Properties of Blended Cement Concrete Containing Effective Microorganism

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Abstract. Concrete with effective microorganism is one of the ways to reduce micro-cracks problem which can contribute to a longer service life of concrete structures and make concrete more durable. This study is to investigate the presence of effective microorganism as self-healing agent in the blended cement concrete on its fresh and hardened properties. Slump test was conducted to measure the workability of fresh concrete. In terms of hardened concrete properties, the concrete was tested for its compressive strength, flexural strength, ultrasonic pulse velocity and expansion and shrinkage. The concrete samples were cast and cured using different curing method which are water curing and air curing. Experimental result shows that the workability of the effective microorganism blended cement concrete was higher than blended cement concrete. In terms of compressive strength and flexural strength the effective microorganism blended cement concrete was lower than blended cement concrete. The UPV value of the effective microorganism blended cement concrete was found to be higher than blended cement concrete. In addition, the expansion and shrinkage of effective microorganism blended cement concrete were lower than the control concrete. Concrete undergone water curing has higher value of compressive strength, flexural strength and UPV than air curing. The study shows that the use of effective microorganism in concrete mix affected the properties of the blended cement concrete.

Introduction

Concrete has becomes a major component in the construction industry as it is cheap, easily available and convenient to cast [1]. Concrete was made from a mixture of cement, fine aggregate, coarse aggregate and water. The cement compounds chemically combined with water to form new compounds that provide the strength and durability of the concrete. It takes a few hours for the initial hardening reaction to occur. The purpose of aggregate in concrete is to increase the compressive strength and maintain the dimension stability. Sometimes, concrete admixture is added to the concrete mix to achieve certain properties in concrete.

However, one of the main problems for concrete is cracking. From the ACI Standard, crack means a complete or incomplete separation of either concrete or masonry into two or more parts produced by breaking or fracturing. There are two types of crack which are structural and non-structural crack. The structural cracks are due to incorrect design, faulty construction or overloading. Meanwhile, the non-structural cracks are due to internal forces developed in materials due to moisture variations, temperature variations, crazing, effects of gases and liquid. Cracks endanger the durability of concrete structures as aggressive liquids and gasses may penetrate into the matrix along these cracks and cause damage [2]. Cracks may grow wider and it will expose the reinforcement to the environment. It will cause the reinforcement to corrode and the concrete structure will be damaged and may collapse. In order to prevent the concrete from defects and degradation, the innovation of self-healing concrete is a promising technique. Self-healing concrete can be defined as concrete that possesses self-healing agents, which will automatically heal concrete structures, when cracks occur during its life cycle [3]. However, autogenous healing is limited to small cracks and only effective when water is available and it is difficult to control. Research shows that bacterial induced Calcium Carbonate (Calcite) precipitation has been proposed as an alternative and environment friendly for crack remediation and improve strength of building materials. It also can improve the compressive strength and stiffness of cracked concrete specimens.

The objectives of this study are as follows:

i) To investigate the effect of effective microorganism on the fresh properties of concrete.

ii) To study the effect of effective microorganism on hardened properties of concrete including compressive strength, flexural strength and expansion and shrinkage

iii) To assess the effect of different curing method on hardened properties of concrete

Literature Review

When cracks occur, aggressive liquids and gasses may penetrate into the matrix and it can reduce the durability of concrete structures. Cracks also can grow wider and exposed the reinforcement to the environment and once the reinforcement starts to corrode, a total collapse of structure may occur. Self-healing concrete would be beneficial in order to solve crack problem and it possesses some natural autogenous healing properties. However, healing only effective when water is available, difficult to control and limited to only small cracks [4]. Self-healing of cracks in cementitious materials can be divided into four categories which are self-healing based on adhesive agents, self-healing based on bacteria, self-healing based on mineral admixtures and autogenous self-healing [5].

Self-healing based on adhesive agents

A researcher stated that self-healing based on adhesive agents can be either a one-component or two-component agents, or even a multi-component agents [5]. One of the adhesive agents used for self-healing process is epoxy. In some investigations, a two-component epoxy was encapsulated and pre-embedded in concrete for self-healing [6]. Both components of the epoxy will be released and mixed with each other when the capsules became intersected by cracks. The components then reacted and hardened to heal the cracks. However, the reaction can be negatively influenced as the ratio of these two components leaking into the cracks cannot be controlled and the optimum mixing could not be achieved [2].

