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Compressive Strength and Flexural Behaviour of Foamed Concrete Slab Containing Hybrid Fibres

Anis Aqilah[1], Noridah Mohamad[1,*], Muhammad Tahir Lakhiar[2], Ashafaque Ahmed Jhatial[3] and Steafenie George[1]

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn, Parit Raja, Johor, 86400, MALAYSIA

[2]School of Engineering,
Monash University, Subang Jaya, Selangor, MALAYSIA

[3]Department of Civil Engineering,
University of Zagreb, CROATIA

*Corresponding Author

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Abstract: Foam concrete has been used widely in the construction industry, due to its lightweight and easy handling. The foam concrete (FC) mixture in this study can contribute to the sustainability of construction due to the utilization of hybrid fibers, which are coir fiber (CF) and steel fiber (SF). The aim of this study is to investigate the compressive strength, flexural strength and crack pattern of precast foamed concrete slab incorporating with hybrid fibers. The three different mixtures of foam concrete were used to cast three different types of specimens, namely control slab (0% fiber), slab with 3% steel fiber, and slab with 3% steel fiber and 1% coir fiber. Compressive strength test was conducted on the cube specimens while four-point bending test was conducted on the slab specimens. It was found that the compressive strength and ultimate load of FC containing SF and CF were 50% and 134% increased, respectively, compared to the control sample. Meanwhile, cracking pattern shows less cracks appeared on surface of FC slab with 3% SF and 1% CF compared to the control slab. Subsequently the load-deflection profile described that FC-3% SF-1% CF is more ductile compared to the control slab.

Keywords: Foamed Concrete, Hybrid Fibre, Compressive Strength, Ultimate Load, Load-deflection Profile.

Corresponding author: noridah@uthm.edu.my

1. Introduction

Concrete's popularity has kept on increasing over the years due to its flexibility and durability as building's material. However, one of the main problems that concrete has is, it's low strength-to-weight ratio. The density of normal weight concrete ranges from 2200 to 2600 kg/m^3 [1-2] and this high density adds self-weight to the structure. One way to reduce the self-weight of concrete is to make it lighter by incorporating foam in a concrete mixture. Precast foamed concrete (PFC) slab can be defined as a concrete slab which is cast in the factory or some other location which includes an expanding agent in it increase the volume of the mixture. Plain foamed concrete is a brittle material, which results in poor fracture toughness, poor resistance to crack propagation and low impact strength [2]. In this research to enhance the tensile and flexural capacity the hybrid fibre, combination of coir fibre (CF) and steel fibre (SF) were utilized.

Problems occur due to the tendency of concrete materials to crack, which is the result of its brittle nature and low tensile strength. Hybrid fibre are combinations of two types of fibre which is coir fibre and steel fibre. Coir is an abundant, versatile, renewable, inexpensive and biodegradable lignocellulosic fibre used in many industrial applications [3-4]. The innovative idea of this research is to develop green foamed concrete containing CF and SF as filler, with density of 1800 kg/m^3. Foamed concrete in this research was added with hybrid fiber from waste which aimed to investigate its compressive strength and structural performance.

Foamed concrete achieves lower self-weight due to the reduction of density, makes the foamed concrete lightweight and easy to fabricate. the lightweight foamed concrete is built up with random air-voids created from the mixing of foam agents in mortar. In this study, foam concrete was incorporated with hybrid fiber materials from the waste industries which is coir fiber and steel fiber and was produced under mixed foaming method. In the foam generator, there is a diluted foaming agent in water and then the pre-foaming solution is expanded with air into the foam. Under adjustable pressure, the foam generator produced foam to be readily mixed with the slurry mixer approximate 10 revolutions per minutes. The fine aggregate (sand) will occupy the voids and slurry mortar act as binder materials in the foamed concrete. Foamed concrete has their own mechanical properties include its compressive and tensile strength.

