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Finite Element Modelling of Structural Behavior of Precast Foamed Concrete Slab (PFC-CF-SF) Containing the Hybrid Fibers Under Flexural Load

Steafenie George[1], Noridah Mohamad[1]

[1]Department of Structural and Materials Engineering, Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia, Parit Raja,86400, Batu Pahat, Johor, MALAYSIA

*Corresponding Author

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Abstract: Reinforced concrete structure is inevitable from cracking. The material properties of the concrete itself, which is brittle, causing the concrete to have low tensile strength. Hybrid fibers that used in this study were coir fiber (CF) and steel fiber (SF). The purpose of the fibers was mainly to control the cracking of concrete. In view of this, a computational study was carried out to determine the structural behavior of Precast Foamed Concrete Slab (PFC-CF-SF) containing hybrid fibers under flexural load. Parametric study of PFC-CF-SF with various slab's thicknesses and length was conducted. The slabs were subjected to flexure load until failure. The ultimate load, load-deflection midspan, and stress distribution of the slabs under flexure load were recorded. To validate the slab model using finite element analysis (FEA) in ABAQUS software, the results recorded from finite element model simulation was compared with the experimental results. From FEA, the result of PFC-CF-SF slab and experimental work was validated with difference of 6.13% ultimate load, and 7.01% difference in load deflection midspan which is in acceptable range of ±10%. The parametric studies of PFC-CF-SF with different length and thickness showed decreasing value of ultimate load capacity and higher deflection with the increment of length. Despite that, an increasing of ultimate load value and declining of deflection was showed with the increasing of slab's thickness. This study proved that PFC-CF-SF was more ductile than plain foamed concrete with higher ultimate load bearing capacity and the usage of fibers in foamed concrete slab was able to control the crack propagation.

Keywords: PFC-CF-SF, ABAQUS, FEA

1. Introduction

Construction industry's coverage was very broad and plays an important role in the development of a country. Thus, the usage of precast foamed concrete was considerably utilized for most building construction because of its comparatively low cost, easy manufacturing and placement compared to conventional concrete. [1] Concrete was categorized as a brittle material which can cause cracking. The formation of crack in concrete will reduce stiffness and the strength of concrete [2]. In order to increase the strength and toughness of concrete, one of the alternatives was by adding fibers in the concrete mixture. The combination of two types of fibers was called hybrid fibers. This study will use steel fiber (SF) and coir fiber (CF) to improve cracking in concrete. This study analyzed the structural behavior of precast foamed concrete slab with hybrid fibers (PFC-CF-SF) under flexural load by using FEA with ABAQUS software. FEA can quickly analyze and predict the failure mode of a structure and provide the important information

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*Corresponding author: steafeniegeorge@gmail.com

regarding the failure mode [3]. Implementing computational modelling will save time and cost as the experimental analysis was time consuming and expensive.

2. Literature Review

According to ACI Concrete terminology, precast concrete was defined as concrete that was cast and cured elsewhere other than its final position in the construction site [4]. There were many benefits in using precast concrete. For example, bad weather problem such as raining would not affect the casting of concrete since the concrete was manufactured in a closed plant. Furthermore, using precast concrete can reduce the construction cost as it does not need skilled worker and a lot of laborers to install the concrete [5].

These days, foamed concrete has been widely used in construction industries. Foamed concrete was adapted in precast walls and slab foundations as it was lighter and have a great thermal insulation [6]. This study will incorporate the use of coir fiber and coconut fiber in the mixture of foamed concrete. Coir fiber was made from natural fiber while steel fiber was manufactured fiber that usually made from stainless steel. The adaptation of fibers in concrete mix has becoming an alternative to overcome concrete problems, such as low tensile strength and its tendency to crack.

Finite element analysis (FEA) was defined as numerical method that is used to overcome engineering problems [7]. ABAQUS was a finite element analysis program that used to simulate the slab model. ABAQUS software generate modelling of specimen in a great deal of detail describing many kinds of specimen's structural behavior [8]. In this study, FEA was used to analyze the structural behavior of precast foamed concrete slab containing hybrid fibers under flexural load. Thereby, the process of modelling precast foamed slab via software application may help to reduce the experimental casting time at the laboratory.