Self-healing based on bacteria

Bacteria can be used to induce precipitation of Calcium Carbonate ($CaCO_3$) to repair cracks in concrete [7]. These self-healing agents can lie dormant within the concrete for up to 200 years. Self-healing agents react when a concrete structure is crack and after cracks occur, water will seep through the cracks and the spores of the bacteria germinate on contact with water and nutrients [8]. After activated, the bacteria start to feed on the calcium lactate. The soluble calcium lactate is converted to insoluble limestone and the limestone solidifies on the cracked surface and seal it up [8]. Figure 1 shows the mineralization and repair through bacteria secreations.

$$CaO + H_20 \longrightarrow Ca(OH)_2 \quad (1)$$

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_20 \quad (2)$$

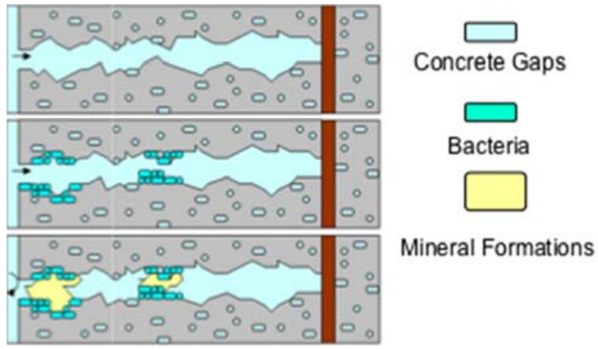

Figure 1: Mineralization and repair through bacteria secretions [9].

A researcher stated that the bacteria should be protected against the alkaline environment in concrete and the decreasing space in the matrix when hydration of cement proceeds [2]. When bacteria spores directly added into concrete, their lifetime can dramatically decreased from 50 years to only a few months. This is caused by the hydration of cement grains. As the cement grains hydrate, most of pores becomes smaller than bacterium spores with the size of 1μm, which causes the cell to collapse[10].

Self-healing based on mineral admixtures

The self-healing based on mineral admixtures can be divided into two groups which are expansive additive and crystalline additive [11]. Expansive additive is the volume of the reaction products is larger than that of the admixtures itself and the expansion depends on the composition of the admixtures [12]. Meanwhile crystalline additive, its components can react with Ca(OH)2 to form crystalline products and it stated that crystalline additive is a cementitious material which contains reactive silica and some crystalline catalysts [11]. These mineral admixtures lead to a remarkable improvement of water tightness of cracks due to self-healing. The advantages of using mineral admixtures for self-healing are self-healing of crack contributed by these minerals proceeds fast because the minerals are able to react intensively with water and the efficiency of self-healing will definitely improves [5].

However, there are some technical problems of this type of self-healing. If the materials are directly added into the concrete mixtures without any protection, they will immediately start to react and causes these added minerals will be consumed before cracking [12]. Other than that, the expansion of the additive causing the expansion to occur in the interior of the concrete matrix which could cause damage [13]. Therefore, when applying mineral admixtures to realize the self-healing, pre-processing like encapsulation is necessary [5].

Autogenous self-healing

Autogenous crack healing can be mainly caused by two mechanisms which are hydration of unhydrated cement particles and dissolution and subsequent carbonation of $Ca(OH)_2$ [14,15]. At a later age, calcium carbonate ($CaCO_3$) precipitation becomes the major mechanism[16]. Researchers agree that for each mechanism to occur the presence of water is essential [4].

The maximum crack width that can be healed by autogenous healing was different reported by many researchers. However, from the aforementioned studies, narrower cracks are more likely to be completely healed by autogenous healing [4]. The effect of crack closure on the autogenous healing efficiency and improve healing was obtained when compressive forces were used to make both crack faces in contact with each other [17]. Figure 2 shows the mechanism of autogenous healing. Firstly, intrinsic self-healing approaches and improved autogenous healing by restriction of the crack width. After that, water was needed for the autogenous healing to occur. Lastly, a process of improving hydration and crystallization.

