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Research paper

The Mechanical Properties of Foamed Concrete with Polypropylene Fibres

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Abstract

With the innovation of foamed concrete, some components of the building can be replaced by lightweight foamed concrete, reducing the self-weight the conventional concrete has. The difference between foamed concrete and conventional concrete is the usage of materials and density. While the density of conventional concrete ranges from 2200 kg/m^3 to 2600 kg/m^3, the foamed concrete is up to 87% lighter. Lower density contributes to lower compressive strength of foamed concrete but reduction in self-weight. Therefore, to enhance the mechanical and physical properties of foamed concrete, Polypropylene fibres (PF) are utilized. In this study, foamed concrete was cast in two densities, 1600 kg/m^3 and 1800 kg/m^3. Four different percentages, 0% (without any content of PF), 0.05 %, 0.10 %, and 0.15 % of PF were added in both the densities of foamed concrete. Compressive strength test and modulus of elasticity were conducted to determine the effect of PF in the foamed concrete. Based upon the results, the optimum percentage of PF was determined to be 0.15% at which higher compressive strength as well as modulus elasticity for both densities was obtained.

Keywords: *Polypropylene Fibres (PF); Foamed Concrete; Compressive Strength; Modulus of Elasticity*

1. Introduction

Concrete, since its inception, has become one of the most popular building materials in the world. It has wide range of construction applications such as residential house, high rise building, pavement and even water storage tank. With the innovation of foamed concrete, some components of the building can be replaced by lightweight foamed concrete to gain advantages such as, sustainability, environmental impact reduction and decreased cost of construction as well as maintenance cost. The foamed concrete is a sustainable building material which uses minimal nature materials, as it does not consist of any course aggregate compared to conventional concrete [1]. Moreover, conventional concrete having its density lie between 2200 and 2600 kg/m^3 [2] is heavier than foamed concrete, indirectly increasing the permanent load of the building causing huge construction cost in design of foundation to stabilize the building [3]. It is indicated that more study is needed to be conducted on foamed concrete in order to be used as load bearing structure. During the construction, it is difficult to control the quality of concrete due to shrinkage and hydration process during casting [4]. Due to these reasons, cracks are developed in the concrete, eventually leading to increase in maintenance cost. While, by adding reinforcement steel bars has been a common solution to overcome cracking condition, utilization of polypropylene fibres (PF) is an alternative replacement for reinforcement bar to tackle the cracking effect [5]. The application of PF in concrete industry becomes cost effective in terms of durability compared to steel [6]. The dry density of foamed concrete ranges from 300 to 1840 kg/m^3 which is 23% to 87% lighter than the conventional concrete [7]. It is a known fact that by decreasing the density ultimately decreases the strength of concrete. Therefore, in this study, PF has been used as additives in foamed concrete to improve its mechanical properties.

2. Literature Review

Foamed concrete is a type of lightweight concrete, mainly comprising of cement, sand and water with a homogeneous void or the pore structure which is created by introducing air (foaming agent) in the concrete [8]. These air bubbles have a strong plasticizing effect on foamed concrete [9], but also produce micro-porous that reduce the interfacial bonding in the matrix, ultimately reducing the density of the concrete. Water is added with foamed agent in generator to generate pre-foamed. This pre-foamed agent is then added in mortar to reduce the wet density of mixer and obtain the desired target of foamed concrete. Due to reduced density, foamed concrete achieves lower compressive and tensile strengths while also developing micro-cracks [10]. Wei et al. [11] found that in foamed concrete of lighter density (less than 500 kg/m3) more micro-cracks occurred compared to density more than 1000 kg/m3 [12]. As a result, physical and mechanical properties vary at every point in the concrete. When load is applied on the concrete, micro-cracks are developed from these defects, which significantly affect the mechanical behaviour of concrete. In addition, foamed concrete consists of least density compared to conventional concrete, contributing to lower compressive strength. Thus, high cement content is required for low density materials prior to the addition of foam, compensate for this reduction in strength [13]. When the dry density of foamed concrete is decreased, the compressive strength also decreases rapidly. The strength can also be affected

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by the size and shape of the sample specimen, the method of pore formation, direction of loading, age, amount of water, characteristic of ingredients used and the method of curing [14].