Fiber reinforcement can increase greatly the energy absorption and impact strength of concrete [5]. The compressive strength of concrete does not depend much on steel fiber because its only strengthening up to 25%. Although the foamed concrete already has reinforcing steel, the addition of steel fiber does not significantly affect the compressive strength of the concrete. This steel fibers are more appropriate than other fibers, because the use of steel fibers in concrete increased the flexural stiffness, tensile stiffness, and concrete performance against tensile stresses [6]. Generally, steel fibers have high tensile strength, in this condition there is no rupturing probability of brittle fibers. The addition of small steel fibers with same lengths and proportion in foamed concrete mixtures increase the flexural characteristic and on the mode failure. This steel fiber generally will have a high impact on bending strengthbecause it enhances more flexural capacity compared to compressive strength. Coir is among one of the natural fibers that is low-cost fiber extracted from coconut palm. There are two types of fibers that have been extracted by the coconut which is brown and white fiber. These two types of fiber have their own properties where the brown fibers are thick, solid and have high abrasion resistance while the white fiber are smoother and finer which make the white fiber more weaker. Coir is an abundant, versatile, renewable, inexpensive and biodegradable lignocellulosic fiber used in many industrial applications.

Coconut fiber showed that this material had the capability to produce light concrete with excellent performance [7]. A recent study showed that 40% replacement of conventional aggregate with coconut fiber can decrease the compressive strength of concrete about 22% and the reduction of the water-to-cement ratio was important to improve this property [8]. Generally, it can be said that concrete made with coconut fiber has higher compressive strength than concrete containing oil palm shell because of the roughness of coconut fiber and its better adhesion with cement flakes [9].

This research investigated the structural behavior of a precast foamed concrete slab containing hybrid fibers as filler. The objectives of this study are to determine the compressive strength of foamed concrete containing CF and SF, andto determine the structural performance of this slab in terms of its ultimate load, crack pattern, load-deflection profile and strain distribution. Comparisonof the structural performance of the control precast foamed concreteslab with precast foamed concrete slab with added CF and SF, subjected to flexure load.

2. Materials and Methods

The laboratory research was performed in three phases in this section; namely, the preparation of materials used, the mixing process of these FC with added CF and SF, and experimental tests conducted on the FC specimens. FC cubes containing CF and SF was tested to determine the compressive strength according to BS–EN 12390:2002 [10] standard and four point bending test was conducted by following the BS EN 12390-5:2009 [11] standard to determine its crack pattern, load deflection profile, ultimate load and strain distribution.

The materials used in this research were cement, fine aggregates, water, foaming agent, coir fiber and steel fiber. Foaming agent is a liquid used for foam generation, which is mixed with water, by using foam generator connected with air compressor. The ratio of foaming agent to water is 1:10 was added in generator to generate pre-foamed, and then obtain the desired density of foamed concrete. Where as CF and SF were used as filler.According to Mohamad et al., [4] 1% CF and 3% SF were optimum percentage to enhance the mechanical properties in FC. Therefore in this researchthe different percentage of CF and SF have been added which is 1% and 3% respectively from the total weight of slab. The coir fiber are cut in range of 50 mm to 100 mm. The grade of steel fiber was HE 0.55/35 with the length of 65 mm is use as filler for the mixture of foamed concrete. The percentage use for steel fiber to add in the foamed concrete mixture is consistent which is 3% for both mixtures because it was the optimum percentage for compressive strength based on result of Mohamad et al., [4].

Plain foamed concrete with targeted compressive strength were mixed using the mixture ratio as listed in Table 1.

Table 1: Mixture ratio for precast foamed concrete (PFC)

Specimen	Filler	
	Steel fiber (SF)	Coir fiber (CF)
PFC control	0%	0%
PFC-3% SF	3%	0%
PFC-3% SF-1% CF	3%	1%

Cube specimens of PFC with added CF and SF had been cast for testing purposes. Three cubes were tested according to BS-EN 12390-3:2002 [10] under compression at 7 and 28 days to determined its compressive strength. Three slab panels having dimensions 700 mm length, 500 mm wide and 100 mm thickness as shown in Figure 1 were casted and tested were tested underfour point bending test was conducted according to BS EN 12390-5:2009 [11]as shown in Figure 2to determined its structural performance in terms of ultimate load, crack pattern, load deflection profile and strain distribution subjected to flexural load.