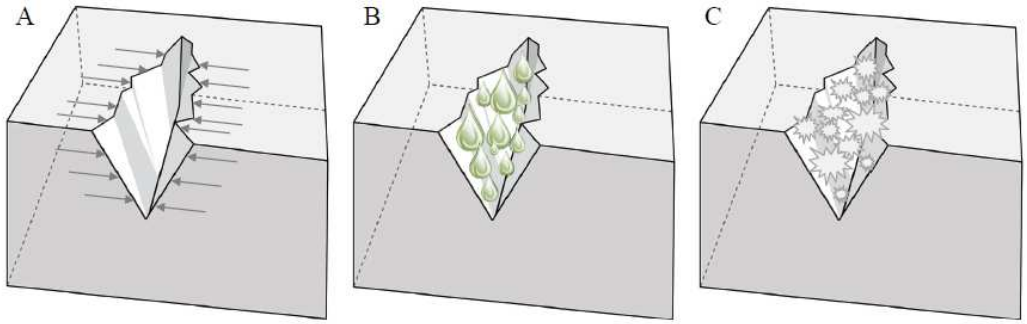

Figure 2: Mechanism of autogenous healing [4]

Methodology

In this study, the fresh properties of concrete were tested for its workability. The workability can be determined using slump test. Meanwhile, the harden properties of concrete were tested using compressive strength test, flexural test, ultrasonic pulse velocity test and lastly the expansion and shrinkage test.

Materials

The materials used for this study were blended cement, effective microorganism (EM), water, 10mm crushed granite and sand. The blended cement was manufactured by grinding Portland Cement clinker and other carefully selected secondary constituents (pozzolanic materials, fly ash and other constituents permitted under BS EN 197-1:2000-CEM II/B-M 32.5R). Meanwhile, the EM used was obtained from the available EM in the market. The constituents of EM include lactic acid bacteria, photosynthetic bacteria, yeast and beneficial microorganisms that exist naturally in the environment. The coarse aggregate has nominal size 10mm was based on the BS882. The percentage of sand passing 600µm sieve was 57%. The aggregates were placed in the laboratory to maintain the uniformity of the moisture condition of the aggregates.

Concrete Mix Design

In this study, there are two (2) types of concrete mix which are blended cement concrete (BCC) and effective microorganism blended cement concrete (EMBCC). BCC is blended cement concrete without any addition of EM meanwhile EMBCC is blended cement concrete with addition of EM. The addition of EM in the concrete mix design was done by replacing 10% of the quantity of water. The characteristic strength of concrete designed was 30N/mm². The concrete mix constituents are tabulated in Table 1.

Table 1: Concrete mix constituents

Type of concrete mix	Amount (Kg/m³)					
	Blended cement	Water	Effective microorganism	w/c	Fine aggregate	Coarse aggregate
BCC	454.5	250	0	0.55	785	851
EMBCC	454.5	225	25	0.55	785	851

Preparation of Concrete and Test Specimens

The size of cube moulds is 100 x 100 x 100mm meanwhile the size of the prism moulds is 100 x 100 x 500mm. The total amount of specimens cast were 36 cubes and 16 prisms comprise of 18 cubes and 8 prisms for each type of mix. The steps taken to cast concrete are firstly, the steel moulds of cube and prism for the test specimen were cleaned thoroughly and the interior faces was oiled. After the concrete being mixed, the mould was filled with concrete in 3 layers. Each layer of concrete was compacted using compactor machine. After the top surface of the test specimens has been compacted, the surface of the concrete was finished level with hand trowel. After finish casting, the test specimens were left undisturbed for about 24 hours in the laboratory to set and harden. After 24 hours or one day the mould was demoulded and the specimens were cured.

Curing method

The test specimens were cured in two techniques until their compressive strength determined at 3,7 and 28 days. The two techniques are water curing and air curing. Water curing method is when the test specimens were submerged in the curing tank using tap water. Meanwhile, for air curing method the test specimens were put openly in the laboratory at room temperature. Figure 3 shows the test specimen after a few days of curing.

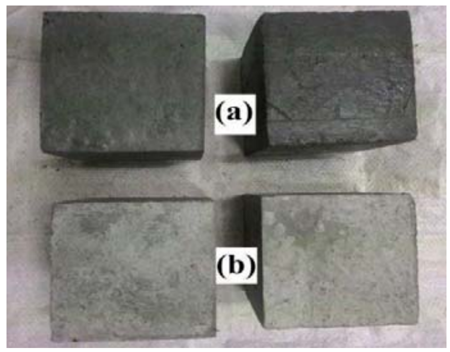

Figure 3: Test specimens after a few days of curing (a) Water curing and (b) Air curing

Based on Figure 3, it can be clearly seen that the type of curing affect the colour of the test specimens. The cube undergone water curing has darker colour than the cube in air curing.

Results and Discussion

This section discusses the data and results collected from the experiment. All data and results were recorded and then presented in the graph and table forms to show the relationship between the tested parameters.

Fresh concrete properties

The concrete was tested to achieve the desired workability. Workability is an important property in concrete since a workable mix will produce concrete, which can be well compacted, transported and placed without segregation. The workability of BCC and EMBCC concretes were discussed in this section.

