Flexural Behaviour of Precast Aerated Concrete Panel (PACP) with Added Fibrous Material: An Overview

Noor Hazlin Abdul Rahim¹, Noridah Mohamad^{1,*}, Abdul Aziz Abdul Samad¹, W. I. Goh¹, and Norwati Jamaluddin¹

¹Jamilus Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia

Abstract. The usage of precast aerated concrete panel as an IBS system has become the main alternative to conventional construction system. The usage of this panel system contributes to a sustainable and environmental friendly construction. This paper presents an overview of the precast aerated concrete panel with added fibrous material (PACP). PACP is fabricated from aerated foamed concrete with added Polypropylene fibers (PP). The influence of PP on the mechanical properties of PACP are studied and reviewed from previous research. The structural behaviour of precast concrete panel subjected to flexure load is also reviewed. It is found that PP has significant affects on the concrete mixture's compressive strength, tensile strength and flexural strength. It is also found that PP manage to control the crack propagation in the concrete panel.

1 Introduction

An innovative new Industrialised Building System (IBS) technology is actively being studied and developed for residential, industrial and commercial building applications. As a developing country, the gap between demand and supply of adequate housing is continuously increasing [1]. IBS is generally preferred due to its prefabrication or precast element which aim to improve the overall construction performance in terms of quality, cost effectiveness, safety and health, waste reduction, efficiency and productivity [2]. Structural components of IBS are manufactured in a factory, on or off site, transported and assembled into a structure with minimal site works [3]. Applications of IBS system in construction has proven to be able to fasten the speed of construction without sacrificing the quality. The IBS system presented in this paper, PACP, is made of precast lightweight aerated concrete with density approximately 80% of the density of normal concrete, in the range of 1440 kg/m³ to 1840 kg/m³ [4].

Aerated concrete is a type of lightweight concrete which does not contain coarse aggregates [5]. Generally, aerated concrete is a mixture of cement, sand, water and pre-formed foam. The pre-formed foam is a mixture of foaming agent which either synthetic or

* Corresponding author: noridah@uthm.edu.my

protein based, water and air. It is also known as foamed concrete which have an air content of more than 25% [6]. Aerated lightweight concrete is defined as a type of concrete which consists of expanding agent [7]. It will increase the volume of mixture and give additional qualities such as self-compatibility and lighter weight. Meanwhile, lightweight concrete is a concrete that has low density compared to the normal concrete [8].

The density of aerated concrete can be achieved by controlling a dosage of foam [9]. It is reported that there is a relationship of compressive strength of aerated concrete with its density, water/cement ratio and cement content [10]. Density of aerated concrete has a significant influence on the ultimate strength of concrete mixture. Higher ultimate strength is obtained in appearance of uniform bubbles. Typical mixture details of aerated concrete and properties of aerated concrete are summarized in Table 1 and Table 2.

Table 1. Typical mix details of aerated concrete [10].

Wet density (kg/m ³)	500	900	1300	1700
Dry density (kg/m ³)	360	760	1180	1550
Cement (kg/m ³)	300	320	360	400
Sand (kg/m ³)	-	420	780	1130
Base Mix W/C Ratio	Between 0.5 and 0.6			
Air content (%)	78	62	45	28

Table 2. Properties of aerated concrete [10].

Dry Density (kg/m ³)	Compressive Strength (MPa)	Thermal Conductivity (W/mk)	Modulus of Elasticity (GPa)	Drying Shrinkage (%)
400	0.5-1.0	0.1	0.8-1.0	0.30-0.35
600	1.0-1.5	0.11	1.0-1.5	0.22-0.25
800	1.5-2.0	0.17-0.23	2.0-2.5	0.20-0.22
1000	2.5-3.0	0.23-0.30	2.5-3.0	0.18-0.15
1200	4.5-5.5	0.38-0.40	3.5-4.0	0.11-0.09
1400	6.0-8.0	0.50-0.55	5.0-6.0	0.09-0.07
1600	7.5-10.0	0.62-0.66	10.0-12.0	0.07-0.06

Aghaee & Yazdi [11] investigated the mechanical properties of structural lightweight concrete with added waste steel wires. Four types of mixtures with different percentage of fibers (0%, 0.25%, 0.5%, 0.75%) were tested under compressive, tensile, flexural and impact. The compressive strength increased in mixtures with up to 0.5% of waste steel wires while decreased in mixtures with more than 0.5% added waste. It was found that the specimens were prevented from brittle failure even with the lower dosage of fibers. The higher percentage of waste steel wires showed the maximum flexural strength and maximum energy absorption. Meanwhile, the ultimate impact resistance by higher fibers content increased about thirteen times higher compared to plain lightweight concrete. Thus, the waste steel wires expected to be as reinforcement in structural lightweight concrete due to its strength and mechanical properties.

