bridge decks, silos, and tunnel linings. Therefore, multiaxial loading should consider both ultimate limit state (ULS) and serviceability limit state (SLS) in the design instead of considering uniaxial loading alone (Lemnitzer et al., 2008).

Multiaxial loading can be classified into three conditions, which are biaxial compression, biaxial tension-compression and biaxial tension. From previous research, experimental data for plain concrete and SFRC are commonly available for biaxial compression and biaxial tension-compression. However, experimental data on biaxial tension of plain concrete and SFRC are very scarce. This is because the multiaxial testing setup is difficult and complex, especially for Fibre Reinforced Concrete (FRC) (Sirijaroonchai et al., 2010).

Since most concrete structures are exposed to multiaxial stresses, it is important to investigate the behaviour of concrete under biaxial stresses in constructing a systematic and reliable model for a construction design. As concrete is weak in tension, steel fibre which is added into the concrete matrix contributes to crack arresting which decelerates the formation and propagation of tensile cracks and eventually increases the concrete tensile strength. The addition of steel fibre can alter the behaviour of concrete under uniaxial tension. However, understanding the behaviour of SFRC under biaxial tension is still lacking. Therefore, it is important to investigate the behaviour of SFRC, especially under biaxial tension.

Biaxial experimental data is mostly limited to biaxial compression and biaxial tension-compression for plain concrete. The complexity to conduct the biaxial tension test, especially for FRC and the extensive cost to purchase the tri-axial testing machine, are the reasons for the limited availability of biaxial tensile experimental data. Therefore, the current study is aimed to construct a simple and economic biaxial tensile testing frame to conduct the biaxial tensile test for both plain concrete and SFRC under an equal stress ratio. This study also aimed to compare the biaxial responses from the experiments with the existing experimental data from (Abdull-Ahad and Abbas, 1989) to verify the suitability of the testing techniques.

According to previous research, there are several loading methods and testing techniques adopted by researchers to carry out the biaxial tension test on concrete, mainly on plain concrete. For the tensile loading, structural glue and epoxy adhesives are used to attach the loading platens to specimens (Hussein and Marzouk, 2000; Kupfer et al., 1969; Lee et al., 2004; Nelissen, 1972). Some researchers used casted-in screw bars to tie with the loading platens in order to perform the tensile test (Kolle, 2006; Shang et al., 2014). Meanwhile, dog-bone shaped specimens were used to carry out tensile test under the multiaxial loading setup (Abdull-Ahad and Abbas, 1989; Shiming and Yupu, 2013).

Some pervious researchers set up multiaxial loading frame by using a simple beam and hydraulic system to control the stress ratio (Kupfer et al., 1969; Lee et al., 2004). Stress ratio is the ratio of stress exerted at minor principal to the stress exerted at major principal. The testing machine consists of two systems in which the first system is comprised of Jack 1, Jack 2 and Jack 3, while the second system is comprised of Jack 4 and Jack 5, as shown in Figure 1. Double acting hydraulic jacks are used, whereby the first system controls the stress ratio by adjusting the Jack 1 distance between Jack 2 and Jack 3, while Jack 4 and Jack 5 are connected to Jack 2 and Jack 3, respectively, in order to apply the stresses (compressive or tensile) on the specimens in the second system of the test machine.

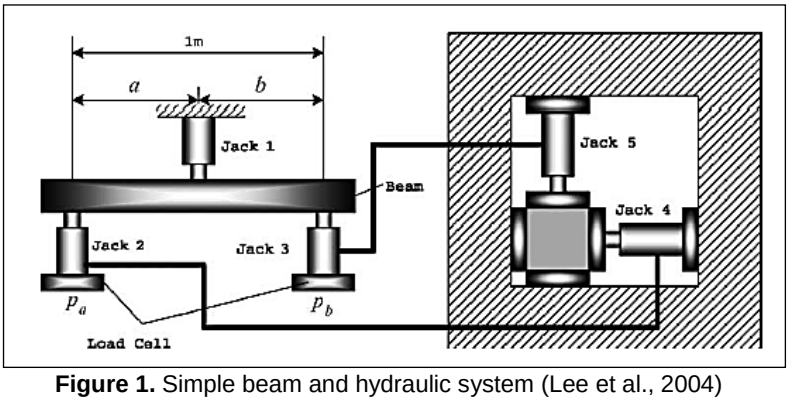

Figure 1. Simple beam and hydraulic system (Lee et al., 2004)

On the other hand, (Abdull-Ahad and Abbas, 1989) constructs the biaxial tensile testing frame that is totally different from those previously discussed. The main structures of the testing frame-consist of a main frame, hydraulic pump, double-acting actuators, load cell and pull equipment, which seems to be much simpler than the simple beam and hydraulic system (see Figure 2). However, there is no clear information about how to alter stress ratio.

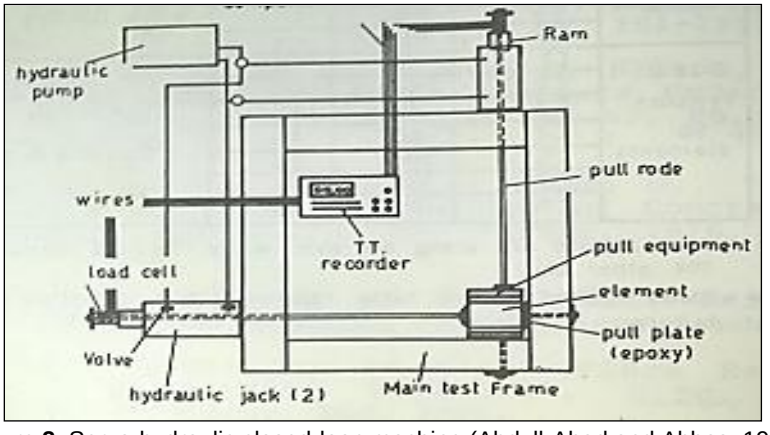

Figure 2. Servo-hydraulic closed-loop machine (Abdull-Ahad and Abbas, 1989)

Furthermore, Kolle (2006) who investigates the biaxial behaviour of steel fibre reinforced high performance concrete (SFRHPC) states that, only a general conclusion can be obtained from the biaxial test results of Abdull-Ahad and Abbas since there are a large scatter of test points for each test series. This becomes one of the reasons in the study to compare the biaxial tensile response of plain concrete and SFRC with only equal stress ratio among the other research previously discussed. Table 1 shows a summary of the loading method and testing technique for biaxial setup among the previous research.

Table 1. Tensile Loading Methods and Testing Techniques available from literature

Investigator	Tensile Loading Methods	Testing Techniques
Kupfer *et al*. (Kupfer et al., 1969)	Brush bearing platens with epoxy adhesives	Hydraulic simple beam system
Lee *et al*. (Lee et al., 2004)	Solid bearing platens with epoxy adhesives	Hydraulic simple beam system
Abdull-Ahad and Abbas (Abdull-Ahad and Abbas, 1989)	Dog-done specimen and epoxy adhesives	Servo-hydraulic closed-loop machine
Hussein and Marzouk (Hussein and Marzouk, 2000)	Brush bearing platens with epoxy adhesives	Servo-hydraulic closed-loop machine
Shang *et al.* (Shang et al., 2014)*	Solid/brush bearing platens with structural glue, casted-in screw bars	Triaxial testing machine
Ren *et al.* (Ren et al., 2008)*	Solid bearing platens with structural adhesives	Servo-hydraulic closed-loop machine
Kolle (Kolle, 2006)*	Casted-in screw Bars	Biaxial testing facility
Foltz *et al.* (Foltz et al., 2017)	Brush bearing platens with epoxy adhesives	Servo-hydraulic closed-loop machine
He *et al.* (He et al., 2015)	Solid bearing platens with epoxy adhesives	Triaxial testing machine

* Biaxial tensile test were not conducted in the experiments.

From Table 1, most research use epoxy adhesives to attach the loading platens with specimens to carry out the tensile loading, whereas for testing techniques, biaxial or triaxial testing machines promise a consistent and controlled biaxial experiments. The advantages of using a hydraulic simple beam system are that the stress ratio for both principals is consistent throughout the experiment and the setup is simpler as compared to a servo-hydraulic closed-loop machine.

EXPERIMENTAL STUDY

Specimen design

At the beginning of the planning stage, it is decided that epoxy adhesives or structural glue is used as the loading method for the biaxial tensile test. However, when the structural glue is tested, bonding failure occurs several times. Therefore, the loading method is changed to casted-in screw bars. The details of casted-in screw bars (or pull-out reinforcement) are shown in Figure 3. The specimen is designed in cruciform shape of which the overall dimension is 300 mm × 300 mm × 100 mm with an effective central area of 150 mm × 150 mm × 100 mm, as shown in Figure 4. For the specimen of uniaxial tension, the specimen design is similar to that of biaxial tension specimen but without the left and right flanges.

The manipulated parameter considered in this study is the steel fibre volumetric fractions which are 0%, 0.5%, 1.0% and 1.5%. For uniaxial tension, 3 specimens are prepared for plain concrete and SFRC with 1.5% steel fibre respectively. A total of 12 biaxial specimens are prepared for the biaxial tensile test, with 3 specimens for plain concrete as the control, and 3 specimens for each batch of SFRC mix with different fibre volumetric fractions, respectively. One of the three results from each batch is chosen for comparison based on the consistency of strength and strain data obtained among specimens.

