Flexural Strength of Lightweight Foamed Concrete using cement to sand ratio 3:1 with Inclusion of Polypropylene Fibre

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Abstract. Lightweight foamed concrete (LFC) is normally created from mixing stable foam to cement paste or mortar. LFC is very light but its strength is decreasing due to the reduction of density. This paper describes the investigation of mechanical properties of LFC with the inclusion of polypropylene fibres such as compressive strength and flexural strength. The cement to sand ratio used in this study was 3:1. All the specimens were tested using the targeted density of 1500 kg/m^3. Polypropylene fibre with 0.25% and 0.40% volume fraction were added to LFC design mixtures. The foamed concrete was designed to achieve the result of effect from volume fraction of polypropylene fibres used with different curing age of 7, 28 and 60 days. The experiment was setup to examine its mechanical properties with accordance to ASTM standard method of testing. From the result analyzed, the inclusion of polypropylene fibre into the lightweight foamed concrete samples has more contribution in flexural strength as compared to control sample without the fibres. The 0.25% and 0.40% percentage of polypropylene fibres added is proven to have contributed more on flexural of LFC. However, 0.25% is an optimal volume of fibres that should be included to contribute the maximum flexural strength of the lightweight foamed concrete.

Introduction

The uses of lightweight concrete has been a feature in the construction industry for centuries, but like other material there are high expectations of the performance raised and now construction industry demanding a consistent, reliable material and predictable characteristics. It was first introduced by the Romans in the second century where 'The Pantheon' has been constructed using pumice, the most common type of aggregate used in that particular year. From there on, the use of lightweight concrete has been widely spread across other countries such as USA, United Kingdom and Sweden [1].

Lightweight foamed concrete can be known as a type of concrete that included an expanding agent in it to increase the volume of the mixture but on the same time, it gives additional qualities such as lessened the dead weight. Structural lightweight concrete has an in-place density (unit weight) on the order of 300 kg/m^3 up to 1840 kg/m^3; 87 to 23% lighter compared to normal weight concrete with a density in the range of 2240 kg/m^3 to 2400 kg/m^3 [2].

Lightweight foamed concrete is normally being created from mixing stable foam to cement paste or mortar. This action generates small-enclosed air bubbles within the mortar thereby making it lighter and possessing special properties such as low thermal conductivity and high fire resistance. It has been stated that foamed concrete is classified as having an air content of more than 25% [3]. Foamed concrete may have densities ranging from as low as 300kg/m^3 to as high as 1800kg/m^3.

Foam concrete need minimum quantity of aggregate or sometimes no aggregates was used, hence it is lightweight and high flow ability. To mix a stable foam concrete, it depends on many factors such as, method of foam preparation, selection of foaming agent, addition for uniform air-voids distribution, material grade and mixture design ratio [4].

Figure 1: Normal concrete

Figure 2: Foam concrete

Fibres inclusion in concrete is well known to have contribution towards properties of concrete. Several studies have proved the effectiveness of adding fibres into concrete mixes where some of the studies resulted in mechanical and durability properties enhancement of concrete. There are two types of fibres usually included in concrete which are the synthetic and natural type of fibres and they have their own advantages in the concrete matrix proportioning of cement composites. Synthetic fibres known as a man-made fibres from researches and developments of textile industries and it was first reported to be a component of construction materials in 1965 [5].

The utilization of synthetic fibre reinforced concrete is presently exists worldwide due to its promising characteristic of optimizing the mechanical properties of concrete. In comparison of synthetic fibres, natural fibres are known to be more environmental friendly. That is why they are currently getting a lot of attention for replacing synthetic fibres [6]. It has been reported that natural fibres have many advantages such as low density, recyclable and biodegradable compared to the synthetic fibres [7]. Besides that, natural fibre exhibit many advantages properties and offer considerable reduction on the cost and benefit associated with processing compared to synthetic fibre [8].

Background Problems

LFC is very light but its strength is reducing due to the reduced density. However, the presence of fibre in concrete matrix can attribute the improvement of the mechanical properties of the lightweight concrete [9]. Therefore, the inclusion of polypropylene fibre is expected to improve or modify the mechanical properties of foam concrete.

Figure 3: Polypropylene fibre

To achieve this aim, the study was carried out based on the following objectives:

i. To produce lightweight foamed concrete using cement-sand ratio (3:1) with 1500 kg/m^3 density.

ii. To obtain optimum w/c ratios for various percentage of Polypropylene Fibre in Lightweight Foamed Concrete.
iii. To study the effects of Polypropylene fibre on mechanical properties of lightweight foamed concrete.