In this research three different mixtures were used such control sample (FC), utilization of 3% SF and incoperation of 3% SF with 1% CF. Three cubes and slab panels were used to investigate the compressive strength and four bending test at 7 and 28 days of curing ages.Table 2 shows the mixture ratio of the foam concrete made for this research.

Table 2: Ratio for mixture of foamed concrete

Materials	Sand to cement	Water to cement	Foam to cement
Ratio	2:1	0.5	0.9

The samples of cube were prepared at the Heavy Structure Material Laboratory, University Tun Hussein Onn Malaysia. For cube samples, there were total of eighteen (18) samples tested for their compressive strength. The total cube sample consists from the different mixture of foam concrete and percentage of CF and CF as shown in Table 3. Six (6) number of cubes represents on each different mixture of foamed concrete. The dimension of cube mould is 100 mm × 100 mm × 100 mm.

Table 3: The mixture of foamed concrete

Mixtures	Cement ratio	Sand ratio	Water ratio	Steel fibre (%)	Coir fibre (%)
Control	1	2	0.5	0	0
PFC-3% SF	1	2	0.5	3	0
PFC-3% SF-1% CF	1	2	0.5	3	1

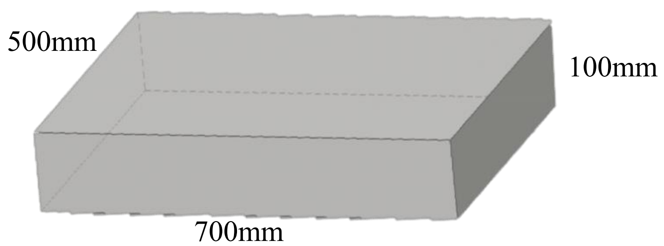


Figure 1: Dimension of panel

The right amount of mixture was calculated by using the formula of density as shown in Eq. 1. with the target density of 1800kg/m^3. Table 4 shows the mixture weight of foamed concrete for cube. All concrete requires curing in order for cement hydration to occur so as to allow for development of strength, durability and other mechanical characteristics. To obtain good concrete, the placing of an appropriate mixture must be followed by curing in a suitable environmentwhere no acidic and alkali reaction occur in atmosphere, especially during the early stages of hardening [12]. Concrete blocks were cured after demolding for 7 and 28 days until strength testing.

$$Density = Mass/volume \qquad \text{Eq. (1)}$$

Table 4: The mixture weight of foamed concrete for cube

Sample	Cubes mixtures		
	Control	PFC-3% SF	PFC-3% SF-1%CF
Cement content	0.57 kg	0.57 kg	0.57 kg
Sand content	1.13 kg	1.13 kg	1.13 kg
Water content	0.28 kg	0.28 kg	0.28 kg
Steel fiber content	-	0.059 kg	0.059 kg
Coir fiber content	-	-	0.02 kg

The tests that had been conducted in this study was compressive strength test and four point bending load test to determine the compressive strength and flexural behaviour of the slab, respectively. Theflexural behaviour studied was in term of its ultimate load, crack pattern, and load-deflection profile. The compressive strength test was conducted according to BS EN 12390:2 [10]. The cubes were taken out from the water tank and let dried for 2 hours before compressive strength test was conducted. The cross-sectional area of the cubes was measured and placed in the center of the machine for the test. Three (3) samples for each mix proportion were tested and their mean value was taken. By using universal testing machine, load deflection profile and crack pattern of a structure wasobtained by conducting a four- point bending testaccording to BS EN 12390: 5 [11].Slab panel with dimension of 700 mm × 500 mm × 100 mm was placed on the testing machine which supported by one pin and one rolled support as shown in Figure 2.