The investigation on flexural behaviour and ductility of reinforced lightweight concrete beam with different concrete strength and addition of polypropylene fiber were carried out

by Nahhas [12]. According to the report, two group of specimens were investigated; namely prismatic concrete beam with different cement dosages (350, 400 and 450kg/m³) and lightweight reinforced concrete beam with different proportions of fiber (0, 30 and 60kg/m³). The addition of polypropylene fiber increased the ductility and toughness capacity of prismatic concrete beam. It also increased the bearing strength and ductility found in lightweight reinforced concrete beam. The higher content of cement with higher proportions of polypropylene fiber increased the ductility about 98%. The results indicated that polypropylene fiber tend to control the formation and growth of cracks and finally increased the performance of reinforced concrete beam.

2 Affect of Polypropylene (PP) on mechanical properties of concrete

Fibers are generally used in concrete to control cracking due to plastic and drying shrinkage. Several previous studies conducted on concrete mixture with added PP fibers have indicated that it has some significant effects on the concrete properties. An experimental study was conducted to explore PP fibers effects on compressive, tensile, flexural, shear strength and plastic shrinkage. Compressive strength increased at the age of 28 days with addition of PP fibers at 0.1% to 0.4% but decreased from original with amount of PP fibers more than 0.4% [13]. Higher dosage of PP fibers decreased the strength of concrete matrix due to higher volumes of fibers interfering with the cohesiveness of the concrete matrix. Tensile strength of concrete is only about 10% of its compressive strength. Thus the addition of fibers to a concrete mixture is beneficial to tensile properties of concrete. It reduces propagation of cracks in plastic and hardened state. The tensile strength of concrete increases linearly about 65% to 70% with addition of fibers up to 0.4% after which it decrease. The large amount of fibers reduced the bond strength between concrete ingredients as compared to less proportion of fibers. The flexural strength increased about 80% by adding 0.2% of fibers while shear capacity of concrete have a good agreement with added fibers. The last results on shear cracking is reduced by 83% to 85% by addition of fibers in the range of 0.35% to 0.5%. Overall result showed a notable increase in flexural, tensile and shear strength [13].

It has also been found that utilizing PP fibers in cement matrix has caused a slight enhancement in compressive and flexural strength. However, mechanical strength was decreased by further increasing of fiber content that beyond 0.3%. It is because of poor dispersion of PP fibers in mortar that increase pore volume and creates more micro defects in cement matrix [14].

In a report by Awang et al. [15], a density of 1000 kg/m³ foamed concrete were used by adding 2 types of fibers namely polypropylene and kenaf. Based on the report, it is shown that addition of fibers had contributed to the peak flexural strength achieved by the specimens before failure. Meanwhile, specimens without fibers experienced immediate failure and broken into 2 parts after the peak flexural strength was reached. This statement is in agreement with the work done by Elsaid et al. where it was stated that when concrete cracks, the fibers prevents the micro-cracks from spreading and breaking into two parts [16].

Ahmad et al. [17] conducted a research on added PP fibers in a concrete mix observed that fibers created bridging across a concrete matrix which help to control shrinkage cracking during plastic stage and matrix micro cracks that occur as the concrete is loaded as illustrated in Fig. 1. It is also found that fibers can prevent the occurrence of large cracks widths. Added PP fibers can control the crack and shrinkage by reducing damages occurred due to shrinkage cracking as shown in Fig. 2.

Fig. 1. Fiber bridging across a concrete crack [17].

Fig. 2. Reducing the damages of shrinkage cracking [17].

A research was conducted to study the effect of variation of PP fibers ranging from 0.1% to 0.4% together with 0.8% steel fibers on the behaviour of fibrous concrete. It was found that the addition of PP fibers has a slight effect on compressive strength. However, it has a significant affect on the tensile strength [18]. Ramujee [19] studied on compressive strength and splitting tensile strength with different amount of PP fibers varied from 0%, 0.5%, 1%, 1.5% and 2%. The sample with added PP fibers of 1.5% showed better results in comparison with others and reveals that fibers used in concrete were enhanced both compressive and split tensile strength of concrete. It was concluded that the increase of formability and bending strength are the extra advantage of adding the fibers to concrete.