To improve the mechanical properties of concrete, fibres are utilized. Over the years various types of fibres have come into use to reinforce the concrete, varying from synthetically organic fibres such as polypropylene, synthetically inorganic fibres such as steel or glass, natural organic such as cellulose or sisal to natural inorganic asbestos [15]. PF are commonly used in concrete, nowadays, for strengthening concrete and protecting it against micro-cracks. Polypropylene is a thermoplastic polymer [16], which is produced by polymerizing propylene, a gaseous by-product of petroleum refining [17]. Propylene monomer are converted into very long polymer chains in the presence of a catalyst under carefully, controlled heat and pressure during the polymerization process [15] as shown in Figure 1.

Figure 1: Long chain of polypropylene.

3. Methodology

A multi-filament PF with fibre size of 19 mm and 0.9 specific gravity is used in this study. Four different percentages of PF were added, 0% (controlled), 0.05%, 0.10%, and 0.15% PF in 2 densities (1600 kg/m3 and 1800 kg/m3) of foamed concrete. Experimental work was carried out to determine the compressive strength and modulus of elasticity. The mix proportion of foamed concrete was selected 1:2 cement-sand ratio, while water content was taken 0.55. Moreover, foamed concrete requires foam agent to control target density. Generally, the amount of foam agent depends on the products manufacture requirement. Therefore, foam agent to water ratio required in this studied is 1:20. The work procedure began with preparing the materials for every single set. All the materials and percentages of PF were mixed together in concrete mixer. Specified amount of water and generated pre-foam were added into the mixer and mixed together with cement mortar in concrete mixer. Hence, the foamed concrete was formed and poured into the mould and unmould after 24 hours. To determine the compressive strength, the samples were put for air curing for 7, 14 and 28 days, while for the determination of modulus of elasticity, samples were cured for 28 days.

4. Results and Discussion

4.1 Compressive Strength

In this study, the foamed concrete specimens with dimension of 100 x 100 x 100 mm were tested separately at 7, 14 and 28 days in laboratory according to BS EN 12390-3:2009 [18]. The average compressive strength from three cube samples for both densities was determined shown in Table 1 while Figure and Figure 3 represent the compressive strength versus days for foamed concrete of density 1600 kg/m3 and 1800 kg/m3 respectively. Based on the results, it was found that adding 0.15% PF obtained highest compressive strength in both densities after 28 days. The addition of 0.15% PF showed an increase in the compressive strength of 3.95% for 1600 kg/m3 and 26.20% for 1800 kg/m3 densities compared to the controlled samples for each density of foamed concrete. There are few reasons that influence compressive strength of foamed concrete, firstly, foam agent has been used to reduce the density of concrete while at the same time it produces air bubbles in the foamed concrete. After concrete hardens, porosity is formed, significantly affecting the strength of concrete [6, 19, 20]. Undeniably, lower density achieves lower strength. Hence, the PF are multi-filament enabling it to break into small size during mixing process. The small size of PF mixed homogenously, empowers it to fill up the void ratio in concrete. This means that, the multi-filament fibres could develop bonding between the particles materials and reduced void ratio to improve compressive strength [19].

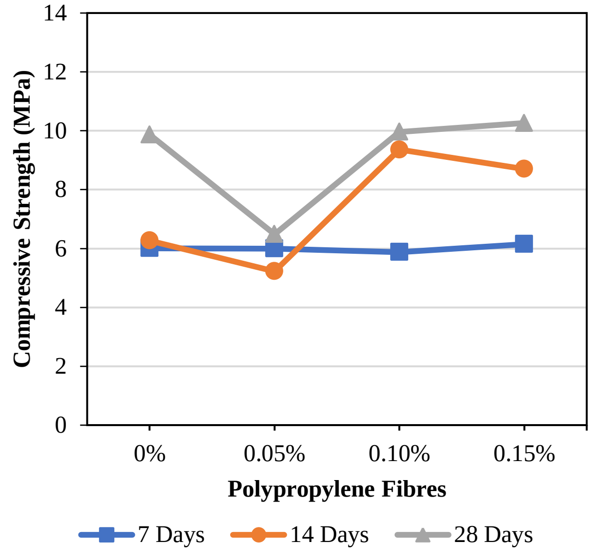

Figure 2: Compressive strength behaviour of 1600 kg/m^3 density of foamed concrete.