2.1 Previous Research on the Structural Behavior of Foamed Concrete Using FEA

The previous research on the structural behavior of foamed concrete using FEA by using concrete damaged plasticity of ABAQUS was summarized in Table 1.

Table 1 - Previous research on the structural behavior of foamed concrete using FEA

Researcher	Findings
Goh et al (2014)	• This paper studied the structural behavior of plain foamed concrete • The simulation of the foamed concrete by using concrete damaged plasticity was done by using ABAQUS will be used to compare with the foamed concrete cube that had been cast in lab experiment. • the damage propagation of the experimental and finite element analysis was similar to each other. This indicate that the finite element analysis can be used to simulate compression test on concrete cube precisely
Najmi (2019)	• This paper studied on the structural behavior of foamed concrete consisting of hybrid fiber • The result demonstrated by this paper shows the compressive, tensile and flexural strength of the foamed concrete mixture was the highest as the percentage amount of coir fiber increase

3. Materials and Methods

The simulation of the PFC-CF-SF was conducted with ABAQUS software. By referring to the simulation of the modelling, the structural behavior of the slab in terms of its ultimate load, crack pattern and load-deflection midspan was tabulated by finite element method. A model validation was carried out to assess the validity of the model used to simulate the PFC-CF-SF in this study. The designation material properties used was according to previous experimental work conducted by Najmi, 2019. A detailed materials property used in this research are shown in Table 2. For constitutive parameters used in concrete damage plasticity model for both compressive and tensile behavior of PFC-CF-SF were listed in Table 2.

Table 2 - Material properties of PFC-CF-SF concrete

Material	Properties
Foamed concrete (3% Steel fiber, 1% Coir fiber)	Density = 1800 kg/m^3 Young's modulus = 1.52 Gpa Poisson's ratio = 0.12
Main reinforcement	Density = 8900 kg/m^3 Young's modulus = 200 Gpa Poisson's ratio = 0.30
BRC wire mesh	Density = 8500 kg/m^3 Young's modulus = 200 Gpa Poisson's ratio = 0.30

Table 3 - Concrete damage plasticity of foamed concrete with 1% CF and 3% SF

Dilation angle	Eccentricity	Initial/biaxial/uniaxial ratio, σc0/σb0	K	Viscosity
27°	0.1	1.16	1	0

Concrete

Compressive behavior from experiment			**Tensile behavior from experiment**		
Yield stress (Mpa)	Inelastic strain	Damage parameter, D	Yield stress (Mpa)	Cracking strain	Damage parameter, D
20	0.0005928	0	1.90	0	0.000
22	0.0006124	0.314	2.10	0.0149	0.182
19	0.00153	0.678	2	0.0314	0.198
18	0.0041	0.792	1.95	0.05321	0.681
17	0.0047	0.813	1.5	0.091	0.814

A model validation was carried out to access the validity of the model used to stimulate the PFC-CF-SF in this study. For validation process, results from 700mm x 500mm x 100mm, subjected to flexural load, were compared with the experimental work conducted in laboratory in similar slab under similar load. The comparison was conducted in the context of its ultimate load, stress distribution and load deflection midspan. The simulation reading is expected to have difference of ±10% from the experimental results.

Parametric study was conducted for PFC-CF-SF with various length and thickness. The length and thickness of the slab were varied from 700mm to 1400mm, and from 100mm to 200mm, respectively. The value of SF and CF were constant at 3% and 1%, respectively, for all slab specimens.

4. Results and Discussion

A FEA model of PFC-CF-SF was generated by using ABAQUS/Explicit in this study to determine its structural performance in terms of its ultimate load, stress distribution and load-deflection under flexural load. The properties of the model were considered based on the material properties of foamed concrete that acquired during the experimental work. This approach was used as an alternative to lessen the cost of conducting experimental work in the laboratory. A parametric study that involved various thicknesses, width and main reinforcement was also done in this study.