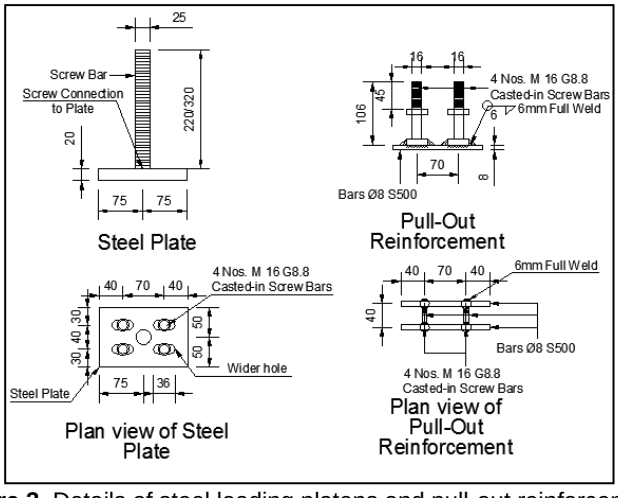

Figure 3. Details of steel loading platens and pull-out reinforcement

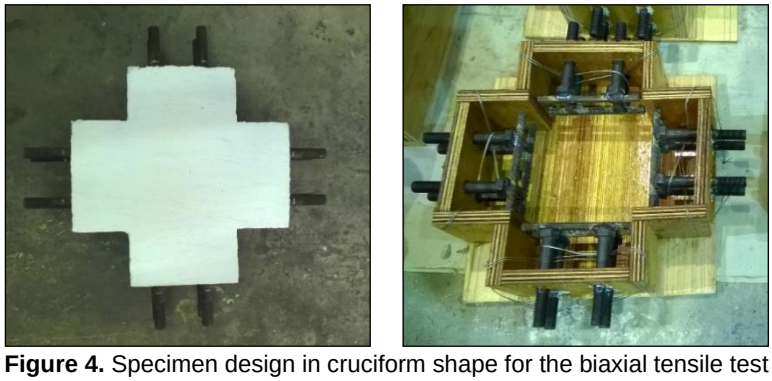

Figure 4. Specimen design in cruciform shape for the biaxial tensile test

Material Properties

Concrete specimens are designed with characteristic strength of 40 MPa and targeted mean strength of 53.12 MPa by using water-to-cement ratio of 0.46. The amount of cement, fine and coarse aggregates for 1 m^3 concrete volume are 543.5 kg/m^3, 948.9 kg/m^3 and 632.6 kg/m^3, respectively. High range water reducing admixture is also added with a dosage of 1L/100 kg of cement to enhance the workability especially in the mix with steel fibre addition. Hooked-end type steel fibre with 60 mm in length and 0.75 mm in diameter is added last into the concrete mix. The tensile strength of the steel fibre is 1050 MPa, as given by the manufacturer.

Testing Facilities

The biaxial testing frame is set up by applying the principal of lever arm as shown in Figure 5. Rectangular hollow steel section with dimension of 150 mm height × 100 width mm × 9 mm thick is used to form the lever arm system for the major and minor principal. The end of the hollow steel section is fixed by using screw bars and connected to the steel bearing platens. The steel loading platens are designed such that the holes which located the casted-in screw bars are wider in horizontal to reduce the specimen restraint movement during testing (Figure 3).

The casted-in screw bars are first screwed to the loading platens and then to the frame. The sides which are screwed to the steel plate position on the frame reactedn to the tensile loading when the load is applied. To eliminate the effects of self-weight due to Beam 1 gravity on the biaxial response during the test, the beam is rested on rollers which enables the movement for the hollow steel section end. Lubricant is applied onto the rollers to reduce friction from the beam movement.

100kN load cell is used for both major and minor principal. The load cell is placed under the actuator, in which the load obtained from the compressive force is the same as the tensile load being applied to the specimen because the distance between fulcrum and specimen is the same as the distance between actuators and fulcrum. After the specimens on the frame are set up, concrete strain gauges of 60 mm in length are lastly attached at the centre of the specimen in both horizontal and vertical directions, and perpendicular to each other to record the strain data during test.

Single-acting actuators are used to apply load during the test. Beam 1 exerts a tensile force at the major principal, while beam 2 exerts a force at minor principal. In order to achieve the same tensile load on the specimen at both major and minor principals, the distance between the specimen and fulcrum and the distance between fulcrum and hydraulic jack is fixed for both Beam 1 and Beam 2. To ensure that the load is simultaneously applied at both principals, a hydraulic jack connector is used. During testing, the load is applied every six seconds for major and minor principals to ensure a consistent loading throughout the experiment. The results obtained for plain concrete and SFRC with 1.5% fibre are then compared with the results from Abdull-Ahad and Abbas (1989) and are discussed in the following section.

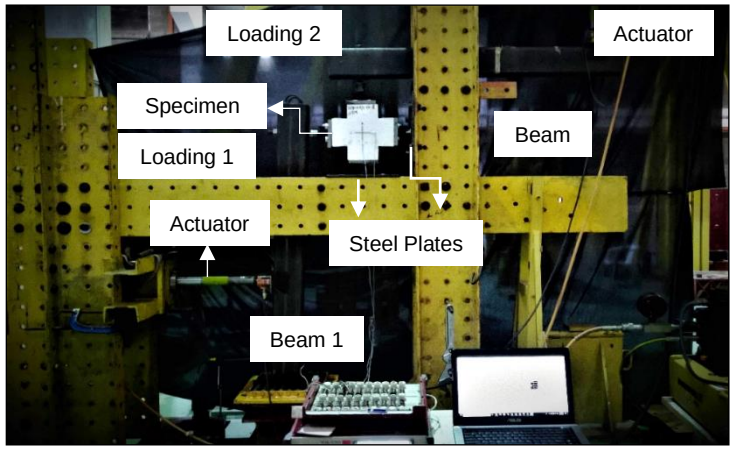

Figure 5. Biaxial tensile testing frame setup

RESULTS AND DISCUSSION

Compressive strength test is carried out on the 28th day with the 150 mm × 150 mm × 150 mm cube specimens. Table 2 shows the average compressive strength for plain concrete and SFRC on three cube specimens with different fibre volumetric fractions. It is obvious that with the inclusion of steel fibre, the compressive strength of SFRC is higher than plain concrete. This is due to the confinement created by steel fibre and its ability in crack bridging, resulting in the retardation of formation and propagation of cracks within the concrete matrix. Besides that, the inconsistent trend with the increment of steel fibre volumetric fraction is in agreement with the findings by previous research (Ding and Kusterle, 2000; Holschemacher et al., 2010; Lee et al., 2015; Swamy, 1974; Van Chanh, 2004; Wafa, 1990).

Table 2. Average compressive strength of plain concrete and SFRC at 28th day

Fibre Content	Average Compressive Strength (MPa)
Plain	46.99
0.5%	54.09
1.0%	50.18
1.5%	56.08

To verify the testing frame setup in the current study, the results are compared with experimental data from Abdull-Ahad and Abbas (1989) and Lee et al. (2004). The only biaxial tensile experimental data available for SFRC is provided by Abdull-Ahad and Abbas. However, for stress-strain relation, only experimental data based on 1.5% fibre volume fraction with aspect ratio of 100, is available. Furthermore, experimental results related to stress ratio of 0.8 instead of 1.0 are the only available data from literature. Since the data is extremely limited, the results for the current study is compared with the data of plain concrete and SFRC with 1.5% fibre volume fraction and stress ratio of 0.8.

Based on Figure 6, the addition of 1.5% steel fibre does not have significant increment for both biaxial tensile strength and strain. In the current study, the results of the strength are similar with Abdull-Ahad and Abbas (1989) where the increment is insignificant. However, the strains for both plain concrete and SFRC does not differ much. As the weakest point of the specimen in current study is at the indented area, cracks are mostly initiate at that region, which upon failure, strain gauges are unable to obtain the data from the post-cracking behaviour contributed by the steel fibre.

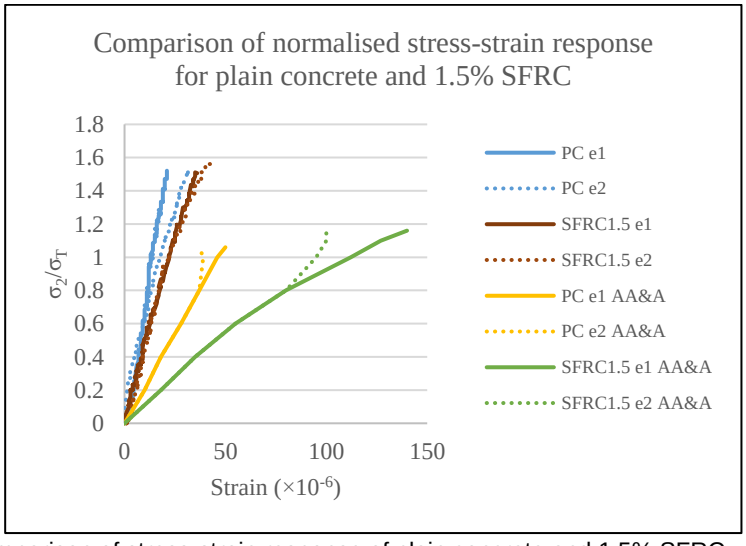

Figure 6. Comparison of stress-strain response of plain concrete and 1.5% SFRC with data from Abdull-Ahad and Abbas (AA&A) (Abdull-Ahad and Abbas, 1989)

However, through observation shown in Figure 7, it is obvious that the inclusion of steel fibre retards the propagation of cracks and eliminates the sudden failure as in plain concrete, where the concrete changes from brittle to ductile behaviour, similar to the behaviour explained by the stress-strain relation from the mentioned research.

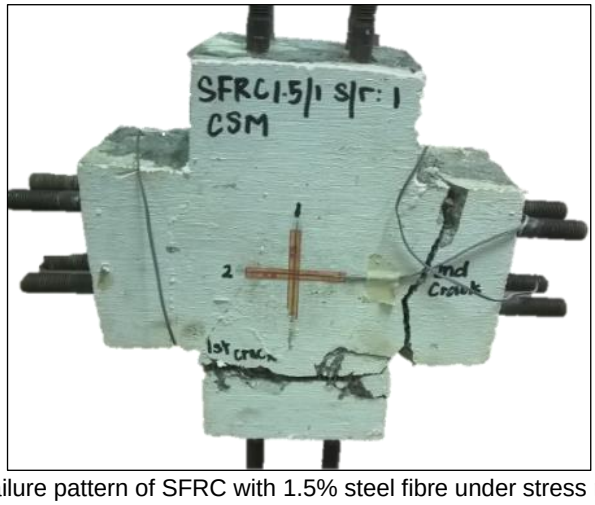

Figure 7. Failure pattern of SFRC with 1.5% steel fibre under stress ratio 1.0

Figure 8 illustrated the comparison of stress-strain relation between plain concrete and SFRC with 1.5% steel fibre under uniaxial tension and biaxial equal tension. It is noticed that the biaxial strength is higher than the uniaxial strength in plain concrete whereas the SFRC shows the opposite results. Kupfer et al. (1969) and Hussein and Marzouk (2000) who conduct a biaxial tensile experiment on plain concrete, conclude that the biaxial tensile strength is similar to the uniaxial strength of the concrete. However, Lee et al. (2004) obtain a smaller biaxial tensile strength than uniaxial strength of the concrete under equal stress ratio. The biaxial strength of plain concrete obtained by Abdull-Ahad and Abbas (1989) agrees with the results from Kupfer et al. (1969) and Hussein and Marzouk (2000).

