Structural Performance of Lightweight Foamed Concrete Slab Strengthening with Fibres: A Review

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Abstract. Light weight foam concrete (LWFC) has a density between 400 kg/m$^3$ to 1600 kg/m$^3$ and has a minimum of 20% entrapped air in volume. The utilization of LWFC makes the building structure light and durable. Fibres can be used as reinforcement in LWFC to increase its structural behaviour in terms of strength and cracking pattern. This paper presents the potential review on the structural behaviour of LWFC consisting fibres. From literature reviews it can be seen that great number of researches used the fibres such as coir, Polyethylene terephthalate (PET), polypropylene (PP), steel, and glass fibres in LWFC. The mechanical and structural properties of LWFC slab were reviewed. From the previous studies it was concluded that LWFC 0.6% glass fibre, 0.4% hybrid steel fibre and 0.3% of coir fibre were optimum where LWFC had high mechanical and structural behaviour of LWFC slab compare to control sample.

1. Introduction
Lightweight foam concrete produced from cement, sand, water and foaming agent. It is a lightweight concrete with lower density of concrete [1]. LWFC has density of 400 kg/m$^3$ to 1600 kg/m$^3$ and a minimum of 20% entrapped air in volume. The micro air voids occupied in LWFC has considerably reduced the weight as the air weight is negligible if compared to the concrete. The heavyweight problem of conventional concrete resolved and lead to a fast construction.

Pollution could occur in many forms and can adversely affect everything if it is not controlled. One of the main pollution’s causes is the massive dumping of solid waste all around the world. The waste problem is going worse in Malaysia as 30000 tons of solid waste is generated every day [2]. The generation of agricultural waste also shows no decreasing sign as the increment of 3% annually was shown that can cause a great impact on the environment if not handled properly. Various preventing actions have been taken to reduce the waste production rate, such as application of fibers in enhancing the concrete properties. Coir, Polyethylene terephthalate (PET), polypropylene (PP), steel, and glass fibers are the common fibers used in concrete modification.
Fibers are well known as fillers in the production of concrete. Filler materials are added to the concrete composition to enhance the cement binding with the concrete materials. It fills up the spaces between particles as and make the concrete well packed. The addition of fiber into concrete can merely enhance the structural strength of concrete such as static flexural strength, impact strength, tensile strength and flexural toughness [3]. Adding fiber to concrete not only increases its material strength but also helps in controlling the concrete crack process. Fibers with low elastic modulus can absorb more energy during cracking due to their elongation behavior. Under other condition, the high modulus fiber can enhance concrete mechanical strength [4].

Reinforcements like plastic and cellulose fibers can improve the energy absorption of composites in the post-cracking stage [4]. Natural fiber possesses the physical and chemical characteristics which can be implemented in the development of reinforced concrete materials. The high modulus fiber such as steel fiber can also be used to increase the tensile and flexural strength of concrete. The expected practical application of these fibers is to increase the strength and control the crack propagation in the slab.

2. Mechanical Properties of LWFC with Fibers.
This section describes the effects of various fibers on the mechanical and structural performance of slab panel. Various fibers such as coir fiber, Polyethylene terephthalate (PET), Polypropylene (PP), steel fiber and glass fiber have great influence on the structural performance of LWFC and the structural behavior of LWFC slab according to previous experimental study as described below.

2.1. Coir fibre
Coir is the common name of coconut fiber which is obtained from coconut (Cocos nucifera), a member of the Areaceae family [5]. Coir fibers are strong and durable due to their high lignin contained in the chemical composition [6]. Lignin is the key to hold holocelluloses tissue together and form a long polymer chain. Furthermore, these polymer chains will overlap in many layers and thus make the it stronger in strength [4].

Study was conducted with different cement-sand-water (1:2:0.55) in research of Mohamad et al. [7]. Foam concrete with 0.1%, 0.2% and 0.3% coir fiber by the total weight of cement were used. The ratio of cement to sand was 1:2 and ratio of cement to water was 0.55, with a target density of 1400kg/m$^3$. The compressive strength at 7, 14 and 28 days were obtained from compressive strength test [8]. Tensile strength and flexural strength at 28 days were obtained from split tensile test and four-point bending test [9].