There are 3 categories of foam concrete mixes prepared in this study involved 0%, 0.25% and 0.40% of polypropylene fibre using cement to sand ratio 3:1. The density for all samples were controlled to 1500 kg/m^3 ± 100 kg/m^3.

Experimental Program

The production of LWC in this study basically divided into two stages; (i) trial mixes using water to cement ratio 0.30 to 0.40 to get optimal mixes and (ii) flexural test using optimum water to cement ratio in mix proportion. The materials used was as the same as for both stages.

Materials

The production of lightweight foamed concrete with cement-sand ratio (3:1) made from six types of raw material which are Ordinary Portland Cement (OPC), sand, water, silica fume, super-plasticizer and foam.

Cement. Ordinary Portland Cement (OPC) was used throughout the study. The OPC used complied with Type I Portland cement in accordance with ASTM C150 (ASTM 2005).

Sand (oven dry 100% passing through 0.60 mm sieve size). Only fine sand was used throughout the production process of lightweight foamed concrete. The sand was dried in an oven at the temperature of 105 °C ± 5 °C for at least 24 hours to remove the moisture in it. The dried sand was then sieved through a 600 μm sieve.

Water. The water used shouldn’t contain any substance as the presence of any other substance can be harmful to the process of hydration of cement and durability of concrete.

Silica fume. Silica fume is added about (10% of cement weight) to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance.

Super plasticizer (SP) - polycarboxylic ether. The new generation of this kind of admixtures is represented by polycarboxylate ether-based superplasticizers (PCEs). With a relatively low dosage (1% by cement weight) they allow a water reduction up to 40%, due to their chemical structure which enables good particle dispersion.

Foam agent. Foam is a form of stable bubbles, produced by mixing foaming agent and water in foam generator. The purpose of the foam is to control the density of lightweight foamed concrete by incorporating dry preformed stable foam into fresh lightweight foamed concrete. For this study, the ratio of foaming agent to water is 0.1 kg: 3 kg (1:30) by volume.

Polypropylene Fibre. Chopped cylindrical Polypropylene Fibre (PP) with 19 mm of length, 22 μm of diameter width crossing were used in this investigation. Characteristic of tensile strength of fibre is 400 N/mm^2 with 0.9 kg/dm^3 density. In this investigation, dosage 0.25 % and 0.40 % of PP was added into each sample of foamed concrete with density of 1500 kg/m^3.

Trial Mix Proportion

The mix proportion with cement-sand ratio (3:1) of the lightweight foamed concrete was used throughout the study. Trial mixes with various water-cement ratio which is 0.3, 0.32, 0.34, 0.36, 0.38, and 0.40 were carried out. The optimum mix proportion was determined based on density and strength of lightweight foamed concrete.

The trial mixes consisted of three types of trial mixes which are foamed concrete with 0%, 0.25% and 0.40% of Polypropylene Fibre. The samples for each mix proportions were cured in water tank for 7 days before undergoing compressive strength test.

Fresh Concrete Properties Test

Flow Table Test (ASTM C1437) [10]. Flow table test was conducted by using a flow table and mould. The flow table was carefully wiped clean and dry, and the flow mould was placed at the center of the flow table. A layer of mortar was placed about 2 mm (1 in.) in thickness in the mould and being tamped 20 times with the tamper. The tamping pressure should be just sufficient to ensured uniform filling of the mould. Then the process was repeated for the second layer of mortar.

Any excess of the mortar was cut off to a plane surface flush with the top of the mould. The table top was wiped clean and dry, being especially careful to remove any water from around the edge of the flow mould and the mould was lifted away from the mortar 1 min after completing the mixing operation. The table was immediately dropped 25 times.

Inverted Slump Test (ASTM C995) [11]. The inverted slump test was conducted by using a slump cone and flat base plate as complied with ASTM C995 (2001). Slump cone was placed inverted and placed at the center of the base plate. The slump cone then filled with fresh lightweight foamed concrete until it was fully filled. Any excessive fresh lightweight foamed concrete was struck off from the surface of the slump cone and the inverted slump cone was lifted to 1 ft height. The four angle of dimension of fresh lightweight foamed concrete spread was measured and recorded.

Hardened Concrete Testing

Compression Test (ASTM C39) [12]. The maximum load carried and compressive strength by the specimen was recorded and calculated using formula as shown in Equation 1 below.

$$f'c = \frac{P}{A} \qquad (1)$$

Where;
f'c = Compressive strength, MPa
P = Maximum load carried by the specimen, N
A = Surface area of specimen that carried load, mm^2
= width (mm) × thickness (mm)

Figure 4: Setup for compression test

Flexural Strength Test (ASTM C293) [13]. After obtaining optimum water-cement ratio during trial mixes, it is used into the production of prism samples for all categories. The flexural strength test was performed on rectangular specimens with dimensions of height (h) and width (w) 40 mm and length (l) 160 mm. Specimens were water cured for 7, 28 and 90 days before undergoing the test session. The effects of Polypropylene Fibre into lightweight foamed concrete on its engineering properties in terms of flexural strength was discussed at the end of the chapter.