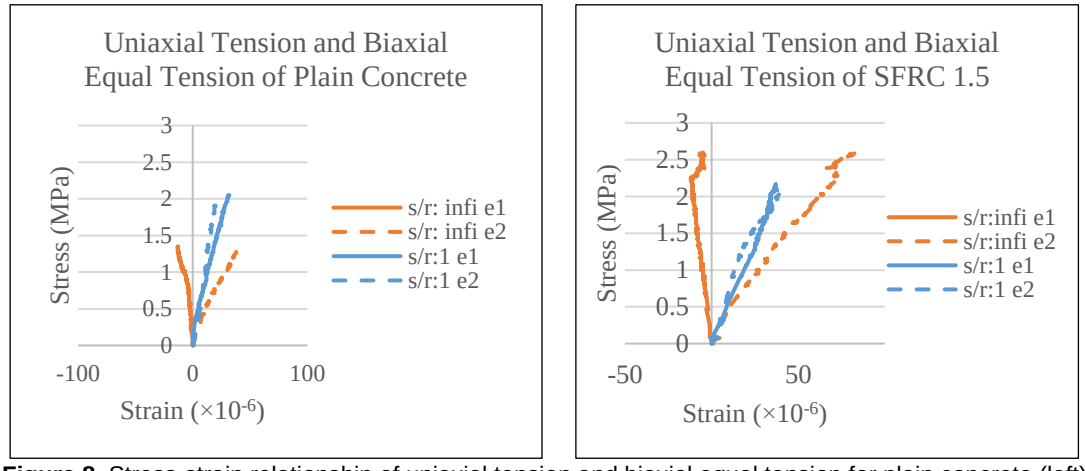

Figure 8. Stress-strain relationship of uniaxial tension and biaxial equal tension for plain concrete (left) and SFRC with 1.5% steel fibre (right)

Results obtained in the current study shows disagreement with the previous reported results. For plain concrete, the introduction of the transverse tensile force required the concrete matrix to withstand the forces in two directions, where it only needs to withstand one direction tensile force originally in uniaxial tension. This causes the concrete matrix to become stiffer and results in a higher failure strength. For the uniaxial tension in SFRC with 1.5% steel fibre, the crack bridging properties of steel fibre enhances the tensile strength as well as the ductility of the SFRC. Similarly with the biaxial tension in plain concrete, the concrete matrix and steel fibre requires to encounter the stresses from two directions. When the capacity of concrete matrix to withstand tensile stress is reached, cracks initiated. The stress redistribution from the concrete matrix to the steel fibre is from two directions, which decreases the failure strength of SFRC even though SFRC becomes stiffer.

Figure 9 illustrated the comparison of the normalised biaxial tensile strength for SFRC from Abdull-Ahad and Abbas (1989) with stress ratio of 0.8, together with the SFRC results obtained from this study under equal stress ratio. The testing techniques used by Abdull-Ahad and Abbas is servo-hydraulic closed-loop machine, in which plate specimens are used to conduct the biaxial tensile test. The testing techniques used in this study is the biaxial testing set up mentioned in section 3.3 which is applied to the concept of lever arm principle. The biaxial strength of SFRC is higher than the plain concrete from Abdull-Ahad and Abbas (1989), while the increase in biaxial strength of SFRC obtained from the current study is insignificant as compared to plain concrete. On the other hand, the current study obtains a similar trend with the findings from Abdull-Ahad and Abbas (1989), where the increment in steel fibre volumetric fraction does not have much contribution on the strength of concrete.

Shang et al. (2014) concludes that the mechanical behaviour of concrete under multiaxial loading is influenced by the testing techniques, testing apparatus or equipment and type of concrete, which is well-agreed through the data comparison and analysis in the current study. Furthermore, the similar trend obtained from the comparison of increment in fibre volumetric fraction on biaxial tensile strength of the concrete shows that the biaxial tensile testing frame setup is suitable in conducting the biaxial tensile test. However, to enable the collection of strain data from post-cracking after failure, it is necessary to modify the shape of the specimens to induce cracking at the effective central area where strain gauges are located.

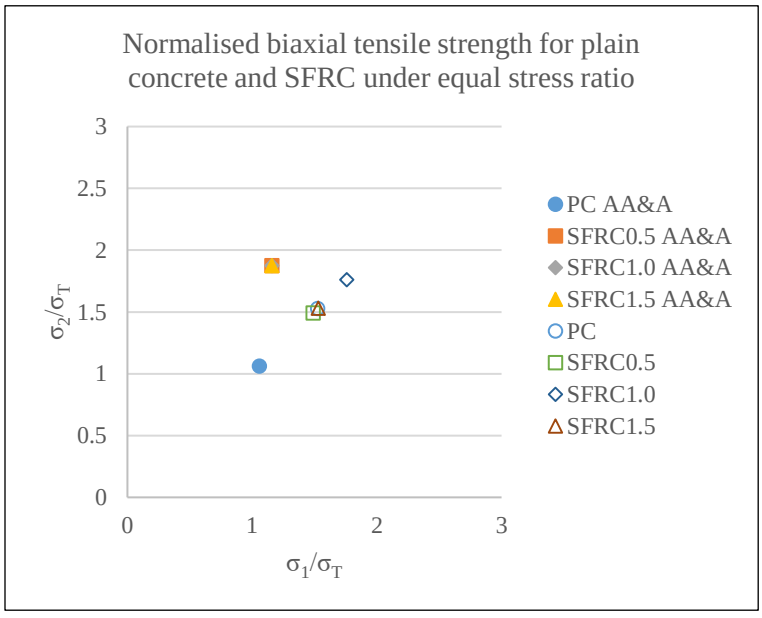

Figure 9. Normalised biaxial tensile strength for plain concrete and SFRC

CONCLUSION

In conclusion, the current study agrees with the experimental results from the previous research, in which the inclusion of steel fibre volumetric fraction does not have significant increment in the biaxial tensile strength of the concrete, but greatly contribute to the ductility and the concrete post-cracking behaviour. The biaxial tensile strength is reported to be similar to the uniaxial strength of the plain concrete, but in the current study, the biaxial tensile strength of plain concrete is greater than the uniaxial tensile strength of the concrete due to the stiffness induced by the introduction of transverse tensile load.

As for SFRC, the opposite observation is obtained where the biaxial tensile strength of SFRC is smaller than the uniaxial tensile strength. This is because the steel fibre, which is only required to cater with the crack formation and propagations from one direction in uniaxial tension, must redistribute the stress from two directions in the biaxial tensile loading which eventually decreases the ultimate failure strength.

Therefore, from the comparison and data analysis with previous researchers, it is concluded that the biaxial tensile testing frame setup is suitable to conduct concrete biaxial tensile testing, although the mechanical behaviour or the stress-strain responses of the concrete is quite different under different loading methods and testing techniques.

For further investigations, it is recommended to modify the shape of the specimens for biaxial tension to obtain the stress-strain response for the SFRC post-cracking behaviour. Since the addition of steel fibre is aimed to improve the post-cracking behaviour of SFRC, it is also necessary to investigate the relationship between toughness and biaxial tensile behaviour of SFRC.

ACKNOWLEDGEMENT

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NOTATIONS

PC = Plain concrete
SFRC = Steel fibre reinforced concrete
e1 = strain for major principal (beam 1)
e2 = strain for minor principal (beam 2)
σ_1 = strength for major principal (beam 1)
σ_2 = strength for minor principal (beam 2)
σ_T = uniaxial tensile strength of plain concrete

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REVIEW OF RETROFITTING USING CONFINEMENT TECHNIQUES TO REINFORCED CONCRETE BEAM-COLUMN JOINT

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Abstract
This paper presents a review of experimental studies on different innovative techniques used to confine beam-column joint. Different behaviour and confinement schemes of concrete jacketing, steel jacketing and FRP confined beam-column joint are described. Extensive research works on different confinement schemes have been done with different performances which make the researcher and engineer to implement suitable confinement techniques. The most appropriate confinement techniques capable to achieve the desired results are selected and discussed to ease the decision to be made for retrofitting beam-column joint. The effectiveness of confinement techniques is based on the behaviour of confined beam-column joint in terms of strength, stiffness, energy dissipation, and ductility as compared to unconfined beam-column joint. Finally, the advantages and disadvantages of each confinement technique are discussed. The methods to reduce the disadvantages are suggested to maximize the performance of each confinement technique. This paper was believed to be able to aid designer or researcher to make any decision related to retrofit beam-column joint using confinement.

Keywords: *External confinement; Concrete jacketing, Steel jacketing, FRP*

INTRODUCTION

Recent earthquake events that occurred at Borneo Malaysia and Indonesia had attracted the attention of researchers, engineers and government agencies to retrofit buildings by strengthening and repairing to reduce the loss of lives and properties. Moreover, the concern on Indonesian earthquake that can affect buildings at Peninsular Malaysia that are earthquake vulnerable were risen by Ramli and Adnan (2016). During seismic events, the beam-column joints become the critical structure element as their failure can lead to a whole or partially collapse of the structure (Sezen et al., 2003; Doğangün, 2004). The increased and concentrated shear forces that pass through the beam-column joints during seismic events cause the small area of concrete and the reinforcement needed to withstand these forces becomes the weakest part (Le-Trung, 2010). Therefore, the structure built according to the pre-1970s's code, weak column-strong beam design, low ductility, poor detailing or non-seismic design structure needs to be strengthened in order to increase the seismic behaviour of the structure, thus ensuring the safety of lives and properties (Ghobarah et al., 2002).

There were several retrofitting techniques proposed to enhance the seismic properties of beam-column joint as reviewed by Engindeniz et al. (2005) including epoxy injection, concrete removal and replacement, concrete jacketing, concrete masonry unit jacketing, steel jacketing and externally bonded FRP composite. These techniques possess disadvantages that hinder applicability as concluded by authors. Recently, retrofitting techniques were proposed to strengthen beam-column joint such as haunch element (Pampanin et al., 2006; Dang et al., 2017; Truong et al., 2017), near surface-mounted techniques (NSM) (Coelho et al., 2012; Mahmoud et al., 2014; Sasmal et al., 2015) and external confinement.

External confinement is one of the popular effective techniques used to increase seismic behaviour of structure as this technique is more socioeconomicaly friendly than demolishing or rebuilding the whole structure (Al-Salloum et al., 2011). External confinement is able to strengthen and repair the structure effectively whenever the need of functionality changes which requires increasing impose loading, damages, increasing seismic properties or construction fault (Mukherjee et al., 2005). There are two types of external confinements, namely passive confinement and active confinement. Passive confinement provides lateral restriction on the dilation of concrete under loading while active confinement allows lateral pressure to the concrete member at the initial stage before lateral dilations (Moghaddam et al., 2010).