The compressive strength at 7, 14 and 28 days were significantly improved when coir fiber was added into foam concrete specimen [7]. Compressive strength of foam concrete increased the most for 0.3% coir concrete fiber, and it have 8.1 MPa which is 24.6% higher than the control specimen. The tensile strength recorded were 0.93 MPa, 0.96 MPa, 1.01 MPa and 1.53 MPa for control, 0.1%, 0.2% and 0.3% of coir, respectively. It shows an increasing trend in enhancement of split tensile strength. This may due to addition of fiber into foam concrete provided a better adhesion between concrete matrix and the fiber where a better grid formed between the concrete particles [7]. The summary of previous studies on coir fibre concrete is presented in Table 1.

Modulus of Elasticity (MOE), also referred as Young’s modulus, is the measurement for material stiffness. It is the ability of material in resisting deformation elastically when load was applied. The highest MOE value in research of Mohamad et al. [7] was 17.143 kN/mm$^2$,
belonged to the foam concrete with 0.3% coir fiber inclusion. Also, the higher the percentage of coir fiber, the higher the value of Young’s modulus.

2.2. Polyethylene terephthalate (PET) Fiber
Polyethylene terephthalate or Terylene is the full name for PET which commercialised as DACRON® [10]. It is strong, stiff, flexible, lightweight and colourless thermoplastic that extensively utilized around the world for fiber manufacture. PET has outstanding performance in thermal and chemical resistance. PET made up of repeating polymer long-chains of ethylene glycol (EG) and terephthalic acid (TPA).

De Silva and Prasanthan [11] studied the effect of PET fiber on the mechanical strength of concrete. Figure 1 presented that the compressive strength increased when PET fiber percentage increased, and it underwent a decreasing trend when fiber percentage more than 1.5% was added. The tensile strength kept increasing when the percentage of PET fiber increasing and the maximum percentage was at 1.5 % of PET. This was due to the fiber bridging involved when crack appear, where the fiber will act as the string to hold it from further cracking. This crack control mechanism provides the foam concrete with ductility behaviour. The tensile strength kept increasing when the percentage of PET fiber increasing and the maximum percentage was at 1.5 % of PET. This was due to the fiber bridging involved when crack appear, where the fiber will act as the string to hold it from further cracking. This crack control mechanism provides the foam concrete with ductility behaviour.

![Figure 1. Compressive Strength with PET Fiber](image)

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2.3. Polypropylene (PP) Fiber
Polypropylene or called PP has the commercial name of ACTISITE® and it is very similar to PET where both are colourless, strong, stiff and flexible. Polypropylene has better strength and stiffness if compared with PET [10]. It also exhibits good material characteristic such as high thermal resistance and fatigue resistance. Polypropylene is the polymer chain of propene (CH₃) monomer.
In the research of Memon et al. [12], foam concrete with 0.05 % PP fiber (1600 kg/m$^3$ density) has compressive strength of 6.49 MPa at 28 days, which is 3.38 MPa lower than the control. The same fiber content but with 1800 kg/m$^3$ has compressive strength of 8.25 MPa at 7 days, which is 19.6% lower than the control specimen. Yet, its compressive strength grew and exceeded the compressive strength of the control specimen by 26%, at 28 days. This explained that a lower strength developed when foam concrete was added with 0.05 % of PP fiber. The compressive strength has a direct effect on MOE, where foam concrete with higher compressive strength has a higher MOE. To conclude, adding more fiber will produce a stiffer foam concrete and simultaneously increase its compressive strength.

2.4. Steel fiber
Steel is a very common material used in construction, especially in producing the structural part of building. Steel can be used in fiber form with the concern to increase the rheology or plastic cracking characteristic of concrete, durability, tensile or flexural strength and impact strength [13]. Suhad et al. [14] carried out experiment by using foam concrete reinforced with steel fiber. They used different fiber lengths, which included hooked-end steel fiber (30 mm and 60 mm), micro steel fiber (1.5 mm) and hybrid fiber (all fiber combination). The cement to sand to water ratio were 1:1:0.3 and target density was 1800 kg/m$^3$. In their research, ASTM standards were used for compressive strength test, split tensile strength test, flexural strength test and modulus of elasticity test. They are ASTM C39, ASTM C496, ASTM C79 and ASTM C469/C469M. It was proven that application of steel fiber in foam concrete can enhance its mechanical properties and structural performance.

Suhad et al. [14] findings show that, the hybrid fiber increased the compressive strength of foam concrete the most, which was 38% higher than control specimen. The longer the fiber length for hooked end, the higher the compressive strength of foamed concrete. Compressive strength increased by following the increment of fiber percentage. This is proven that steel fiber of 60mm with 0.4 % fiber content increased the compressive force more than the one with 0.2 % of fiber percentage.