4.1 Validation of FEA model

In this study, a model validation based on the experimental work was done to assess the validity of the concrete damage plasticity model used in FEA. The experimental work has the same material properties and dimension of model which was used for validation and to simulate the structural performance of PFC-CF-SF subjected to flexural load in terms of its ultimate load, crack pattern, stress distribution and load-deflection midspan. For validation in terms of ultimate load, based on the result showed in table 4, the difference of percentage between experimental work and FEA was 6.13% which is within acceptable range which was ±10%.

Table 4 - Ultimate load of PFC-CF-SF slab under flexural load for experimental and FEA model

Slab	Ultimate load		$\frac{P_{u(FEA)} - P_{u(EXP)}}{P_{u(EXP)}} x\ 100\%$
	Experimental	FEA	
PFC-CF-SF	37.5	39.8	6.13%
PFC-CF-SF = Precast foamed concrete slab containing coir fiber and steel fiber			

In term of load deflection, the result of both data in figure 1 and table 5 showed that the graph of FEA work was in good agreement with experimental result. The graph also shows PFC-CF-SF has a ductile behavior compared to plain foamed concrete. The characteristic of hemicellulose in coir fiber contributed to the elongation of the fibers and causing it to act like springs with bending and twisting. (Hearle, 1943).

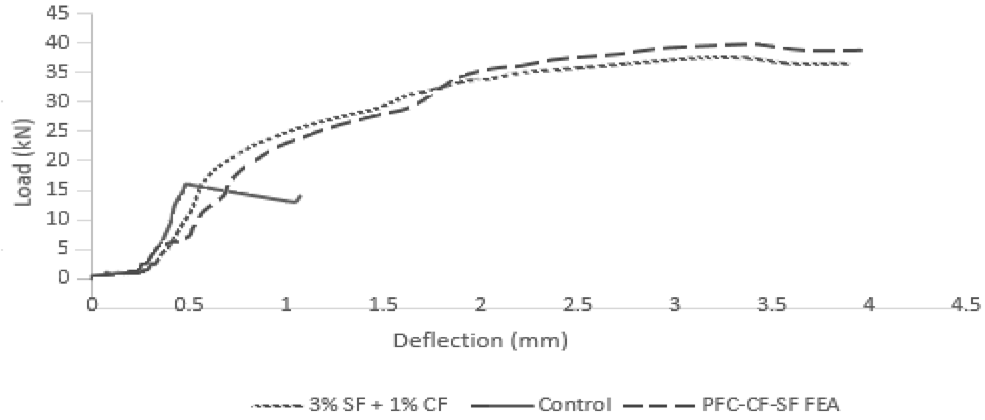
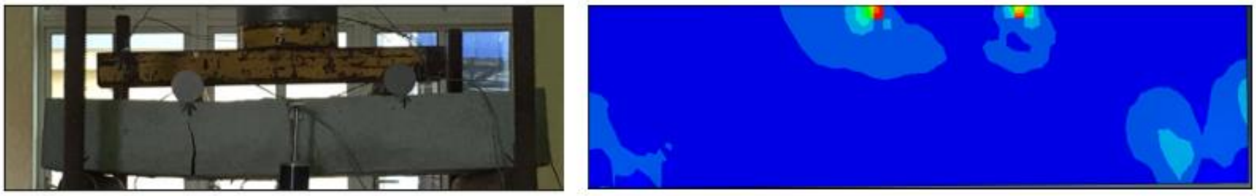


Fig. 1 - Load versus deflection of experimental and FEA work

Slab	Load versus maximum displacement		$\frac{P_{u(FEA)} - P_{u(EXP)}}{P_{u(EXP)}} x\ 100\%$
	Experiment	FEA	
PFC-CF-SF	3.14	3.36	7.01 %
PFC-CF-SF = Precast foamed concrete slab containing coir fiber and steel fiber			