Extensive research works have been done using different confinement techniques on beam-column joint. However, the variety of external confinement techniques and schemes with different performances cause the designer or researcher to doubt applying these techniques, thus hinder the widespread use in construction. This paper presents the review of external confinement including concrete jacketing, steel jacketing and FRP confinement which is suitable to be implemented to retrofit beam-column joint. The past research works are selected based on the desired behaviour of seismic performances achieved on different techniques and schemes. Lastly, the advantages and disadvantages are highlighted to aid researcher and engineer to make decisions of selecting confinement techniques and schemes to retrofit beam-column joint.

CONFINEMENT TECHNIQUES

There are different types of external confinement techniques used to confine beam-column joint such as concrete jacketing, steel jacketing and fibre reinforced polymer (FRP). The main objective of the confinement is to increase beam-column joint seismic behaviours such as strength, ductility, stiffness and energy dissipation.

Concrete Jacketing

One of the earliest methods is used to confine column and beam-column joint to strengthen or repair the deficient structure members. Concrete jacketing encases the existing column together with beam-column joint with new concrete, longitudinal and transverse reinforcement for strengthening the beam-column joint whereas for repairing, additional steps are required to repair the damaged concrete. The damaged concrete can be repaired by epoxy, mortar or removing the damaged concrete and construct new concrete.

Alcocer and Jirsa (1993) have studied on four 2/3 scaled interior joint with slab confinement using normal strength concrete under bidirectional cyclic loading. The study investigated the behaviour of strengthening and repairing beam-column joint with level of damage and jacketed column reinforcement as variable. The experiment results showed that the specimen SDB resulted in the highest seismic behaviour among other specimens. SDB specimen confining scheme used distributed column longitudinal steel around the perimeter with additional corner ties with hooks and confined beams with added top, bottom and transverse reinforcement as shown in Figure 1. Steel cage was used to confine beam-column joint which was welded in situ as shown in Figure 2. The initial stiffness and strength of the SDB specimen were reported 6.4 and 5.7 times, respectively, as compared to the original specimen although cracks were formed at the jacketed column face.

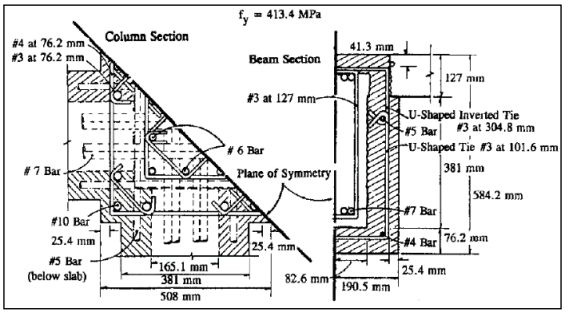


Figure 1. Specimen SDB confinement scheme (Alcocer et al., 1993)

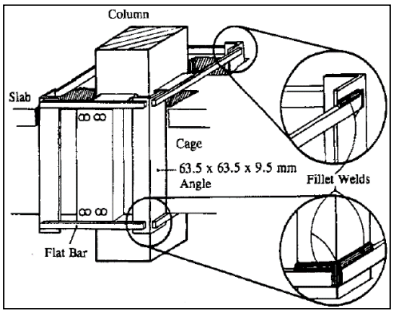


Figure 2. Joint confinement cage (Alcocer et al., 1993)

Different concrete materials as confining materials were performed by Shannag et al. (2002) to repair 1/3 scaled interior beam-column joint by using high performance fibre reinforced concrete (HPFRC). The behaviour of repairing non-seismic designed specimens was studied under lateral cyclic loading. The repairing works were done by applying 15 mm thick of HPFRC mix covering the entire joint and the maximum moment column regions without any additional reinforcement. The results showed that the load carrying capacity increased 3 times, ductility increased 15-20%, and energy dissipation capacity increased 20 times for the HPFRC repaired beam-column joints as compared to the reference specimens. They also reported that the confinement can relocate the plastic hinge from beam-column joint to beam which led to ductile failure manner.

The effectiveness and suitability of using concrete jacket and shotcrete as confining materials to half scaled exterior joint with transverse beam and slab was investigated by Tsonos (2010). The specimens lacked column and joint transverse reinforcement as required by modern codes and tested under cyclic and constant axial load test. All the confined specimens showed higher seismic behaviour and SP_2 specimen achieved the highest results for stiffness, strength and energy dissipation which increased 135%, 145% and 215%, respectively, as compared to original specimen. The SP_2 was confined at the two sides of column with additional reinforcement at the column corner as shown in Figure 3. Figure 4 shows the plastic hinge formed at the beam which could be observed with the concrete spalled at the bottom beam near column face.

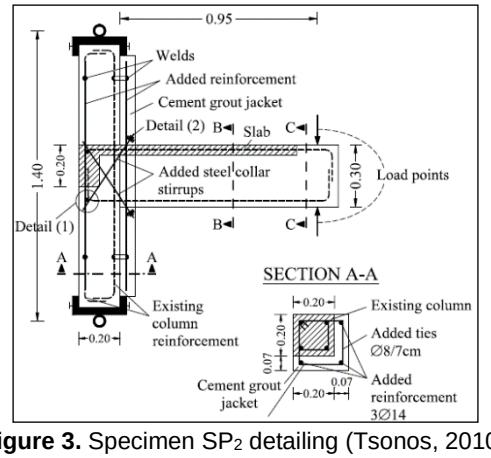


Figure 3. Specimen SP_2 detailing (Tsonos, 2010)

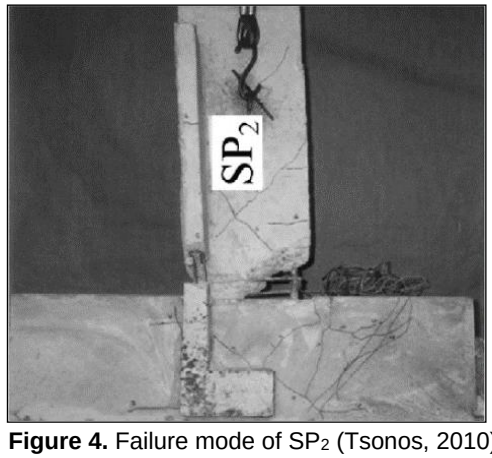


Figure 4. Failure mode of SP_2 (Tsonos, 2010)

Steel Jacketing

The steel jacketing can be divided into two different techniques according to the method and materials used namely steel cage jacketing and steel straps or pre-stressed steel angle. It is worth mentioning the difference between these techniques because steel cage jacketing is a passive confinement while steel straps is an active confinement which allows pre-tensioning of steel straps using hydraulically mechanical fastener. The joint enlargement using pre-stressed steel angle technique also behaves as active confinement as the pre-tensioning of steel rod is able to actively confine the beam-column joints.

Ruiz-Pinilla et al. (2014) investigated the behaviour of steel jacketing confinement to full scaled interior beam-column joint under strong beam-weak column concept. The beam-column joints were strengthened by steel cage as shown in Figure 5 consisting of steel angle welded with steel strips and tested under cyclic and axial load. The use of vertical bar as shown in Figure 6 showed higher load carrying capacity of 2.5 times compared to original specimen than other specimens. The authors reported that the use of steel jacketing prevents column failure, improves bending strength and increases joint resistant section.

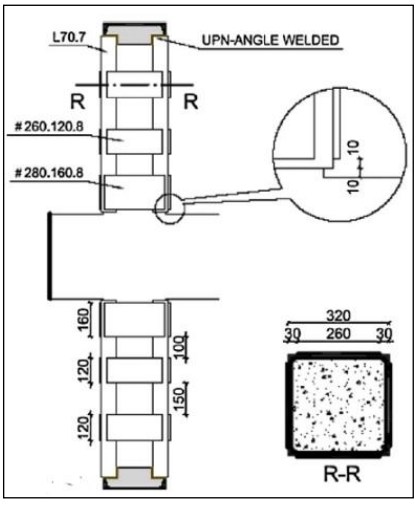


Figure 5. Steel cage confinement at column (Ruiz-Pinilla et al., 2014)

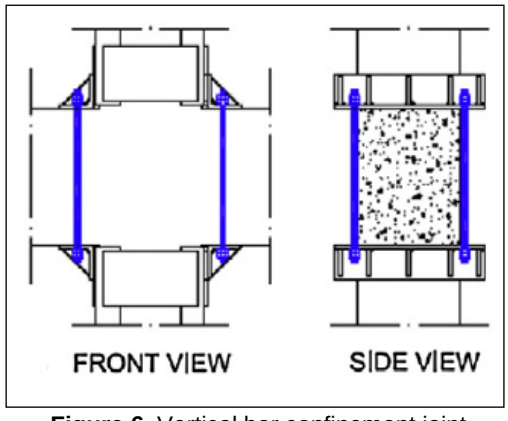


Figure 6. Vertical bar confinement joint (Ruiz-Pinilla et al., 2014)

Shafaei et al. (2014) conducted a study to evaluate the effectiveness of using an innovative technique called "joint enlargement using pre-stressed steel angles" to confine half scaled non-seismic design exterior beam-column joints. The confinement scheme used steel angles mounted with pre-stressed cross-ties as shown in Figure 7 which created active confinement to the beam-column joints. However, the limitation of using this technique would cause higher member shear forces due to shortened member length which was needed to reanalyse the load distribution through the structure. The confined beam-column joints showed increase in ductility, maximum peak load and energy dissipation for 352%, 67% and 341%, respectively. The confinement techniques are able to transform the plastic hinge away from column face and joint panel as shown in Figure 8.