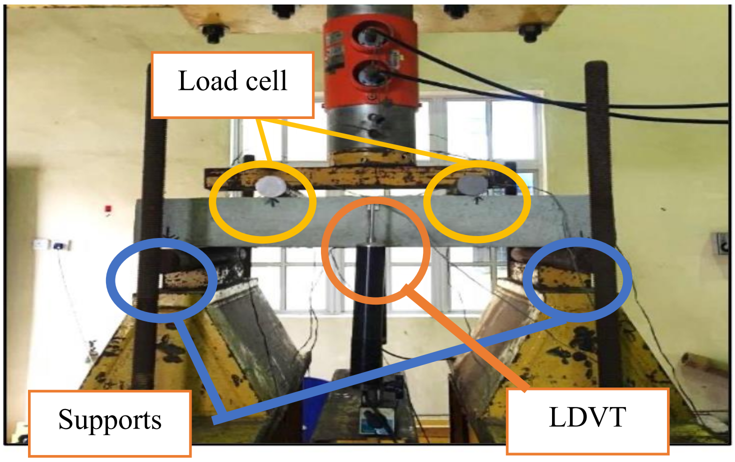


Figure 2:Four point bending test apparatus

3. Results anddiscussion

Compressive strength of FC containing the CF and SF are shown in Figure 3. The compressive strength was significantly increased when the SF and CF were added. From Figure 3 it can seen that 50% compressive strength at 28days was improved when hybrid fibres were incoperated in FC compare to control sample. According to Keerio et al., [1] with the addition of hybrid fibre in FC, the internal bonding between ingredients also increase.This leads to enhancement of the strength properties of FC. Similar behavior was also detected in this study when the hybrid fibres were added in FC, where it was noticed that the compressive strength improved continuously.

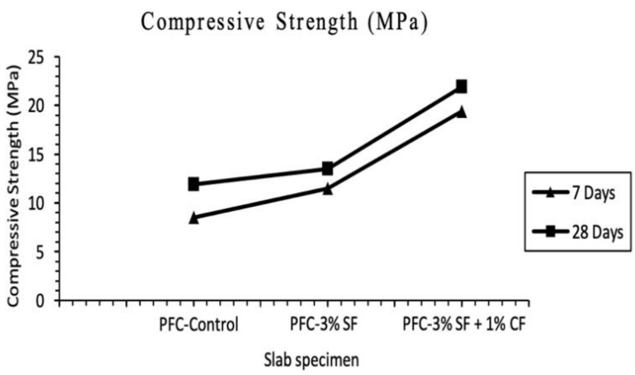


Figure 3: Compressive strength of specimen

Consequently the ultimate load of precast slab were also recorded. Table 5 and Figure 4 shows the results of ultimate load recorded for all slab specimens. The ultimate load outcomes defines that the ultimate bearing capacity of precast slab were enhanced when the SF and CF were added in the FC. Whereas ultimate load of FC-3%SF were 10.6% higher than the ultimate load of FC-3%SF-1%CF. The addition of coir fiber affected the ultimate load of the foamed concrete, and make the specimen more brittle. This is because, CF absorbed water content in the foam concrete mixture. Water absorption caused gradients of the water content within the fresh foam concrete. This lead to reduction of the flexural strength of the mixture.