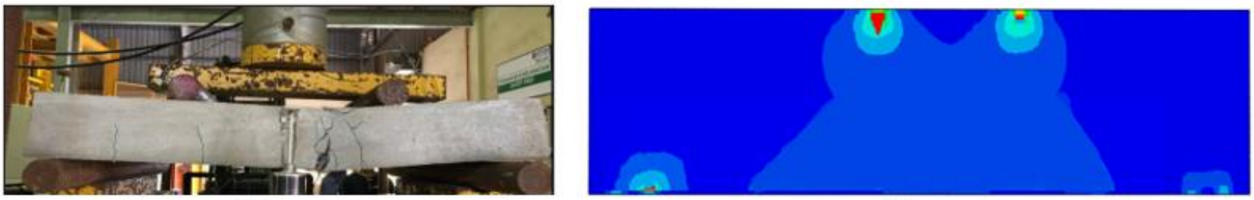
Table 5 - Maximum displacement of PFC-CF-SF of experimental and FEA works

For validation in terms of stress distribution, from figure 2 below, the stress distribution in PFC-CF-SF of FEA model was mainly similar compared to experimental work. However, stress distribution of experimental work of plain foamed concrete in Figure 3 showed larger crack width around loading area compared to PFC-CF-SF slab. The stress distribution of FEA model was mostly similar with the experimental result where it showed larger stress distribution on loading area. This proved the usage of fibers controls the crack propagation of concrete. The data showed that the concrete damage plasticity model and material properties used in this study was proficient to model the stress distribution of FEA model.



(a) (b)

Fig. 2 - (a) Stress distribution of PFC-CF-SF slab from experimental work (a) and (b) FEA



(a) (b)

Fig. 3 - (a) Stress distribution of plain foamed concrete slab from experimental work; and (b) FEA (Adeniyi et al., 2019)

4.2 Parametric Study

A parametric study on the structural performance of PFC-CF-SF slab under flexural load was conducted by using FEA, ABAQUS/Explicit in various length and slab thickness. A total of 6 FEA models were simulated with the same material properties. Results of the ultimate load, stress distribution and load-deflection midspan were tabulated and discussed.

4.2.1 Ultimate Load Carrying Capacity of PFC-CF-SF

The ultimate load of PFC-CF-SF slabs with different length and thickness were analyzed by using finite element analysis in ABAQUS/Explicit. The results were tabulated in Table 6.

Table 6 - Ultimate load carrying capacity of PFC-CF-SF slab

Slab	*L × h × w* *(mm)*	Ultimate load, P_u, (kN)	Slenderness ratio, (L/t)
PFC-CF-SF1	700×100×500	39.8	4.67
PFC-CF-SF2	700×200×500	44	3.50
PFC-CF-SF3	1000×100×500	36	6.67
PFC-CF-SF4	1000×200×500	38	5.00
PFC-CF-SF5	1400×100×500	32	9.33
PFC-CF-SF6	1400×200×500	35	7.00