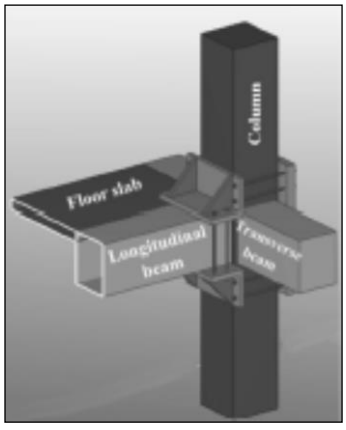


Figure 7. Confinement scheme by using joint enlargement using prestressed steel angles techniques (Shafaei et al., 2014)

Figure 8. Plastic hinge relocation at drift ± 10% (Shafaei et al., 2014)

Garcia et al. (2014) studied the effectiveness of confined beam-column joint using post-tensioned metal straps (PTMS) to repair the damaged full scaled frame. The frame was damaged under shaking table, and repaired using PTMS at beam-column joint as shown in Figure 9. The PTMS techniques used high strength metal straps post-tensioned by using hydraulically-operated steel strapping tools and mechanically fastened "push type" seals to maintain the tensioning force. The PTMS repaired beam-column joint reduced the stiffness degradation from 70% to 20%, and able to resist PGA = 0.35g from PGA = 0.15g, without stability compromise.

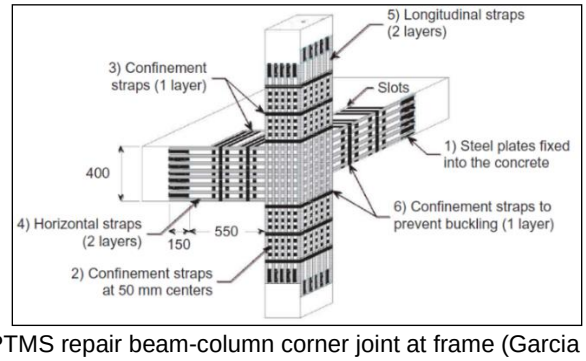
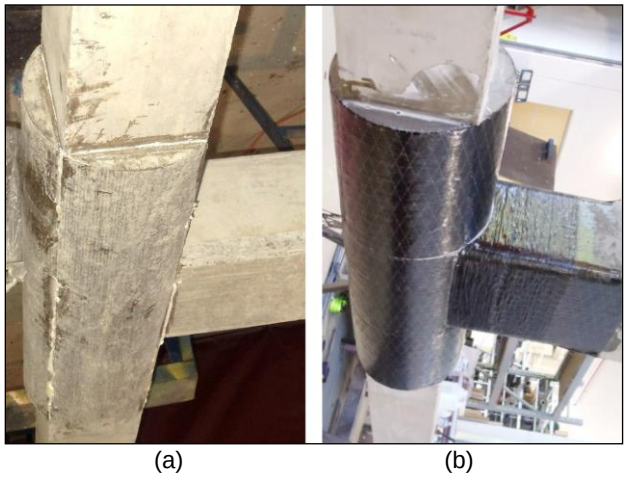


Figure 9. PTMS repair beam-column corner joint at frame (Garcia et al., 2014)

Fibre-Reinforced Polymer (FRP)

FRP is the most popular confining material among those techniques discussed as many research works have been done to confine beam-column joint and other structural members as well because of the advantages it possesses. The FRP confining scheme mainly focuses on the warping and stripping with adhesive bond to the surface of concrete members to increase its seismic behaviour. However, due to the flexibility of FRP, there were different confinement schemes proposed to confine beam-column joint. Different types of FRP such as carbon fibre reinforced polymer (CFRP), glass fibre reinforced polymer (GFRP), aramid fibre reinforced polymer (AFRP) and basalt fibre-reinforced polymer (BFRP) can be used as confining materials.

Hadi and Tran (2016) carried out tests to confine beam-column joint by adding concrete cover with CFRP warping under cyclic loading. The modified column section from square to circle as shown in Figure 10 was intended to increase the effectiveness of CFRP confinement and reduce CFRP debonding. The authors reported that the confined beam-column joints achieved 87% increase in ductility, peak load of 140% and 407% energy dissipation. They also reported that the confinement was able to transform the plastic hinge from beam-column joint to beam.



(a) (b)

Figure 10. (a) Modified column section from square to circle by adding concrete cover. (b) CFRP confinement around the circle section of column (Hadi and Tran, 2016)

El-Amoury and Ghobarah (2002) used GFRP as confining material to repair and strengthen the full scaled exterior beam-column joints under cyclic load and constant axial load. The specimens had non-seismic design constructed under pre-1970s' codes. The results of strengthened specimen TR2 increased load carrying capacity and energy dissipation capacity for 52% and six times respectively than the control specimen. The confinement scheme of TR2 was shown in Figure 11.

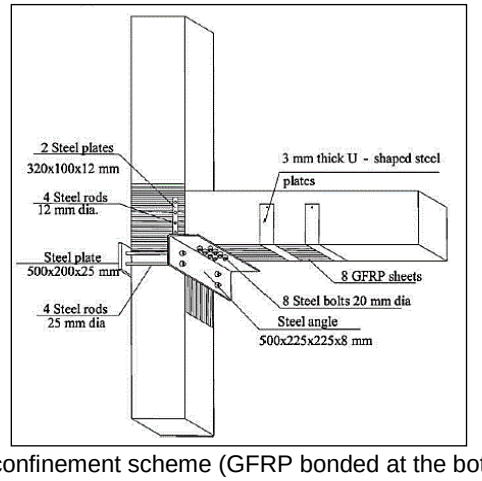


Figure 11. Specimen TR2 confinement scheme (GFRP bonded at the bottom beam face with two U-shaped of steel plates and steel angles at the lower beam-column corner. The joint was wrapped with two U-shaped of GFRP anchored by steel plates and tie rods driven through the joint) (El-Amoury et al., 2002)

Tsonos (2008) studied the effectiveness of proposed FRP confinement on beam-column joint. The proposed confinement scheme consists of longitudinal CFRP bond and transverse warping at the beam-column joint. The slab was drilled to allow the CFRP transverse warping at beam that goes through. The confined beam-column joints namely $FRPF_1$ and $FRPS_1$ increased stiffness, energy dissipation capacity and strength as compared to unconfined beam-column joint after tested. $FRPF_1$ increased 50%, 135% and 170% while $FRPS_1$ increased 70%, 200% and 190% for stiffness, energy dissipation capacity and strength, respectively.

Esmaeeli et al. (2017) focused on the performance of using GFRP sheets with steel cage confinement to strengthen full scaled corner beam-column joint. Bidirectional cyclic loading was applied to the corner beam-column joints which was insufficient joint transverse reinforcement. The confined corner beam-column joint as shown in Figure 12 showed increase in 28% ductility, 1.4 times stiffness and 10.4 times energy dissipation as compared to the original specimen.

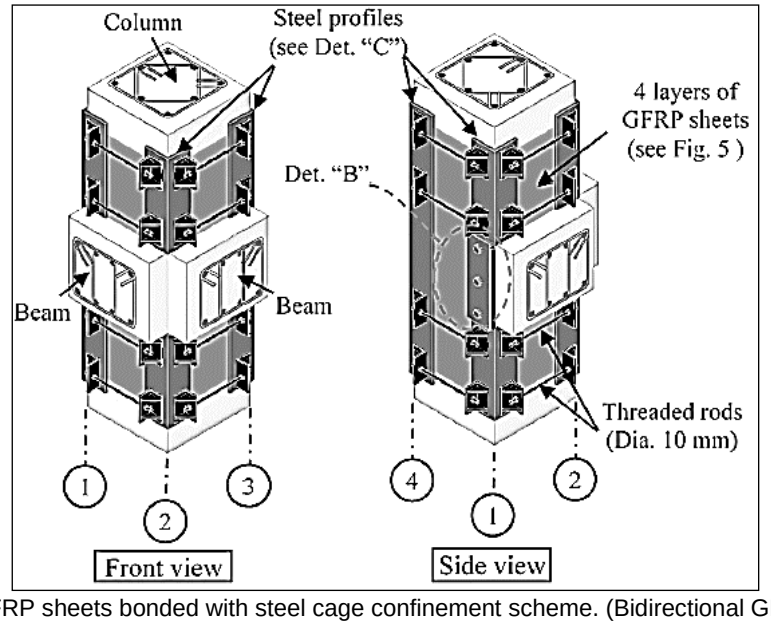


Figure 12. GFRP sheets bonded with steel cage confinement scheme. (Bidirectional GFRP sheet warping around the column without bonding on beam with threaded rods tie to each angle steel). (Esmaeeli et al., 2017)

ADVANTAGES AND DISADVANTAGES

Every confinement technique has its own advantages and disadvantages. It is important to determine the advantages and disadvantages of the confinement techniques used to strengthen or repair the structure in order to ensure the safety and stability of the overall structure integrity to prevent catastrophic collapse of the structure during seismic events.

Concrete Jacketing

The overall performance of concrete jacketing was the highest among confinement techniques in terms of ductility, stiffness, strength and energy dissipation capacity from the past research works. The high performances are due to increase of the structure member sizes

such as column, beam and joint with additional reinforcement or use of high strength concrete materials. However, the construction methods of concrete jacketing were difficult on-site which required intensive labour. The increase of the structure member size was hardly accepted by architect and increased the structure self-weight which led to uncertainty to apply the concrete jacketing as strengthening and repairing technique. As many concrete materials have been investigated, the use of high strength concrete, shotcrete (Tsonos, 2010), ferrocement (Bansal et al., 2016; Shaaban et al., 2018) or ultra-high-performance hybrid fibre reinforced concrete (UHP-HFRC) (Sharma and Bansal, 2019) which required only thin jacketing on the structure member eliminate the problems of increased member size and self-weight of structure.

Steel Jacketing

The use of innovative techniques which were the active confinement to the beam-column joint such as joint enlargement using pre-stressed steel angles or PTMS eased the construction method with less labour needed as well as increased the effectiveness. The effectiveness of using active confinement has been studied for column (Ma et al., 2016; Rousakis et al., 2014; Teng et al., 2015; Harajli et al., 2014), for beam (Shahverdi et al., 2016; Ma et al., 2016), and for beam-column joint (Shafaei et al., 2014; Garcia et al., 2014; Yurdakul et al., 2016; Hadi, 2011). Besides, the active confinement to improve the bond and anchorage between reinforcement and concrete has also been reviewed (Sulaiman et al., 2017). However, the steel jacketing using steel cage as confinement material required a lot of labour, complicated procedure as well as increased structure self-weight. The aesthetic of using steel jacketing needed the acceptance of the architect as the exposure of the confining materials. The corrosion of the steel materials also requires attention in the long-term durability unless proper protection or non-corrode materials such as stainless steel or alloy are used.