Suhad et al. [14] investigated the tensile strength of foam concrete in another ways, where hybrid fiber with combination of long and short fiber was used in foam concrete production. First observation from the findings was that, hooked-end steel fiber enhanced the split tensile strength more than micro steel fiber. This is due to the hooked end steel fiber provided more friction/adhesion compared with micro steel fiber with smoother surface. Hybrid fiber increased split tensile strength the most by about 3 times compared with the control specimen. The improvement of concrete ductility and stiffness was due to the cross-bridging effect when long and short fiber used together, in Figure 2. The bridging strength at crack was purely based on the fiber’s material strength.

![Figure 2. Cross bridge effect in concrete crack [14]](image-url)
2.5. Glass fiber

Glass fiber is mainly used in manufacturing of exterior facade panels and as precast concrete for architecture. Glass fiber can be a good choice as the fiber in concrete. They are produced through the bottom of a heated platinum tank or bushing in a process in which molten glass is drawn in the form of filaments [15].

Dawood and A. J. [15] had studied the performance of lightweight foamed concrete with glass fiber. They used a ratio of 1:2.25 for cement-to-sand ratio, 0.49 for cement-to-water ratio and micro-glass fiber in percentages of 0.06%, 0.2%, 0.4%, and 0.6%. The specimens have been cured with water bath. Compressive strength test by ASTM C109 on cubes of 50×50×50 mm and flexural strength obtained in compliance with ASTM C 348 with prisms of 40×40×160 mm. The optimum percentage of micro glass fiber was 0.6%. The compressive strength increased when the fiber content increased. This relationship is shown in Figure 3, the compressive strength at 28 days with different admixture. The compressive strength of foamed concrete was increased also when superplasticizer was added.

![Figure 3. Compressive Strength at 28 day [15]](image)

Structural behaviour of LWFC Slab. The flexural strength of foam concrete varied with the different fiber percentage [7]. The higher the proportion of coir fiber, the higher the flexural strength of foam concrete. 0.3% coir is the optimum percentage where it has the highest ultimate flexural load and smallest intensity of flexural crack. The same trend was reported in the research of Dawood and A. J. [15]. The flexural strength in foam concrete series I (without superplastisizer) increased by 5%, 7.19%, 11.37% and 16.14% for F1, F2, F3 and F4 respectively when compared with control specimen, which was 7.48 MPa. Series II (with superplastisizer) having almost the same flexural strength leanings by 7.75%, 10.15%, 12.2% and 15.44% for foam concrete with 0.06%, 0.20%, 0.40% and 0.60% of glass fiber. The flexural strength increased when added with fiber because the fiber form bridges at the crack that prevent further expansion of crack [14].

Moreover, the maximum flexural load obtained in the research of Goh et al. [16] was 62kN, as it had the highest depth for the slab dimension. All the slabs from those reviews generally behaved in ductile manner when subjected to flexural load and flexural crack appeared at the mid-span. Flexural crack appeared and the first crack was occurred at 30 kN load which was half of the ultimate load. The foam concrete panels undergone large deformation before it completely failed. This was proven in its load-deflection profile (Figure 4), and show it ductile behaviour.
3. Conclusion

The mechanical properties of LWFC were improved when fiber was added. The compressive strength, split tensile strength, and modulus of elasticity were found to be directly proportional to the fiber content in LWFC. Whereas LWFC with 0.6% glass fiber had the most improvement in compressive strength, which were 51% (Series I) and 60.7% (Series II) higher than the control specimen. It is possible due to micro glass fiber had better adhesion with the surface of LWFC compared to other fibers. For split tensile strength, the 0.4% hybrid steel fiber increased the most, which was 150% increment. This is because of the cross-bridge effect obtained from hybrid steel fiber that holds the micro and macro crack during the split tensile strength test. Furthermore, 0.3% of coir fiber increased the modulus of elasticity the most, which was 97.8% higher than the control specimen.

Addition of fiber into LWFC enhanced its flexural strength too. Among all the fibers, 0.6% glass fiber enhanced the most for flexural strength of LWFC, which was 19.25% (Series I). This may due to the fiber bridge formed is stronger compared to other fibers. Moreover, the maximum flexural load obtained from those literature reviews was 62kN, in the research of Goh et al. [17] as it had the highest depth for the slab dimension. All the slabs from those reviews generally behaved in ductile manner when subjected to flexural load and flexural crack appeared at the mid-span.

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