Results from the work by Parveen et al. [18] show that the flexural strength increases with increase in PP fibers due to the additional load taken by fibers that were present in concrete matrix with the optimum value of 0.3%. It is caused by improper mixing of fibers with the matrix takes place due to balling effect of fiber which increase amount of vibration to remove air voids from the mix that causes bleeding problem. The fibrous concrete are more ductile compared to plain concrete. This is caused by the load which was transferred from composites to the fibers at crack surface when the matrix cracked, which prevents the brittle failure of the composites. The 0% and 0.1% of PP fibers behaves like a brittle material which is in elastic energy whereas it become non-linear behaviour with PP fibers more than 0.1%. From this study, it was found that concrete with higher percentage of PP fibers possess higher toughness in plastic energy.

According to Han et al. [20], the evaporation of concrete surface of water is a factor in creating the concrete paste fracture in concrete which to the formation of tension stress since the concrete start to strengthen. Developing such stress during concrete strengthening can lead for crack where the stress is more than concrete strength. The cracks caused by the

paste contracting in the concrete are formed in the first hours after pouring the concrete in the formworks and before the concrete reaches its initial strength [21]. It is stated that the best and acceptable method for preventing the cracks formation caused by paste contract is by using fibers [22, 23].

From the previous studies above, it can be concluded that PP has a great potential to be used in concrete mixture as construction material. It was proven that PP fibers added to concrete mixture resulted with slightly increase in compressive strength and significant increase in tensile and flexural strength. It was also proven that added PP fibers have managed to reduce the crack propagation.

3 Behaviour of precast panel under flexure

This paper focuses on the overview of flexure behavior of the precast aerated concrete panel subjected to flexure load. Since it has been proven that PP has great influence in increasing the flexural strength and controlling the crack propagation occurred in concrete panel, the aerated concrete panel studied by the authors is added with PP fibers.

Several previous studies on flexure behavior of precast concrete panel have been studied and investigated by many researchers. Mohamad et al. [24] tested four full scale precast lightweight foam concrete sandwich panel with similar width, height and various thicknesses. The specimens with a double shear steel connector of 6 mm diameter and steel reinforcement of 9 mm diameter were tested under flexure load. It was found that the ultimate flexure load of panel was influenced by compressive strength and thicknesses. The crack pattern showed the crack started at mid span which is in between point of loading and later propagated toward the right and left zones of slab as illustrated in Fig. 3.

Fig. 3. Crack pattern of Precast Lightweight foamed concrete sandwich panel (PFLP)[24].

Mustaffa et al. [25] investigated structural behaviour of twelve reinforced foamed concrete slab with welded wire mesh under bending. All specimens were tested under four point bending test with varying densities and types of reinforcing steel wire mesh. The higher density of foamed concrete influences the attained ultimate load of slab under test. Mode of failure of all slab panels was found to be similar. The results obtained is found to be reliable to predict ultimate load and structural behaviour of reinforced foamed concrete.

Mugahed et al. [26] conducted experimental and analytical programme of six precast foamed concrete sandwich panels as a one-way working slabs tested under lateral loads. Two dimensional FEA model were carried out by using LUSAS software. Results showed that the increase of aspect ratio has caused decrease on ultimate flexural strength. The crack

patterns appeared in one-direction which similar to reports on solid slabs specifically when both concrete wythes act in composite manner. The results obtained from experimental and analytical studies gives a reasonable degree of accuracy.

Benayoune et al. [27] studied FEA of composite precast concrete sandwich panel under flexure by using LUSAS software. Parametric study were conducted with different aspect ratios of slabs. A two dimensional nonlinear model that acting as one-way panel and three dimensional nonlinear model acting as two-way panel with having shear connectors spanning in both directions were simulated. It was found that the placement of shear connectors in both directions gives better load distribution. The ultimate load increased with the increased of shear connectors' number.

Joshani et al. [28] studied the damage model of fracture process of steel concrete composite slabs by using FEA of ABAQUS software. Three dimensional nonlinear model of composite slabs were analysed subjected to four point bending test. Fig. 4 shows damage status in concrete including crack initiation point and propagation path. The results of numerical analysis match the experimental results accurately.

Fig. 4. Damage status at concrete when mid span deflection reached 2.3mm [28].

Mokhtatar et al. [29] studied the behaviour of reinforced concrete slabs subjected to impact loading by using ABAQUS software. The response such as time-impact force graph, damage wave propagation, effectiveness of mesh density, effect of projectile size and final crack pattern were verified against existing experimental results. It is shown that the FEA is able to simulate and predict the impact behaviour of structural systems satisfactorily.