Fibre-Reinforced Polymer (FRP)

The use of FRP as confining material is the most popular due to its advantages such as ease of the construction time and cost, in spite increasing the seismic performance of beam-column joints. The view of FRP confined structure could be accepted by architects as the confining materials are easily covered up and required only small space. Besides, the high strength to weight ratio, good corrosion resistance, flexibility to confine various shapes of structure members and high durability are the advantages of FRP which lead to extensive research works done on it. However, the weakness of debonding and early rupture issues of the FRP are still being debated. To overcome this issue, external mechanical anchorages were applied to the FRP confinement scheme to increase the anchorage of FRP to concrete surface such as cutting grooves on concrete surface (Sattarifard et al., 2015), modified concrete cover from square section to circular shape (Hadi and Tran, 2016) and the combination of steel cage and FRP confinement (Esmaeeli et al., 2017). These proposed techniques successfully prevented early debonding of FRP and increased the FRP confinement performance.

Each confinement technique possesses advantages as well as drawbacks in retrofitting beam-column joint. Therefore, the researcher and engineer need to consider these advantages and disadvantages before implementing any confinement techniques to retrofit beam-column joint. Confinement techniques' disadvantages could be minimized and thus maximized the performance of using these techniques to retrofit beam-column joint.

CONCLUSION

Several confinement techniques are presented according to the most desired performance resulted from the research works. The use of external confinement has been proven effective to increase the seismic behaviour of the beam-column joints. The confinement scheme in concrete jacketing, steel jacketing and FRP is modified to ease construction method and reduce the time as well as cost to strengthen and repair the beam-column joints. Each of the confinement technique possesses its own advantages and disadvantages. However, the disadvantages of using the confinement techniques need to be alerted and eliminated to confirm the structure integrity during the seismic event to maximize the performance of confinement techniques. Therefore, proper judgement about the advantages and disadvantages needs to be carried out when deciding the confinement technique and scheme to be used.

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STABILITY OF CUT SLOPE AND DEGRADATION OF ROCK SLOPE FORMING MATERIALS – A REVIEW

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Abstract
Rock slope stability evaluation is complex due to various influencing factors that contribute to the instability of the slope. The stability of the slope depends on the slope geometry, strength of slope forming materials, rock type, discontinuity characteristics, weathering rate, and groundwater condition. Rock masses forming cut slopes usually start to deteriorate after the excavation phase due to stress relief and weathering. Deterioration of cut slopes is one of the parameters that contributes to the instability events of cut slopes. A review on the types of slopes failure, factors of instability, degradation of engineering structures and degradation of rock was carried out and thoroughly presented in this paper. It can be observed from the reviewed studies that the main factors influencing the degradation of rock slope include the history of rock, weathering, surrounding environment and the disturbance caused during the construction stage of projects through or besides the slopes. Degradation in the form of drying and wetting also plays an important role in deteriorating the rock masses resulting in various types of failure.

Keywords*: Rock slope; Degradation; Cut slope; Weathering*

INTRODUCTION

Slope failure of cut slopes along highways and rural roads is the most hazardous for users, planners and governments due to the high risks of human lives and the economic losses encountered every year across the globe. Cutting natural slopes in order to make room for new developments either for infrastructural or industrial purposes alters the geometry of slopes and increases the susceptibility of failure. The stability of natural slopes that is subjected to modification for development was studied by Sutejo and Gofar, (2015). The study utilized the limit equilibrium method to analyse the instability that occurred due to changes in the slope geometry and the reduction of strength. The results indicated a decrement of slope's strength and factor of safety due to cutting the slope. The authors recommended the application of shotcrete at the face of the slope and the erection of retaining wall at the toe of the slope in order to prevent further occurrences of failure. Moreover, extensive laboratory and numerical simulations were conducted for road cut slopes at the area of Uttarakhand, India that experienced regional and local landslides every year. The numerical analysis was performed using FLAC3D that was compared with the available field studies. The geometry of the slopes was determined based on detailed field measurements while the geo-mechanical inputs required were obtained from laboratory testing. The results indicated that all the slopes that were observed in the study were unstable except for one whereby the mechanism of failure was found to be caused by a circular failure (Singh et al., 2008).

According to Kainthola et al. (2015), the failure of cut hill slopes after construction depends highly on the geometry of slope, strength of slope forming materials, orientation and distribution within the rock mass, hydrological conditions and characteristics of

discontinuities. The slopes that are composed of weak materials or topped on a rock jointed mass are prone to failure at any time. In their study, a universal distinct element code was used to model a sixty-meter basaltic cut slope in Mahabaleshwar, India. The analysis showed the slope remained stable when the maximum strength of slope's material was used and became unstable (FOS = 0.9) when the minimum strength was applied. The studied area is predicted to receive heavy rain every year thus appropriate remedial measures should be applied such as through the erection of retaining walls with drainage holes along the cut slope. In addition, Mori et al. (2017) investigated the slope failure of a cut slope of an expressway in Hokkaido, Japan using the limit equilibrium stability analysis and the approaches that consider iso-thermal seepage simulation. The simulation was performed using a commercial code called SVOffice 5GE from SoilVison Systems Ltd. The results of the performed back analysis showed that failure of the slope was triggered by the rainfall that caused an increase in the degree of saturation as a result of infiltration of rainwater and snow-melt. However, the main reason for failure was the overflow of water from the drainage ditch. In another study of a rock cut located nearby a residential area in Madinah, Saudi Arabia investigated by Aqeel et al. (2018), they pointed that different kinds of rock failure such as rockfall and wedge failures may occur which could potentially cause some large loose blocks to fall down. The probability of the wedge failure to take place was noted to be about 67% while the probability of toppling failure was less than 10%. Based on the results obtained, the authors recommended anchoring the intact rock and constructing a catch ditch. As noted by Erso¨z and Topal (2018), cut slopes are very sensitive to weathering particularly right after the excavation stage as weathering agents start to degrade and alter the engineering properties of the rock masses. In their study, the effects of weathering and excavation were found to be changing between 10 and 50 cm of rock masses within a 5-year lifespan.

The previous literature revealed that cut slopes are unstable and that the slope forming materials start to deteriorate once the geometry of the slope is modified. The stability of cut slopes can be significantly affected over time by the interruption induced during the construction of roads, railways and pipelines. Many research studies have been conducted investigating the stability of cut slopes using traditional and advanced techniques of analysis. Most of the studies focused on the aspects of instability and failure of cut slopes after construction (e.g. Taherynia et al., 2014; Sharma et al., 2013; Verma et al., 2013; Alavi Nezhad Khaili Abad et al., 2013; Zhang et al., 2012; Alavi Nezhad Khaili Abad et al., 2011a; Mohamad and Alavi Nezhad Khaili Abad, 2011b; Chun et al., 2008). Over the years, many researchers applied various techniques to study the stability of slopes prompting landslides such as GIS, limit equilibrium methods, finite element, distinct element methods, finite differences, statistical and analytical methods (e.g. Akgun et al., 2011; Cho, 2009; Suchomel and Masin, 2010; Westen et al., 1997). All these methods have some disadvantages such as modelling the internal deformation within the slope. In view of this, this paper attempts to provide an extensive review on the degradation of the slope forming materials and its extensive effect on the stability of the cut slopes which may contribute to the body of knowledge on factors affecting instability for proper control of the stability of slopes.

THE EFFECTS OF DEGRADATION BY WEATHERING ON SLOPE STABILITY

Slope failure that is commonly known in layman term as landslides results in the loss of hundreds of lives and properties every year around the world. Due to the great impact created by landslides on human lives, infrastructures and economy, finding appropriate cost effective

and reliable techniques that can predict the occurrence and magnitude of landslides are pertinent. Landslides are likely to occur when the slope forming materials move rapidly downward after failing along shear zone. One of the main causes of landslides is the deterioration of the earth's materials forming the slope over time. The degradation of the slope materials can be described as the process of strength reduction due to the deterioration over time at which the mechanical properties of the slopes are extensively reduced. The degradation of a slope's' strength and the deterioration of slope forming materials are caused by weathering agents such as water, wind, temperature or ice. Weathering plays an important role in reducing the stability of rock slopes due to the formation of unfavourable orientations which results in degrading the strength (Huisman et al., 2004). During degradation, cracks appear on the surface of the rock and can be enlarged over time until the rock mass turns into a fractured rock or a soil-like material. On the other hand, the degradation of slope is caused by the erosion of soil particles downward the slope due to climate changes, modifications of the slope during construction and clearance of vegetation from hill slopes. Degradation of slope will usually result in the event of successive landslides (Voulgari, 2015). According to Alavi Nezhad Khalil Abad et al. (2016a), weathering in tropical climates results in the formation of thick weathered rock masses with several weathering profiles. Hence, when the rock mass is severely weathered, its strength will be weakened and will eventually deteriorate.

Meanwhile, weathering of rock has been studied by various researchers in many fields including engineering geology, geology, rock mechanics, morphology and soil mechanics (e.g. Alavi Nezhad Khalil Abad et al., 2015; Arikan and Aydin, 2012; Miscevic and Vlastelic, 2014; Mukhlisin and Taha, 2009; Alavi Nezhad Khalil Abad et al., 2016b; Alavi Nezhad Khalil Abad et al., 2014a; Alavi Nezhad Khalil Abad et al., 2014b). However, detailed research works investigating the relationship between the effects of weathering and the instability of slope are scarce and not well understood. The instability of slopes induced by deterioration of surface materials can be in the form of landslides, rock falls and settlement. Weathering process was described by Tating (2015) as the process of alteration and breakdown of the soil and rock masses that are caused by differences in temperature and ground water. Weathering can affect the surface material at a certain rate while the weathered material functions to protect the underlying materials from further effects of weathering. However, weathered surface material that exists in slopes will either fall as a result of gravity or will be washed down by the rainfall. This will cause the underlying material to be weathered and the weathering rate will be similar to that which occurred in the origin material. The weathering rate in a cool humid environment is a factor of 3.5 less than that reported in areas at which the environment is at a tropical humid environment. According to Hencher and Knipe (2007), weathering will affect the durability of the rock mass and will influence the aperture, persistence and frequency of the rock joints.

Weathering causes the development of new discontinuities within the intact rock, increases the mechanical discontinuities, decreases the strength of the rock and induces different types of slope failures. In addition, weathering process can be categorized into two distinct categories; physical and chemical weathering. Physical weathering is the disaggregation of the rock without any mineralogical changes while chemical weathering is described as the decomposition of the rock minerals resulting in stability or instability of secondary mineral products (Miscevic and Vlastelica, 2011). Weathering is categorized into three different types; mechanical, chemical and biological. In tropical areas, the chemical weathering will have carbonation, oxidation and hydration processes. Miscevic and Vlastelica

(2011) reported that quick changes in the rock properties from the initial rock properties to soil-like ones can be induced by the weathering processes. The durability behavior of certain kinds of rocks such as mudstone, sandstone, marls, shale, ignimbrites, and conglomerates is related directly to the slope stability problems. This can be due to rapid slope degradation as a result of loss of strength and weakness of the bonds within the rock mass. Moreover, degradation of the surface material of the slope will cause unexpected settlements and reduction of the intact strength in the long term which will affect the overall stability of the slope.