Figure 4 shows the relationship between the average slump and type of mixes which were BCC and EMBCC. The BCC mix has higher degree of workability and satisfying the targeted slump. Meanwhile, the EMBCC mix has higher slump than the BCC mix, however the EMBCC slump has exceed the range of 60 to 180mm slump. It shows that the EM has affected the workability of EMBCC by improving the workability of concrete mix. In addition, the blended cement containing fly ash might improve the workability of concrete mix. Figure 5 shows the types of slump for blended cement concrete and effective microorganism blended cement concrete. The BCC mix was categorized as true slump meanwhile the EMBCC mix was categorized as collapse slump.

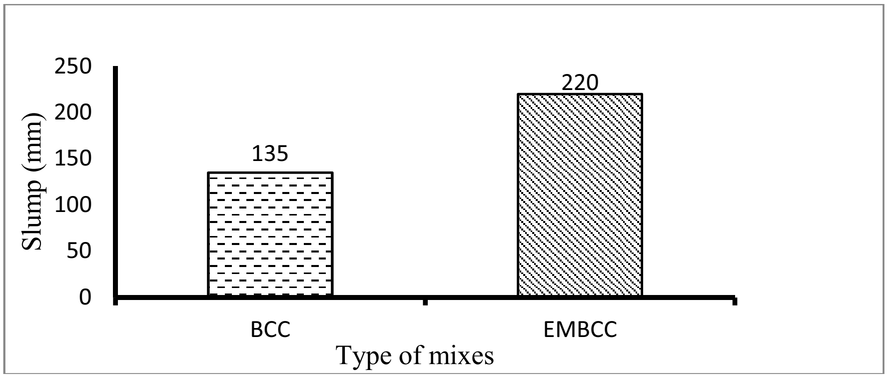

Figure 4: Average slump versus type of mixes

Figure 5: Types of slump for (a) Blended cement concrete and (b) Effective microorganism blended cement concrete

Harden concrete properties

In this study, the test conducted to determine the harden concrete properties are compressive strength test, flexural test, ultrasonic pulse velocity test and expansion and shrinkage test. The tests were conducted after a few days the specimens being cured.

Compressive strength test. The compressive strength test was conducted using compression machine with a constant rate of 6 kN/s until the specimen crushed at the maximum load applied. The compressive strength was determined for both type of mix at the age of 3, 7 and 28 days. Meanwhile, the modified compressive strength was tested at the age of 7 and 28 days using the broken concrete prism after flexural strength test. The results of the compressive strength and modified compressive strength for mixes blended cement concrete in water (BCCW), blended cement concrete in air (BCCA), effective microorganism blended cement concrete in water (EMBCCW) and effective microorganism blended cement concrete in air (EMBCCA) are tabulated at Table 2.

Table 2: Cube and modified compressive strength

Type of mixes	Compressive Strength (MPa)			Strength ratio (%)		Modified Compressive Strength (MPa)		Strength ratio (%)
	3 days	7 days	28 days	3/28	7/28	7 days	28 days	7/28
BCCW	20.9	30.9	35.4	59	87	24.7	31.9	77
BCCA	21.1	28.2	29.6	71	95	28.6	30.0	95
EMBCCW	12.4	16.9	28.1	44	60	15.7	26.2	60
EMBCCA	12.4	17.7	23.2	53	76	14.9	22.4	67

Table 2 shows the results of cube and modified compressive strength of all mixes. The table shows that the strength ratio at the age of 7 days for BCCA was higher than BCCW with 95% and 87%, respectively. Meanwhile, the strength ratio of EMBCCA was also higher than EMBCCW at the age of 7 days which were 76% and 60%, respectively. However, the EMBCCW did not achieve at least 70% of the 28 day strength might be due to the concrete was not compacted properly. Other than that, the strength ratio for the BCCA was higher than BCCW at the age of 3 days with 0.71 and 0.59, respectively. The strength ratio EMBCCA was higher than EMBCCW at the age of 3 days which gained 0.53 and 0.44, respectively. However, the strength for both types of concrete mixes had achieved more than 40% from the 28day concrete strength.

Based on Table 2, the strength ratio of modified compressive strength for BCCA were higher than BCCW with 0.95 and 0.77, respectively. Meanwhile, strength ratio of EMBCCA was slightly higher than EMBCCW which gained 0.67 and 0.60, respectively. However, the strength of the EMBCCW and EMBCCA did not achieved 70% of concrete strength at the age of 7 days might be due to specimen preparation error.