Table 1: Design Mix Proportions for mechanical properties

Mix details	**Cement-Sand Ratio**	**Water-Cement Ratio**	**Number of samples**	**Volume of Polypropylene Fibre (g)**
LFC-CS[1]	3:1	0.34	3	0
LFC-0.25PF[2]	3:1	0.32	3	5.18
LFC-0.40PF[3]	3:1	0.32	3	8.29

Note:
[1]LFC-CS = LFC with 0% of polypropylene fibre added
[2]LFC-0.25PF = LFC with 0.25% of polypropylene fibre added
[3]LFC-0.40PF = LFC with 0.40% of polypropylene fibre added

Flexural Strength Test. The maximum loaded carried by the specimen was recorded and flexural strength was calculated by using formula in Equation 2 below.

$$R = \frac{3PL}{\frac{1}{3}bd^{\frac{1}{3}}} \quad (2)$$

Where;

R = Flexural strength, MPa
P = Maximum applied load indicated by the testing machine, N
L = Span length, mm

Figure 5: Setup for flexural test

Result and Discussion

Flow Table and Inverted Slump Test

Table 2: Design Mix Proportions for mechanical properties

Water to Cement Ratio	Average Flow Table Test Value (cm)		
	0 % PP	**0.25 % PP**	**0.40 % PP**
0.30	19.9	19.9	18
0.32	21.1	20.4	18.5
0.34	24	23.5	22.3
0.36	>25	25	24.5
0.38	>25	>25	25
0.40	>25	>25	>25

Table 3: Design Mix Proportions for mechanical properties

Percentage of PP Fibre (%)	Optimum Water Cement ratio	Inverted slump test(d_2-d_1) (mm)
0	0.34	420-410
0.25	0.32	420-410
0.40	0.32	420-410

Table 1 and 2 shows the result of flow table and inverted slump spread measurement of the fresh concrete. Mostly flow table spread for water to cement ratio 0.36 to 0.40 displayed value of 25 cm above. This result shows that they have exceed the limit of spread which means the fresh concrete was too slurry caused by the excessive water content. This kind of result will lead into the segregation to the samples where the foam and cement are separated as the foam moves upward and the mortar settled at the bottom part.

The inverted slump spread measurement was taken in stages 2 to test the workability of the concrete. The limit of the spread measurement of inverted slump test is 500 mm and all the results shown an acceptable value ranging from 410 mm to 420 mm.

Trial Mixes (Compressive Strength Test)

Figures 4 to 6 show the data of compressive strength in different percentage of Polypropylene fibre inclusion. There is an improvement of strength using water to cement ratio starting 0.30 before it decreases at 0.36 for control LFC and 0.34 for LFC with content 0.25% and 0.4% fraction of Polypropylene fibre. Referring to the graph below, water to cement ratio 0.38 and 0.40 for all LFC samples is greatly higher than the rest of the water-cement ratio because the specimens suffered segregation resulting mortar concrete instead of foamed concrete.