Furthermore, it was stated by Arikan and Aydin (2012) that fracturing of rock and faulting are critical influences in the development of weathering profiles. As the weathering increases, the amount and type of clay minerals within the rock increases and the strength decreases. According to Aydan et al. (2014), when the rock mass undergoes weathering, it will be transferred from its solid state to soil-like state. During the process of weathering, the bonds between the grains or particles become weaker and the porosity increases. The degraded rock will fall and will eventually be washed away. The rate of weathering is usually high at the toe of the slope due to the capillary forces.

Guerra et al. (2017) reviewed several studies related to the erosion of slope and found that the prominent factors that induce erosion could be the slope angle, rainfall intensity and volume, land management, clearance of vegetation and land use. The occurrence of a catastrophic landslide depends on the magnitude and frequency of each of these factors. In addition, degradation is caused by a gradual deterioration of the slope forming materials downward the slope through the influence of gravity without necessarily driven by the effects of water or ice. Although erosion occurred naturally by rainfall and slope angle, it is often human activities that accelerate this process.

The above reviewed studies revealed the importance of weathering in the degradation of rock slope strength. It was clearly stated that weathering results in increasing the amount of clay minerals within the rock mass which leads to degradation and eventually slope failure. Therefore, weathering in the form of temperature, rainfall and ice is considered to be the main influencing factor in the degradation of the slope forming materials.

SLOPE STABILITY ANALYSIS

The stability of natural and man-made slopes is the main concern of current geotechnical research as their failure may cause various hazardous catastrophes (Alavi Nezhad Khalil Abad et al., 2014c). Landslides occurred when the slope's material move rapidly downward after failing along shear zone thus accounting for many hazards. It is possible to assess those hazards and the potential for slope failure by conducting a slope stability analysis. Nowadays, various tools can be utilized to study the stability of slopes including experimental, analytical and numerical methods that concern the stability of the slope (Chrysoula, 2017). Each method of stability analysis has its own advantages and can be used efficiently to investigate the scenario of each slope. For instance, Al-Bared et al. (2015) conducted a slope stability analysis for disused quarry slope at Jalan Kuari, Cheras, Kuala Lumpur, Malaysia. They used two methods of analysis; limit equilibrium method and finite element method. Although limit equilibrium method is considered to be a traditional method, the results showed its reliability and accuracy as it was successful at matching the results of the analysis that were derived from field study conducted at the site.

Slope stability can be defined as the resistance of an inclined surface to the occurrence of failure by sliding or collapsing. For a safe, economical and useful design, slope stability analysis is performed. Slope stability analysis is conducted for both natural and man-made slopes such as embankments, road cuts and excavations. Designing optimal slopes with regard to safety, assessing the equilibrium conditions for the excavated slopes and investigating the possibility of failure are the main purposes for analyzing the stability of slopes. The stability of the slope can primarily be assessed by the factor of safety that is a very useful index to be used when finding out how close or far is the slope from failure that can be achieved using the limit equilibrium methods. The slope is considered to be stable when the Factor of Safety (FS) is more than 1 and when the resisting shear strength is greater than the driving shear stress. However, when the resisting shear strength equals the driving shear stress and if FS is nearly 1, the slope is going to fail. Besides, the slope will be considered to fail when FS is less than 1 (Liu and Chen, 2007). Furthermore, in order to analyze an existing slope, it is important to determine the geometry of slope, fracture parameters, type of rock, discontinuities characteristics, strength of the slope forming material and rock mass properties. Besides, slope stability analysis is also performed to identify the different types of failure that currently exist and the ones that are likely to occur in future. To conduct the analysis, the parameters governing the failure of the slope and those induced by the boundary conditions must be determined to identify a suitable slope stability method (Raghuvanshi, 2017). The geometry of natural slopes is a detrimental factor that estimates the stability of the slope and the design of the berm width and height from the rock cut face. It is common that the stability of the slope to be decreased when the height and degree of the slope increase. For natural slopes, limit equilibrium method is the most suitable method of analysis due to its simplicity and accuracy of the results provided (Abd-Allah et al., 2014).

In addition, the estimation of stability for natural slopes in mountainous areas is crucial for safe construction practices. The instability of slopes is indicated by pre-existing geological features such as joints, faults or bedding planes in which wedge failure, plane failure and toppling / rock fall are the common modes of failure (Lee and Wang, 2011; Yoon et al., 2002; Hoek and Bray, 1981). A rock slope may fail due to one or a combination of these three different mechanisms. If the rock mass is classified as a homogeneous material, circular failure may occur. To evaluate the stability in a jointed rock mass, all modes of failure have to be analyzed (Pain et al., 2014).

Plane Failure

According to Raghuvanshi (2017) who reviewed various studies on plane failure in rock slopes, the formation of plane failure is very common in sedimentary and meta-sedimentary rocks. The occurrence of plane failure in sedimentary rocks happened when the structural discontinuity plane in the form of bedding plane, joint sets and faults dip towards the excavation in an angle that is smaller than the slope angle but is greater than the friction angle of the discontinuity surface. In addition, the rock slope may undergo this mode of failure when blocks or wedges that are free to move through the rock are formed from a combination of discontinuities in the rock mass. The pattern of the discontinuity may contain a single discontinuity or a pair of discontinuities that intersect each other, or a combination of multiple discontinuities which are attached together to form a failure mode. According to Tang et al. (2016), the stability of rock having plane failure mode depends on several factors such as geometry of rock, groundwater condition, rock type, dynamic loading, surcharge conditions,

human activities, and rainfall. These factors have been investigated by many researchers (e.g. Girma et al., 2015; Raghuvanshi et al., 2014; Wang and Niu, 2009; Dahal et al., 2006; Ayalew et al.,2004) over the years. Figure 1 demonstrates a standard view of the plane failure.

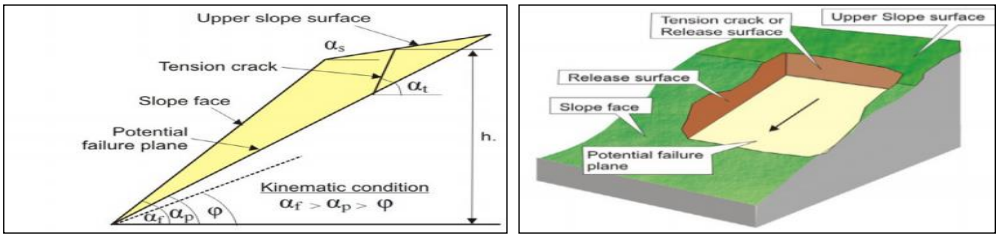

Figure 1. A standard view of plane failure (Left) and typical plane failure in 3D (Raghuvanshi, 2017)

Wedge Failure

The wedge failure is defined as a failure at which a rock mass slides along two intersecting discontinuities daylighting at the toe of the slope while the upper plane forms the tension crack. The occurrence of this kind of failure depends on the presence of two or more sets of discontinuities within the rock mass which have a connection line that strikes vertically to the slope and dip to the plane of the rock slope. Furthermore, one of the factors that results in the wedge failure is when the dip angle of one of the intersection joints is larger than that of the friction angle of the surface and the jointing line intersects the plane of the slope (Wyllie, 2004). Figure 2 illustrates the occurrence of wedge failure within the rock mass. Mineo et al. (2018) studied an unstable rock cliff at Taormina, Italy to assess the failure criteria and to identify the mode of failure. Kinematic analysis was conducted in the study and the results showed that the failure occurred in form of wedge / planar mode. The study proposed appropriate mitigation measures in order to minimize any future impact of the slope failure.

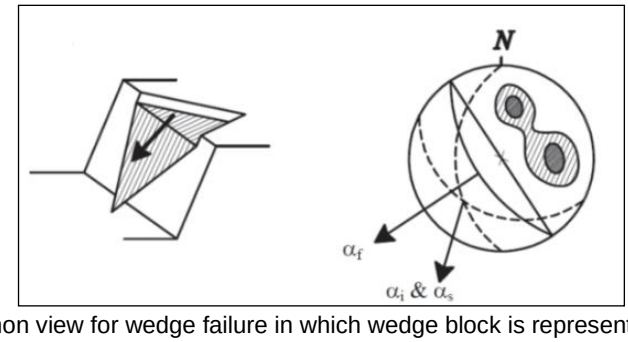

Figure 2. Common view for wedge failure in which wedge block is represented (Taheri, 2012)

Toppling / Rock fall Failure

Rock fall failure occurs due to several influencing factors such as weathering, erosion, seismic and biological events that are responsible for the changes in the forces acting on the rock. These may include changes in the pore water pressure, erosion of the surrounding materials, deterioration of the materials forming the slope and growth or leverage of roots by wind. Areas that are close to the active construction are perceived to be areas of potential rock fall more than those induced by degradation, biological, and other weathering events (Youssef et al., 2012). According to Asnida et al. (2015), the main reason behind the extensive rock fall

event is due to human activities especially those related to construction. Due to weathering, the slope materials deteriorate within time resulting in converting the fractured rock into soil. Besides, the root growth of trees enlarges the existing discontinuities and detaches the fractured rock. Hwang and Ohnishi (2012) used a new 3-D computerized method to simulate and evaluate the deformation and failure of rock instead of the common 2-D methods. The results obtained were compared with the actual failure of slopes and the method used in their study showed its potential applicability to simulate a rockfall and other failure mechanisms of rock.

On the other hand, toppling is a rock mass failure that can be described when the rock column has reached the surface of the rock by a very steep dipping discontinuity whereby the rock at the top of the column starts to slip and rolls down to the base of the slope. Toppling failure takes place when the rock masses are jointed, closely spaced and the dipping discontinuity sets dipping away from the slope surface. During excavation or road cuts, the removal of the confining and overburden rock can result in partial relief of the constraining stresses in the rock that may induce toppling failure. This type of slope failure can be classified into block toppling and block flexural toppling depending on the mode of failure (Wyllie, 2004). Figure 3 illustrates the toppling failure starting from the pre-failure stage up to the failure stage.