At the same time, Figure 6 was plotted based on the results of compressive strength. Figure 6 and Table 2 show that the compressive strength for both type of mixes were increased proportionally with the increase of concrete age. Based on Figure 6, the BCCW has the highest compressive strength than other type of mixes. Meanwhile the EMBCCA has the lowest compressive strength than other type of mixes. In addition, from the Figure 6 it can be clearly seen that the concrete undergone water curing had higher compressive strength than concrete in air curing.

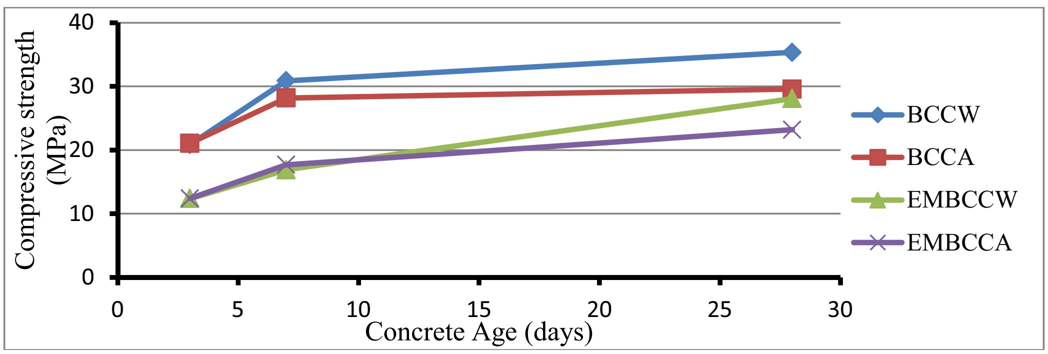

Figure 6: Compressive strength versus concrete age

Figure 7 shows the relationship between modified compressive strength and the concrete age. Based on Figure 4.4, the EMBCC has a huge different with the BCC when the concrete at the age of 7 days where the EMBCC were lower than the BCC. However, when concrete at the age of 28 days, the compressive strengty of EMBCC was slightly lower than the BCC. In addition, the concrete specimen which undergone water curing has higher modified compressive strength value than the concrete specimen undergone air curing.

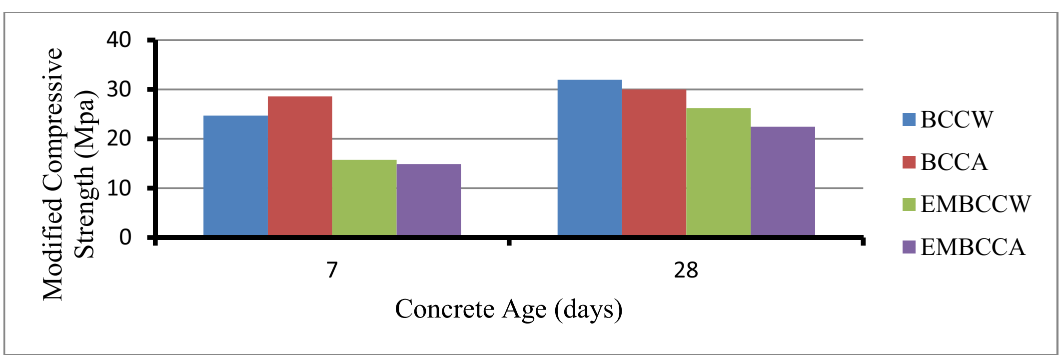

Figure 7: Modified compressive strength versus concrete age

Table 3 shows the compressive strength of the pre-crack concrete. At the age of 7 days, PEMBCC was loaded with 50% load from the compressive strength of EMBCC at age of concrete 7 days. As an example, during the age of concrete at 7 days the EMBCC was tested until it fails using compression machine to get the value of concrete compressive strength. After that, 50% from the compressive strength was used to pre-crack the cube. Based on Table 3, the strength ratios of PEMBCCW and PEMBCCA at the age of 7 days was lower due to concrete specimen was not tested until failure.

Table 3: Compressive strength of pre-crack concrete

Type of mixes	Compressive Strength (MPa)		Strength ratio (%)
	7 days	28 days	7/28
PEMBCCW	7.2	24.2	30
PEMBCCA	7.9	21.6	37

Figure 8 shows the relationship of compressive strength of pre-crack concrete and concrete age. The compressive strength of the pre-crack effective microorganism blended cement concrete in water (PEMBCCW) was higher than the pre-crack effective microorganism blended cement in air (PEMBCCA) due to the PEMBCCW had undergone water curing meanwhile PEMBCCA had undergone air curing that affects the hydration process of cement.