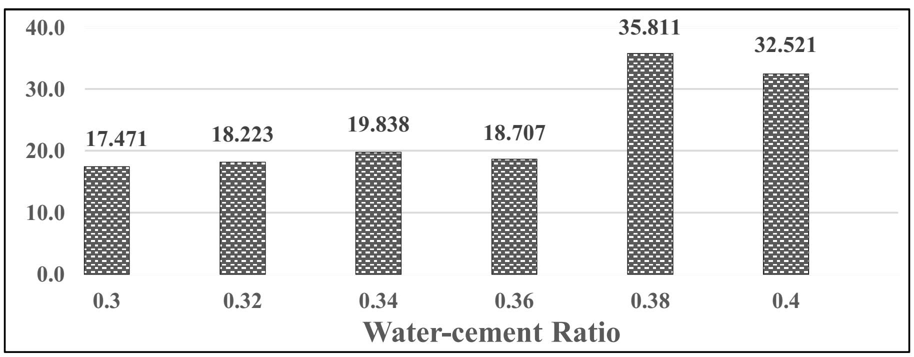

Figure 6: Compressive Strength of LFC-CS

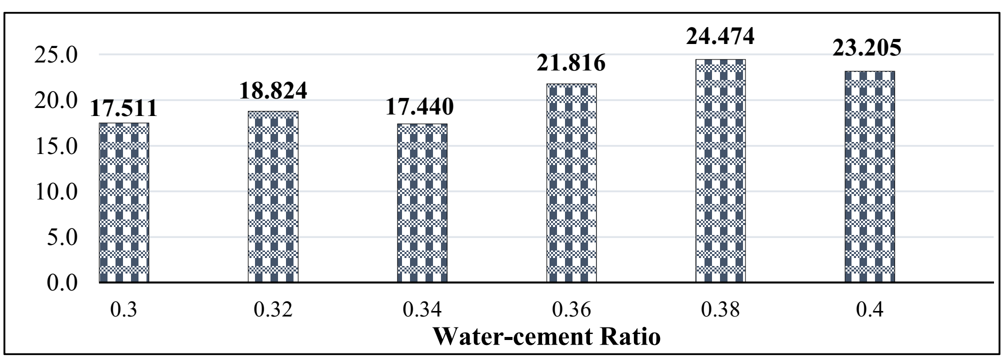

Figure 7: Compressive Strength of LFC-0.25PF

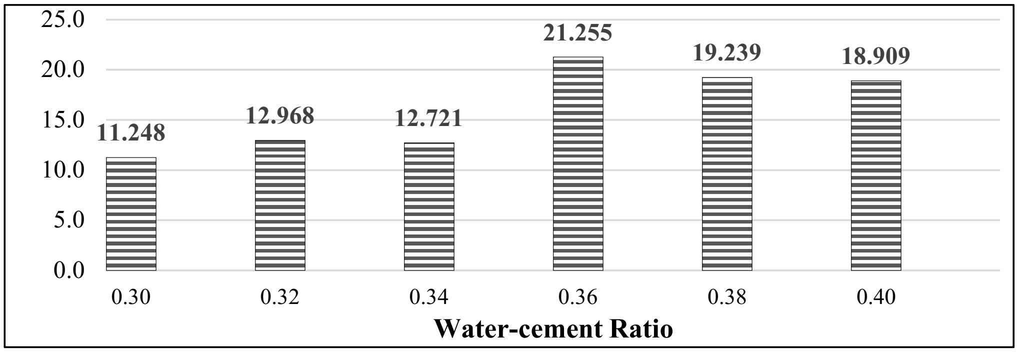

Figure 8: Compressive Strength of LFC-0.40PF

By not considering the segregated samples as lightweight foamed concrete, for LFC-CS, the highest compressive strength was achieved by 0.34 water-cement ratio mix proportion, which is 19.838 MPa. For LFC-0.25PF, the highest compressive strength was achieved by 0.32 water-cement ratio with 18.824 MPa. For LFC-0.40PF, water-cement ratio 0.32 mix proportion was achieved the highest compressive strength which is 13 MPa. It is known that the inclusion of fibres slightly decrease the average compressive strength of concrete [14]. From the data above, it's proven the addition of polypropylene fibre in lightweight foamed concrete decreases the maximum of compressive strength.

Flexural Strength Test

Figures 9 below shows the data of flexural strength in different percentage of Polypropylene fibre inclusion and curing age days. The flexural strength for all samples is increase as the curing age days increase. From the graph below, it shows that 0.25% and 0.4% fraction of polypropylene fibre inclusion improved the flexural strength compare to the control lightweight foamed concrete at every curing age days. This can be proved that the fibre inclusion can enhance the flexural strength of LFC. The highest value of flexural strength is achieved by 0.25% fraction of polypropylene fibre at age 90 days was recorded, while the lowest reading of flexural strength is recorded by control samples of lightweight foamed concrete with 0% fraction of polypropylene fibre volume on 7 days. Visually as well, the difference strength of flexural in higher and lower percentage of polypropylene fibre inclusion of lightweight foamed concrete can be seen at 7days, 28days and 60 days. The 0.25% fraction of polypropylene fibre has higher flexural strength than the 0.40% of polypropylene fibre added in LFC.