Newberry et al. [30] studied pre-stressed concrete sandwich panels subjected to blast loads by using ABAQUS software. FEA used to analysed static and dynamic behavior of foam insulated concrete sandwich wall panels through ultimate capacity. The experimental program used for model development and validation involved both static and dynamic testing of full scale wall panels.

Soronakom et al. [31] studied numerical simulation of full scale elevated slab subjected to a point load at mid span of the central slab. The analysis used concrete damage plasticity model in finite element software ABAQUS with fiber content of 80kg/m^3 and 100kg/m^3 . FEA were carried out to calibrate the predicted load deflection response with the averaged experimental response in order to obtain material parameters such as Young's modulus, Poisson ratio and tensile crack relationship. The simulation reasonably agreed with the experimental program.

Abdullah et al. [32] conducted three-dimensional finite element model of steel-concrete composite slab under bending by using ABAQUS software. The quasi static analysis using ABAQUS/Explicit was chosen due to its precise solution where it is dominated by brittle cracking behaviour. A static load is time independent. A dynamic load is time dependent and for which inertial effects cannot be ignored. A quasi-static load is time dependent but is

"slow" enough such that inertial effects can be ignored. In ABAQUS, explicit dynamic is used for quasi static analysis. In this analysis, the prescribed displacement was increased slowly enough to eliminate any significant inertia effect. The kinetic energy was chosen as an indicator for the quasi-static response based on the conservation of energy principle. The principle states that the time rate of change of kinetic energy and internal energy for a fixed body of material is equal to the sum of the rate of work done by the external forces. The quasi static response was ensured by keeping the kinetic energy level due to the movement of the model to below 5% of the internal energy at any instance during the time step period. In this way, the external work done by the load is balanced mostly by the internal energy of the whole structure, as is actually happens in static analysis. Limiting the kinetic energy level was attained by adjusting the combination of time step period and the total displacement at the loading nodes accordingly, and monitoring the plots of the kinetic and internal energy with respect to time step period. Longer loading periods can reduce dynamic effects but may increase analysis time significantly. An optimum analysis period was obtained after several trials.

It has conclusively been shown from the review above that FEM has been used for modeling and analysis of structural study due to several limitations such as cost, time and energy required in conducting full-scaled tests. FEA has been proven to be able to predict the ultimate load and structural behaviour of model. The results from previous researches showed a good correlation with the experimental programme.

4 Precast aerated concrete panel with added polypropylene fibers (PACP)

Under flexure load, concrete panel was found to experience crack which started at the mid span and propagated towards its right and left zones. This crack will increase gradually until panel attain its ultimate load and fail. As such, it is critical to find alternative means to control crack propagation in the panel under flexure to avoid abrupt failure.

Therefore, a study on flexural behaviour of PACP tested under four point load as illustrated in Fig. 5, is proposed. The flexural behaviour studied is in the context of its ultimate load, flexural stress, flexural strain, crack patterns, load-deflection profile and the strain distribution on the concrete surface.

PACP is fabricated from cement, sand, preformed foam, water and added with polypropylene fibers, PP. The contribution of PP in the concrete mixture is to strengthen the concrete and to control crack propagation in the concrete against the applied load. It is further strengthened with steel bar reinforcement and stirrups as shown in Fig. 6.

Fig. 5. Test setup specimen with location of strain gauges and LVDT.

Fig. 6. Steel reinforcement and stirrups in PACP panel.

A three dimensional nonlinear finite element model will be developed by using ABAQUS software to study the PACP's behaviour under flexure loading. The data obtained from experimental results and theoretical calculation will be used as input data in FEM. The results will be analysed for its ultimate flexure load, crack pattern, load-deflection profiles, flexural stress and strain distribution. Parametric study will be conducted by performing series of simulations on both solid and hollow PACP with various heights, overall thicknesses, slenderness ratios and diameters of reinforcement in order to investigate the behaviour of panel is influenced by the size difference. The flexural stress achieved from FEM will be analysed and compared with the values from classical formulae and previous researchers.

5 Conclusion

Precast panel system has been the attractive alternative in the construction industry due to its advantages. Its applications as structural element has led to research on its behaviour under various types of load. PACP discussed in this paper is a precast system which is cast and fabricated from aerated foam concrete with added polypropylene fibres. Its main advantage is greater strength to weight ratio due to the lightweight aerated foam concrete used. Flexural behaviour of PACP subjected to four point bending test will be studied. Under flexure, the cracks initiated and developed in the panel will influence its failure mode. PP fibres are expected to increase PACP's structural integrity by controlling the crack propagation occurred in the slab panel.

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