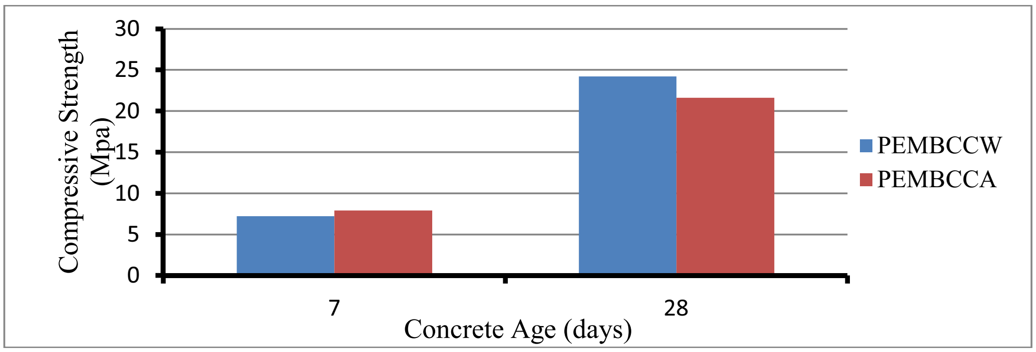

Figure 8: Compressive strength of pre-crack concrete versus concrete age

Flexural strength test. The flexural strength test was conducted with a loading constant rate of 0.13 kN/s. The flexural strength test was conducted for both type of concrete mixes at the age of 7 and 28 days. The detail of test results are tabulated in the Table 4.

Table 4: Flexural strength of concrete

Type of mixes	Flexural Strength (MPa)		Strength ratio (%)
	7 days	28 days	7/28
BCCW	2.1	2.9	72
BCCA	1.8	2.8	64
EMBCCW	1.4	2.4	58
EMBCCA	1.1	1.3	85

Table 4 shows the result of flexural strength of all concrete mixes. The strength of BCCW was higher than BCCA which gained 72% and 64%, respectively at the age of 7 days. Meanwhile, the EMBCCA has higher strength than EMBCCW which were 85% and 58%, respectively.

Based on Figure 9, the bar chart represents the flexural strength with the difference of concrete age. Figure 9 shows that the flexural strength increased proportionally with increasing of concrete age. Based on Figure 9, the flexural strength of BCCW was the highest compared to the other concretes at the age of concrete 7 and 28 days. Moreover, the BCC specimen has higher flexural strength in both curing methods than the EMBCC specimen. In addition, the BCCW and EMBCCW specimens have higher flexural strength than BCCA and EMBCCA, respectively. It shows that the specimen undergone water curing method has higher flexural strength than the specimens undergone air curing method due to different level of cement hydration process.

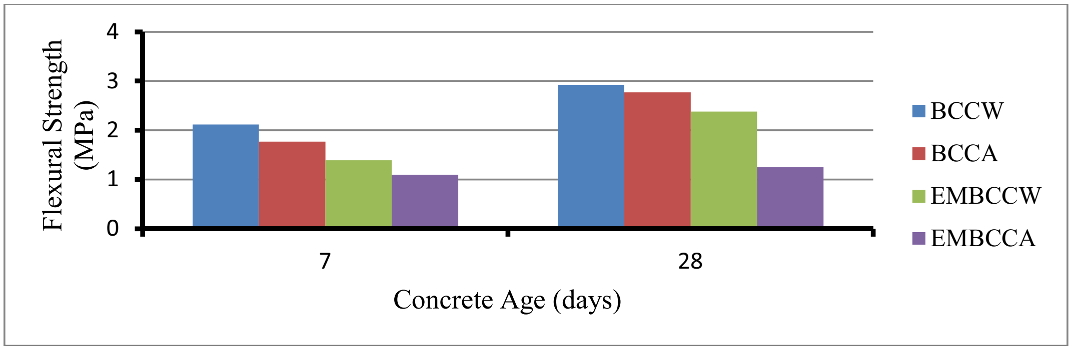

Figure 9: Flexural strength versus concrete age

Ultrasonic pulse velocity (UPV) test. The UPV test was used to evaluate the effectiveness of curing and effective microorganism as crack repair agent. The test was conducted to BCC and EMBCC concretes for both cube and prism.