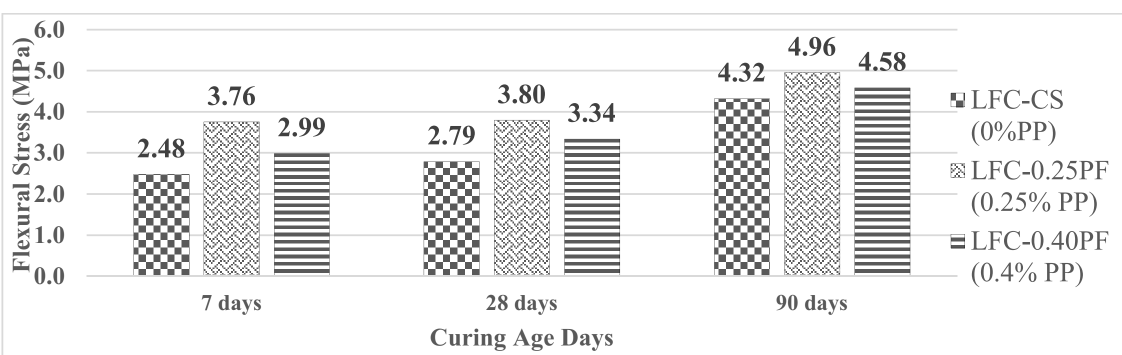

Figure 9: Flexural strength development up to 90 days of Age for LFC-CS, LFC-0.25PF and LFC-0.40PF

Based on the flexural test conducted, the flexural strength increases as the curing age days increased for all samples. From the results, it is observed that the addition of polypropylene fibre in the concrete mix has a positive effect on the flexural strengths of concrete. Addition of polypropylene in low percentages, about 0.25%, increases the flexural strength. However, the flexural strength decreases when 0.40% of polypropylene fibres are added. The sudden decrease in flexural strength is maybe due to the non-uniform fibre distribution in the specimen. It is safe to say that the increase in strength is due to additional load absorbed by the fibres present in the concrete matrix.

Moreover, the specimen with the addition of polypropylene fibre did not cracks into two parts and holds the partner together because of the randomly oriented fibres crossing the cracked section resisted the cracks from spreading and avoid the section from bending.

Figure 10: Complete failure of control specimen without the inclusion of fibre

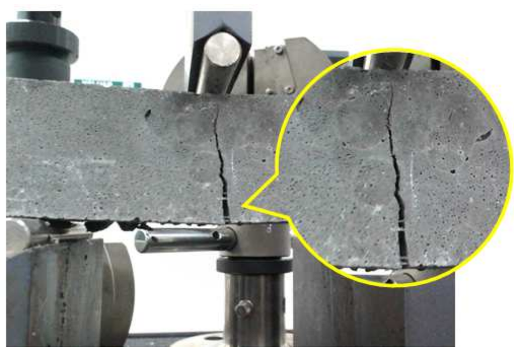

Figure 11: Progress of bending test of specimen with fibre inclusion

Figure 12: Cross section of samples with fibre after test

Conclusions

This experiment was conducted to determine the effect of polypropylene fibre inclusion to the properties of lightweight foamed concrete. There are several significant conclusions are obtained from the experimental result:

1. The production of lightweight foamed concrete using cement-sand ratio (3:1) with 1500 kg/m^3 density successfully achieved by prepared three types of lightweight foamed concrete including LFC-CS, LFC-0.25PF and LFC-0.40PF with controlled density 1500 kg/m^3 ± 100 kg/m^3 ranging from 1400 kg/m^3 to 1600 kg/m^3 as mentioned in the first objective.
2. Following the first objective, this study is conducted to obtain optimum water-cement ratios for various percentage of Polypropylene Fibre (PP) in Lightweight Foamed Concrete. This was achieved by prepared the sample with 0 %, 0.25 % and 0.40 % of polypropylene fibre through trial mixes. The optimal water to cement ratio for LFC-CS, LFC-0.25PF and LFC-0.40PF are 0.34, 0.32 and 0.32 respectively.
3. The mechanical properties covered in this study was flexural strength only. Based on the result, it can be concluded that the inclusion of PP fibre into the LFC can improved in flexural strength of LFC. However, there is an optimal volume of fibres that should be included to contribute the maximum flexural strength of the lightweight foamed concrete.
4. The highest flexural strength was achieved by 0.25% PP fibre at 90 curing days with 4.96 MPa. The flexural strength also increased as the curing age increased.

Limitation and recommendation for future studies

The research work on lightweight foamed concrete with the addition of Polypropylene Fibre is still limited. But it promises a great scope for future studies. Following aspects related to the properties of lightweight foamed concrete need to be further study and investigate.

1. The effect of different cement to sand ratio such as 2:1 and 1:1 with Polypropylene Fibre on engineering properties of LFC.
2. The effect of longer period of curing age on engineering properties of LFC in terms of compressive strength, splitting tensile strength, flexural strength, and Void test.
3. The effect of different types of fibre on engineering properties of LFC in term of compressive strength, splitting tensile strength, flexural strength, initial surface absorption, Poisson's ratio, Poisson's ratio toughness and Void test.

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