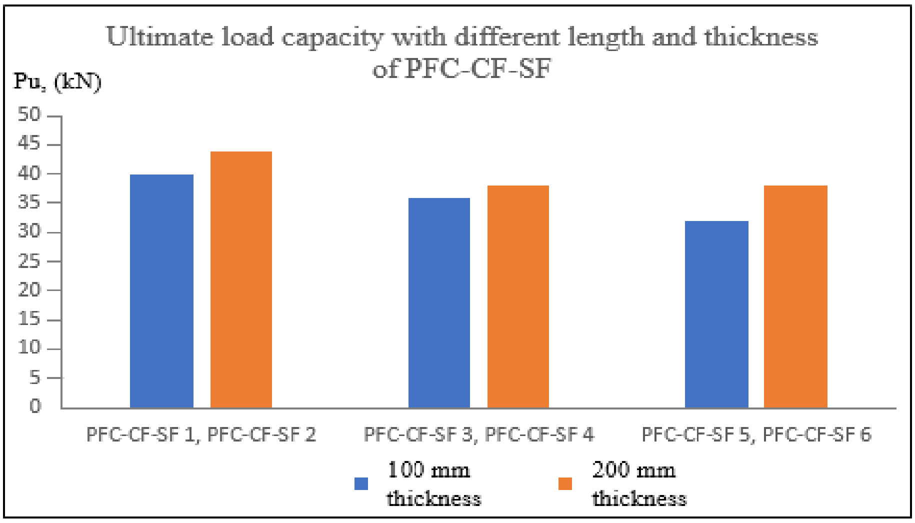


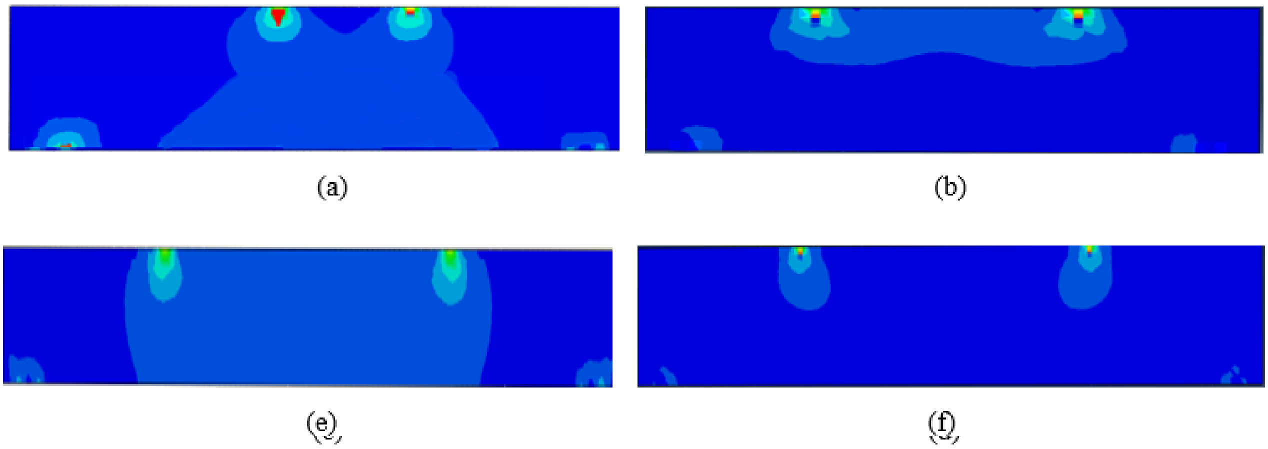
Fig. 4 - Comparison between ultimate load and slab thickness

From the data figure, as the length of slab increased, the ultimate load was decreasing along with the slenderness ratio. This showed that longer slab has higher slenderness ratio and it had the tendency to fail at lower load. Based on the result, the ultimate load carrying capacity was dependent on slenderness ratio of the particular designation.

In terms of different slab thickness, it was shown that thicker slab can bear higher load. This was also due to span-to-depth ratios of the slab. Span-to-depth ratios controlled the deflection of the slab. In order to achieve higher load bearing capacity of slab, one may increase the size of slab depending on the purpose of the structure.

4.2.2 Stress Distribution of PFC-CF-SF

The possible failure zone occur in the slab can be determined by evaluating one of the important parameters which was stress distribution of the model. Figure 5 (a) to (f) demonstrated the result of stress distribution of slab with different length and thickness. From the figure below, the color exists in each slab indicated the region of stress. Brighter color from slightly white to green and red implies the increasing of stress at that particular region.



(a)

(b)

(e)

(f)

Fig. 5 - (a), (b), (c), (d), (e), (f): Stress distribution of FEA model PFC-CF-SF

Based on the results, Figure 5 (a), (c), and (e) with 100 mm thickness have higher stress region compared to figure 5 (b), (d), and (f) with 200 mm thickness. By comparing to the stress distribution with to the increment of length, figure (a), (c), and (e), the stress region was higher as the length increase from 700 mm, 1000 mm, and 1400mm.

Thicker slabs with 200 mm thickness have less stress distribution compared to 100 mm thickness. This is due to the span to depth ratio factor that affected the stress distribution of the FEA model. In Table 6, lower span to depth ratio which also known as slenderness ratio contributed to better load bearing and control of deflection.

The increasing of length of slab affected the distribution of stress as well. Longer length of model tends to have higher deflection and causing the decreasing of ultimate load carrying capacity, hence causing failure to the model.

4.2.3 Load Deflection Midspan of PFC-CF-SF

A parametric study of six PFC-CF-SF FEA model was simulated in terms of its load deflection midspan. Table 7 shows the dimension and of PFC-CF-SF slab with different length and thickness. The result was then tabulated into two graphs shown in Figure 6 and 7 which was load deflection midspan in terms of two different thickness with increment of length.