UPV of cube specimen

The UPV test of cubes were conducted at a certain age of concrete. Figure 10 shows the relationship of UPV and concrete age. Based on Figure 10, the EMBCCW, BCW and PEMBCCW have slightly similar value of UPV. However, the EMBCW has the highest value of UPV at the age of 28 days. Then, followed by EMBCCA and BCCA which also have slightly different value of UPV. The PEMBCCA has the lowest UPV value compared to other type of concretes. Figure 10 shows the concrete undergone water curing method which are BCCW, EMBCCW, PEMBCCW have higher UPV value than concrete undergone air curing method which are BCCA, EMBCCA and PEMBCCA.

Table 5 shows the UPV value of BCC and EMBCC specimens and Table 6 shows the UPV value of PEMBCC specimen. Based on Table 6, the pre-crack was done when the concrete at the age of 7 days. The UPV values were taken before and after the pre-crack process. Table 6 shows that there were dropped of UPV value after the pre-crack process which means there was a crack in the concrete because crack causing the diffraction of pulse and reduced its velocity. After a few days of curing, the UPV value started to increase possibly because the hydration of cement and the reaction of EM in the concrete.

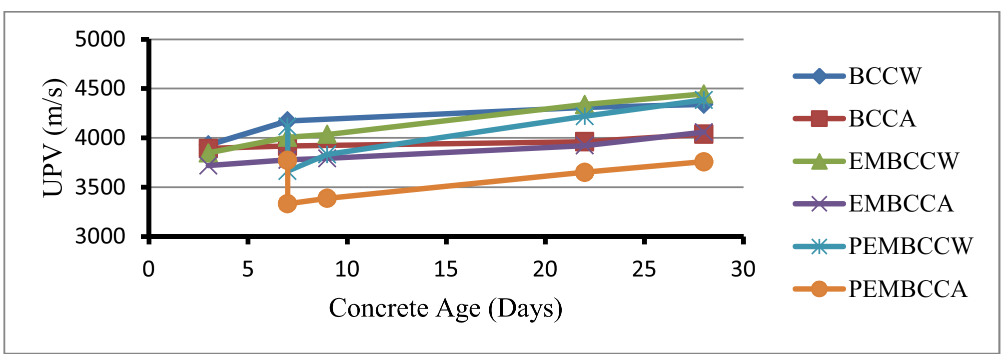

Figure 10: UPV versus concrete age

Table 5: UPV of BCC and EMBCC

Type of mixes	UPV, m/s		
	3 days	7 days	28 days
BCCW	3928	4173	4341
BCCA	3893	3917	4038
EMBCCW	3847	4005	4446
EMBCCA	3720	3777	4058

Table 6: UPV of pre-crack concrete

Type of mixes	UPV, m/s			
	7 days (before pre-crack)	7 days (after pre-crack)	22 days	28 days
EMBCCW	4116	3662	4220	4385
EMBCCA	3774	3333	3652	3759

UPV of prism specimen

The UPV value of prism was taken at a certain period of concrete age. Figure 11 shows the relationship of UPV value of prism and concrete age and Table 7 shows the UPV value of prism. Based on Figure 11, the UPV value of BCCW specimen was the highest and followed with slightly different by EMBCCW. Meanwhile, the UPV value of EMBCCA was the lowest than the other type of concretes. Based on Table 7, the UPV value of BCCW and EMBCCW which undergone water curing has higher value than the concrete undergone air curing which are BCCA and EMBCCA. Again, this was due to the degree of cement hydration process between water and air curing process.

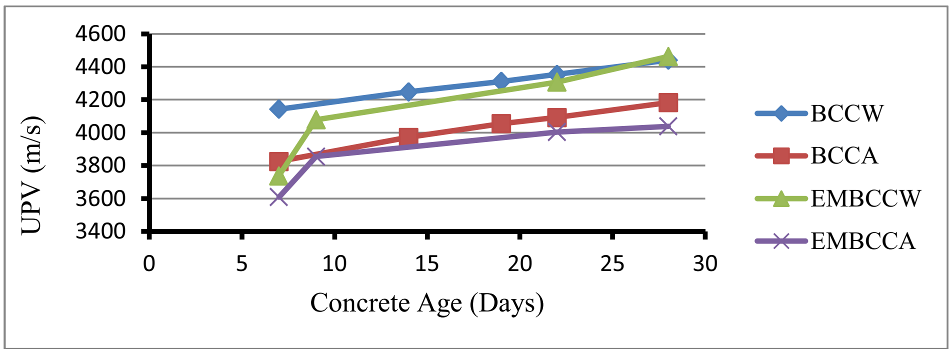

Figure 11: UPV of prism versus concrete age

Table 7: UPV of prism

Type of mixes	UPV (m/s)		
	7 days	22 days	28 days
BCCW	4142	4354	4441
BCCA	3826	4093	4183
EMBCCW	3738	4308	4462
EMBCCA	3609	4004	4039

Expansion and shrinkage test. The expansion and shrinkage test was conducted to investigate the prism expansion and shrinkage due to different exposures. The prism which undergone water curing is categorized as expansion meanwhile prism undergone air curing categorized as shrinkage. The data collected from the test are tabulated at Table 8, Table 9 and Figure 12.