Table 5: Result of ultimate load

Slab specimen	Ultimate load (kN)
PFC-Control	16
PFC-3%SF	41.5
PFC-3%SF-1%CF	37.5

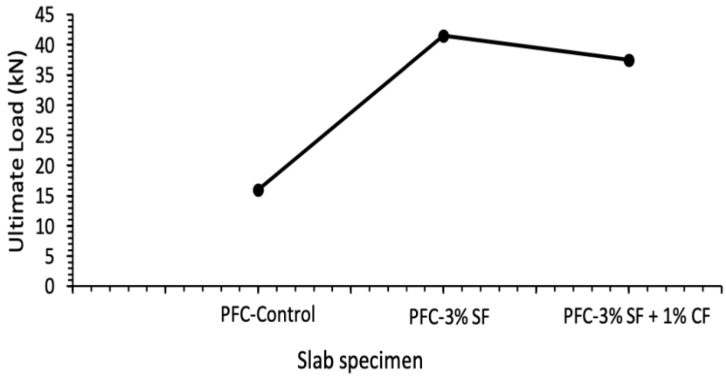
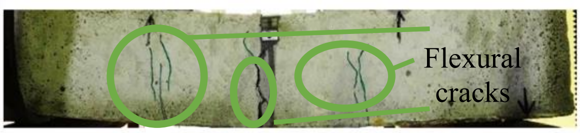


Figure 4: Ultimate load of PFC for control, 3% SF and 3% SF + 1% CF

The cracking pattern of precast FC slab were investigated by the physical observation obtained from the four-point bending test. Table 6 shows the cracking pattern of precast FC slab.

Table 6: Crack pattern of foamed concrete

Physical observation	Specimens
	PFC-Control
	PFC-3%SF
	PFC-3%-SF-1% CF

Cracks that formed on the control specimen is a formation of a straight line in the middle of the specimen, with largest crack width on the right side compared with other specimens. The second specimen which consists 3% of steel fiber, showed straight line crack occurred at its left, right and mid-span. The specimen which contain 3% of steel fiber and 1% of coir fiber showed that the specimen has less crack propagation and the cracks have less width compared with other specimens as shown in Table 2 . Based on the observation, it is proven although the ultimate load of foamed concrete with addition 3% of steel fiber and 1% of coir fiber are slightly decreased, the specimen managed to control the crack propagation.

Subsequently, Figure 5 shows the load-deflection profile for all specimens where the resulted was obtained from the LVDT which have been placed at the middle specimen during the four-point bending test. From the load deflection curves as shown in Figure 5, it can be seen that PFC-Control slab behaved in a brittle manner while the other two specimens behaved in a more ductile manner. PFC-3%-SF-1%CF is the most ductile slab with the highest deflection. It is obvious from this load-deflection profile that the hybrid fiber contributes to the ductility of the slab. The added CF in the PCF-3%SF managed to increase the ductility further.

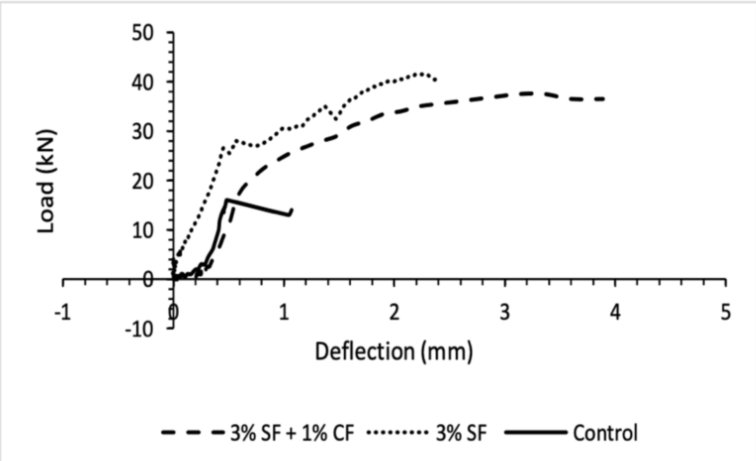


Figure 5: Load deflection profiles

4. Conclusion

It is concluded that FC containing SF and CF has graet impact on the compressive strength and ultimate load. It can be seen from Figure 3 and Figure 4 the compressive strength and ultimate load 50% and 134% increased, respectively, compared to the control sample. Cracking pattern shows the less cracks were incurred on the surface of FC slab with 3% SF and 1% CF compared to control slab. Subsequently the load-deflection profile described that FC slab with 3% SF and 1% CF is also more ductile compared to the control slab.

Acknowledgement

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