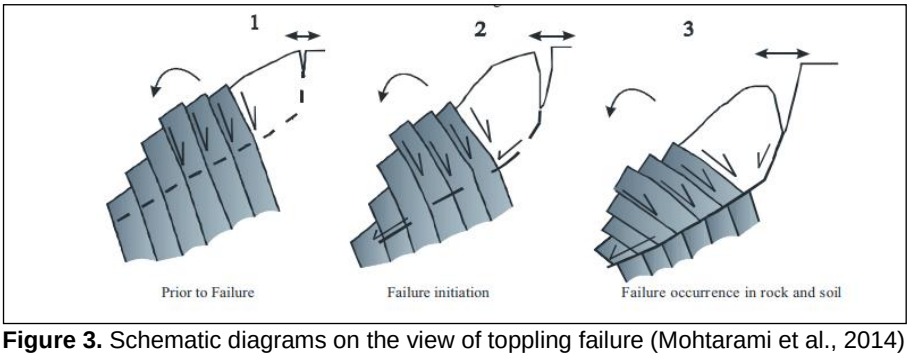

Figure 3. Schematic diagrams on the view of toppling failure (Mohtarami et al., 2014)

Circular Failure

Circular failure usually occurs in soil slope, mine dump and very weak or fractured rock mass. The circular failure will occur when all the joints are oriented favourably so that large scale failures such as plane and wedge failures are not possible (Taheri, 2012). In addition, this kind of slope failure is favourable to the slopes that are formed from a homogeneous material. Circular failure will occur when individual particles forming the rock mass are very small compared to the size of the slope and when the particles are not interlocked together as a result of their shape. Hence, the crushed rock in a very large mass will behave like a soil and large failures will occur in a circular mode. Highly weathered rocks and randomly oriented discontinuities also have a tendency to fail in a circular manner (Hoek, 2006).

The above literature review on slope stability and the types of failure in rock shows that it is simple to assess using conventional methods such as limit equilibrium method or advanced techniques such as numerical analysis. However, the limitation of these methods are their inability to predict the time to failure and the condition of the slope over long periods of time.

DEGRADATION OF ENGINEERING STRUCTURES

Degradation of engineering structures can be in the form of strength reduction due to changes in geometry as a result of gravitational forces. Structures that have been constructed long time ago suffer successive destruction and transformation since their erection. There are many approaches that have been used to recover the initial geometry of the structures but most of them require a priori information about the initial diameters of the structures that is considered complex to be achieved.

The degradation of rammed-earthen walls of a fortress located at the southern Siberia, Russia was studied by Alfimov et al. (2013). The studied fortress site is dated back in the eighth century and is rectangular with a cross section of (215 ×160 meter). The walls of the fortress were made from clay and were built using a Chinese technique called hangtu technique. Hangtu is a process by which a wet clay is put into a wooden frame and compacted using a wooden ram to produce a hard layer of clay 12 to 15 centimetre thick. Factors that induced the degradation of walls are assumed to be natural factors due to the remote location of the fortress and the low population density. Factors that caused the slow and continuous degradation could be due to gravity, water, wind, and vegetation. The degradation of the wall materials was modelled using the Fisher-Lehmann approach. Based on the Fisher-Lehmann approach, degradation of the walls can be modelled if it follows one of the following scenarios. In the first scenario, the weathering process is assumed to be symmetrical on both sides of the wall while the second scenario assumed non-symmetrical weathering on both sides of the wall. The initial wall height was estimated by comparing the uncovered profiles of the walls with the prediction of Fisher-Lehmann's model. The walls were assumed to have a trapezoidal shape with a base angle assumed to be between 75° and 90°. In addition, Delmonaco et al. (2010) conducted a series of laboratory tests, in-situ geotechnical analysis and field surveys to assess the causes of degradation in the structure of 11 rock churches in Lalibela, Ethiopia. The results indicated the presence of montmorillonite which is the primary reason for the progressive degradation of the rock.

DEGRADATION OF ROCK

Slope degradation has recently attracted the attention of geologists and geomorphologists due to their functional value in engineering construction and also their theoretical associations in landscape development. Slope degradation can be defined as the processes of strength reduction within time of the geo-materials forming the slope due to several natural factors. Those factors can be the properties of the slope forming material and weathering that can be in the form of rainfall, temperature; dry and wetting processes. In addition, factors that cause degradation can also include man-made factors such as stress relief due to modifying the slope geometry, geometrical changes due to excavation and road cuts mostly during construction. The degradation process is a random process that is not constant per unit time. When the rock mass is less weathered, the degradation rate is smaller than that encountered with further progressive weathering. The weathering factors usually cause physical, geotechnical and chemical changes in the slope's materials in response to the new environment. The stress relief enlarges the existing discontinuities, increases stresses, and results in creating new discontinuities within the rock mass (Huisman et al., 2004).

According to Huisman (2006), weathering processes should be taken into account during the calculation of the engineering life time of man-made rock slope especially with the presence of unfavourable orientations. A road cut was excavated in the northeast part of Spain and partially failed few years later due to block sliding over the bedding plane. The reason of the slope failure was due to the considerable degradation of the rock mass induced by weathering on the bedding plane. The continuous weathering weakened the strength of the rock mass and resulted in reducing the friction angle of the bedding plane. Degradation of rock cut slopes over time in Sabah, Malaysia was studied by Tating et al. (2013) in which they found that it was the result of the fast deterioration encountered at several cut slopes within a relatively short time of about 10 years. Although the slopes were designed for a service lifetime of more than 30 years, some slopes started to deteriorate and showed instability within less than 30 years after the construction. The main reason behind this issue was the degradation of the slope's material because of weathering and stress relief that were neglected during the designing of the slopes. Weathering and stress relief are responsible for degradation processes that cause changes in the physical, chemical and geotechnical properties of the slope's material in response to the surrounding environmental changes. In the study, the relationship between the weathering rate and the exposure time for the strength of the intact rock in humid areas for sandstone was observed. The relationship between the intact rock strength and the exposure time is expressed in a logarithmic function in formula (1):

$$IRS\ (t) = 105 - 34\log\ (1+t) \tag{1}$$

In which IRS is the strength of the intact rock in MPa at time t, t is the time of exposure in years, 105 is the value of the strength of the sandstone in MPa unit during the time of excavation of the cut slope and 34 is the apparent decrease rate in the strength of sandstone in MPa in a similar environment of the study area.

Moreover, Kobayashi et al. (2010) carried out a numerical simulation for the degradation of rock slope using coupled thermal, hydraulic and mechanical model. This study was focused on modelling the mechanical degradation of granite and tuff rocks. In this study, the developed model considered the volumetric changes resulting from the damaging processes and was applied to the coupled thermal, hydraulic and mechanical simulations. The parameters of the damage were obtained by conducting a uniaxial test on samples that were degraded by freeze and thawing processes. In addition, three different locations were selected in order to examine the weather conditions which included heavy rain, severe temperature and average weather. The boundary conditions were set to be rainfall intensity and ambient temperature and the behavior of the slope was simulated for one year. Then degradation was assessed by the progress of damage variable and the stress ratio. The results showed that the top part of the slope was most affected by the degradation. Moreover, a high progress of degradation was encountered at the parts of slope that have large variations of temperature throughout the year. Soft rock was degraded significantly compared to hard rock in terms of rainfall influences. EL-Sohby et al. (2004) studied the degradation of slope in Mokattam plateau, Egypt which experienced several rockfall and landslide events. The analysis showed the triggering factor that caused the instability events to be the infiltration of water due to rainfall. The water infiltration caused degradation of the clay strata at the bottom of the cliff which affected the overlaying limestone leading to failure. Moreover, Qin et al. (2018) conducted experimental testing in order to evaluate the effects of weathering in the form of

drying and wetting cycles on an altered rock. The results showed degradation of the mechanical properties, the strength in particular, of the rock samples subjected to the drying and wetting cycles. The shear strength degraded under the drying and wetting cycles and the displacement was increased which may lead to sudden slope failure. Belem et al. (2007) proposed two models that can predict the degradation of rock joint surface during shearing. The first model was developed based on the evolution of surface roughness while the second model was based on the contact angle during shearing. The results indicated good agreement between the experimental degradation and the one obtained from the proposed models. Tovar and Colmenares (2011) investigated the effects of drying and wetting cycles on samples of shale rock using triaxial and direct shear tests. The results revealed a big reduction in shear strength of the shale subjected to successive drying and wetting cycles. The reported physical degradation in the form of drying and wetting cycles took place in a short period of time and provide justifications for the failure of the natural deposits of shale in the atmospheric environment. Besides, Zhao et al. (2017) also evaluated the effects of degradation in the form of drying and wetting cycles on sandstone samples. The results exhibited a reduction in the tensile strength of sandstone. However, the reduction is not permanent as the reduction is caused by a chemical deterioration as it was observed that when the clay minerals are low, the reduction may disappear during drying.

A study was conducted by Varela et al. (2001) to determine the dominant factors leading to the physical degradation of soil. The results showed that degradation took place when there was an alteration in the total porosity, pore size distribution, bulk density and mechanical strength of the soil. Besides, levelling the slope would result in the highest impact on soil degradation as the soil will easily be washed away by the rainfall. Moreover, the degradation of soil slope is highly affected by the fluctuation of groundwater table (Alsubal et al., 2018a; Alsubal et al., 2018b).

The review of the previous studies in slope degradation revealed instability of almost all slopes associated with all forms of degradation. It was clearly stated that the main factor accelerating degradation is weathering. When the rate of weathering is high, degradation of rock takes place in a faster rate and vice-versa. The phenomena of long-term drying and wetting initiated by weathering results in the weakening the rock mass and the formation of new discontinuities.

CONCLUSION AND RECOMMENDATION

The review through many research studies on cut slopes shows that most of the cut slopes are unstable and failure is predicted if no mitigation measures are implemented. The main factor affecting the stability of the cut slope is the degradation of the slope forming materials which current methods of stability analysis fail to consider. In this review, weathering is considered to be the most significant factor influencing and triggering the degradation of the slope. Weathering of rock slope can be initiated by various factors mainly through rainfall and temperature which play an important role in the deterioration of the cut slopes. Degradation of rock slope increases with the increase of the wetting and drying cycles over a long period of time. In order to control or reduce the deterioration of the slopes, slope stability analysis should be conducted followed by implementing appropriate remedial measures. Moreover, this study recommends a consideration of the deterioration of the slope materials

within the available stability analysis methods or the development of a tool that will be able to predict the engineering degradation of rock within time.

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