Table 8: Expansion and shrinkage BCC

Age (days)	Expansion ($x10^{-6}$)	Shrinkage ($x10^{-6}$)
3	50.1	-29.5
4	139.6	-72.5
7	204.1	-139.6
14	322.2	-161.1
16	402.8	-188.0
18	456.5	-188.0
22	494.0	-204.1
28	499.4	-220.2

Table 9: Expansion and shrinkage EMBCC

Age (days)	Expansion ($x10^{-6}$)	Shrinkage ($x10^{-6}$)
3	12.1	-8.1
6	24.2	-48.3
7	32.2	-51.0
9	43.0	-75.2
22	45.6	-142.3
24	61.8	-150.4
28	80.6	-153

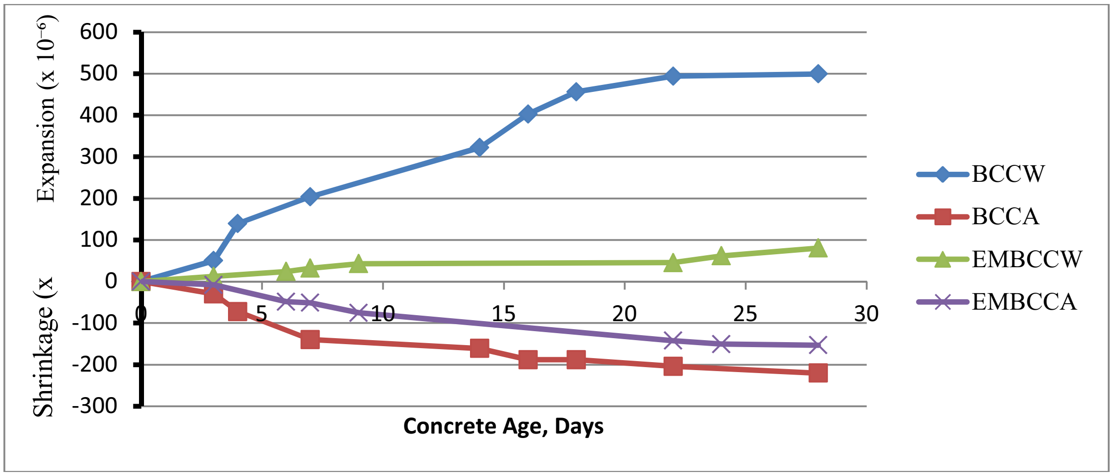

Figure 12: Expansion and shrinkage versus concrete age

Tables 8 and 9 show the expansion and shrinkage value of BCC and EMBCC, respectively. Figure 12 shows the relationship of expansion and shrinkage and concrete at different ages. Based on Figure 12, the BCCW has higher expansion of concrete than EMBCCW which possibly due to existence of pores. The existence of pores causes the water to penetrate into the concrete and expand. Figure 12 shows the EMBCCA has lower shrinkage value than BCCA which probably because of the existence of EM that fill the cracks and reduce the shrinkage of the concrete.

Conclusion

The conclusions that can be derived for this study are as follows:

1. Effective microorganism blended cement concrete has high workability than blended cement concrete. Thus, the inclusion of EM has increased the workability of the blended cement concrete.
2. Blended cement concrete has higher compressive strength than effective microorganism blended cement concrete. The use of EM in the blended cement concrete does not increased the compressive strength of the concrete.
3. Flexural strength of blended cement concrete was higher than the effective microorganism blended cement concrete.
4. UPV value of effective microorganism blended cement concrete was higher than the UPV value of the blended cement concrete.
5. Expansion and shrinkage of blended cement concrete were higher than the effective microorganism blended cement concrete. Thus, the addition of EM has possitive effect by decreasing the expansion and shrinkage of concrete
6. Different method of curing affect the colour of the specimens which water curing specimen was darker than the air curing specimens. In addition, concrete undergone water curing has higher value of compressive strength, flexural strength and UPV than concrete in air curing.

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