Table 7 - Parametric Study of PFC-CF-SF Slab

Slab	Dimension, $L \times t \times w$ (mm)	Thickness of slab (mm)	Ultimate load (kN)	Load deflection midspan (mm)
PFC-CF-SF-1	700×100×500	100	39.8	3.6
PFC-CF-SF-2	1000×100×500	100	38	4.3
PFC-CF-SF-3	1400×100×500	100	40.5	4.6
PFC-CF-SF-4	700×200×500	200	43	3.4
PFC-CF-SF-5	1000×200×500	200	41	4.2
PFC-CF-SF-6	1400×200×500	200	38	4.5

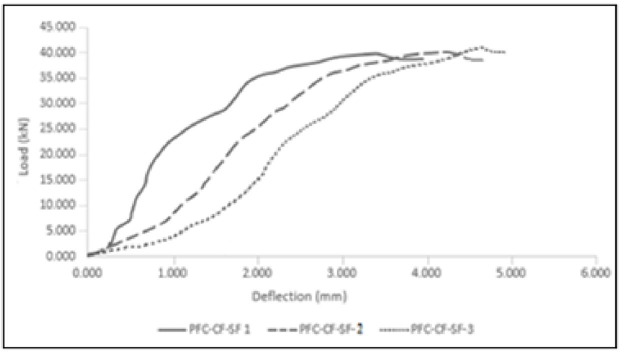


Fig. 6 - Graph of load versus deflection slab with fixed thickness 100 mm

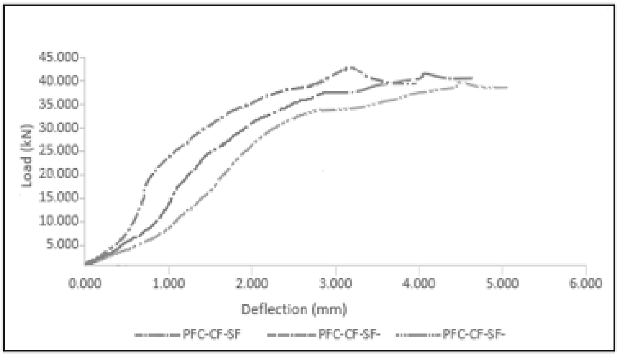


Fig. 7 - Graph of load versus deflection slab with fixed thickness 200 mm

From the data obtained in Table 7, the ultimate load and deflection of slabs with 100 mm thickness was lower than 200 mm thick slab. This showed that thicker slab can bear higher load. This was due to span-to-depth ratios of the slab as span-to-depth ratios controlled the deflection of the slab. In order to achieve higher load bearing capacity of slab, one may increase the size of slab depending on the purpose of the structure. Based on the result, the ultimate load carrying capacity was dependent on slenderness ratio of the particular designation.

5. Conclusions

The usage of ABAQUS software in this study have the capability to analyze the structural performance of PFC-CF-SF slab precisely. The ultimate load and load versus midspan deflection PFC-CF-SF slab was modeled by using ABAQUS/Explicit and had been validated with the experimental results within an acceptable range of 10% to verify the capability of computational model describing the structural performance of PFC-CF-SF slab accurately under flexural load.

The stress distribution in FEA model was mainly similar compared to experimental work. The stress distribution on experimental work of plain foamed concrete showed more propagation of cracks around loading area compared to PFC-CF-SF slab. The stress distribution of FEA was mostly similar with the experimental result conducted in the laboratory. This proved the usage of fibers controls the crack propagation of concrete. Nevertheless, cracking pattern at the flexure zone was not able to be simulated as the simulation required different and more complicated algorithm to extract the damage characteristic to monitor the crack damage status in concrete.

The parametric study of PFC-CF-SF was done with different lengths and thickness of slab using ABAQUS/Explicit had proved that the various length and thickness applied to the model affect the ultimate load capacity and the deflection of the slab. As length of PFC-CF-SF slab increases, the slab was subjected to larger deflection.

As a summary, the application of software modelling of PFC-CF-SF slab subjected to flexural load can predict the structural performance of slab precisely.

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