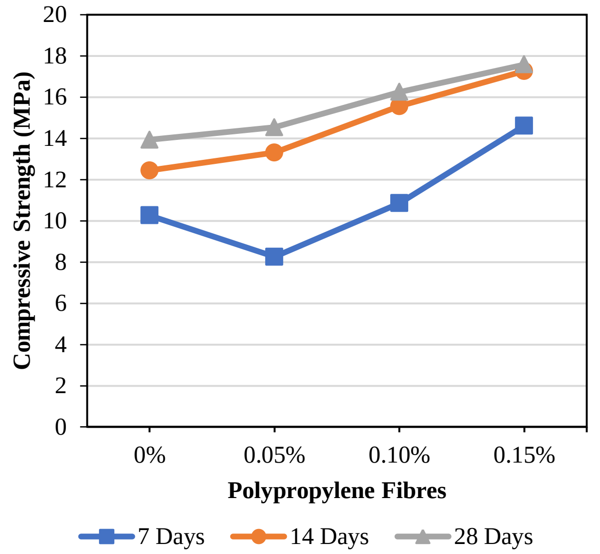

Figure 3: Compressive strength behaviour of 1800 kg/m^3 density of foamed concrete.

Table 1: Compressive strength of foamed concrete for density 1600 kg/m^3 and 1800 kg/m^3.

Target density (kg/m^3)	PF Fibres (%)	Compressive Strength (MPa)		
		7 Days	14 Days	28 Days
1600	0%	6.01	6.27	9.87
	0.05%	6.0	5.23	6.49
	0.10%	5.88	9.36	9.96
	0.15%	6.15	8.70	10.26
1800	0%	10.26	12.44	13.93
	0.05%	8.25	13.31	14.53
	0.10%	10.85	15.56	16.25
	0.15%	14.61	17.26	17.58

4.2 Modulus of Elasticity

The samples having diameter 150 mm and length 300 mm were tested in laboratory after 28 days curing according to ASTM C469 [21]. The results are shown in Table 2 and represented in Figure 4. Based on both result modulus of elasticity, the maximum Young's modulus obtained in foamed concrete specimen which has 0.15% PF. The density for 1600 kg/m3 achieved 14.41% increase in Young's modulus compared to controlled sample. While density for 1800 kg/m3 showed an increase of 65.06% compared to controlled foamed concrete. The modulus of elasticity influenced by materials additives used in foamed concrete. The synthetic fibres itself consists of 3.5 kN/mm2 modulus of elasticity, although indirectly, slightly increased the stiffness of foamed concrete. Moreover, compressive strength also influences stiffness of concrete. In this study, higher the compressive strength obtained higher Young's modulus [22].

Table 2: Results of modulus of elasticity of foamed concrete for both densities.

Polypropylene Fibres %	Modulus of Elasticity (N/mm^2)	
	1600 kg/m^3	1800 kg/m^3
0.00%	7945	10643
0.05%	8051	10819
0.10%	8377	16131
0.15%	9090	17567

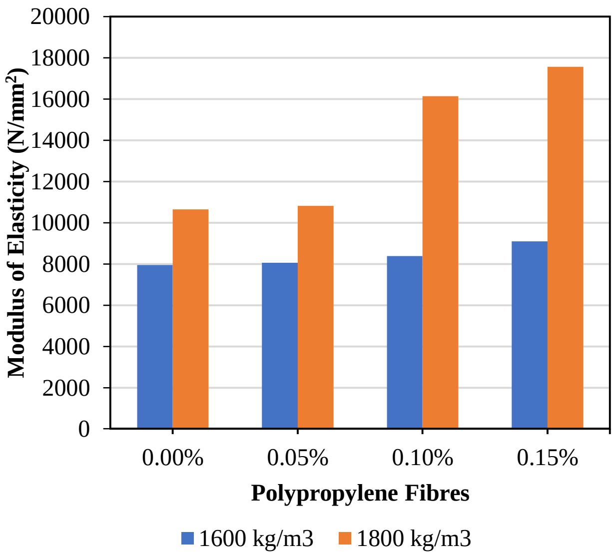

Figure 4: Modulus of elasticity of different densities of foamed concrete.

5. Conclusion

Based on the study, the following conclusions can be drawn:

1. The compressive strength has a linear relationship with the percentage PF added in both densities.
2. Both densities of foamed concrete obtained higher compressive strength when 0.15% PF were added, achieving 10.26 MPa and 17.58 MPa for densities 1600 and 1800 kg/m^3 respectively.
3. The compressive strength was influenced by density of foamed concrete. This meant that for bigger density such as 1800 kg/m^3 used less foam agent compared to 1600 kg/m^3. Meanwhile, foam agent produced air bubble after mixed with mortar and micro-crack occurred. During force acting on surface of foamed concrete it could not resisted more loading.
4. PF being a multi-filament enables it to separate itself into fineness filament and act as filler characteristic to fill up voids created by foam to bond between the inner granular particles.
5. As far as modulus of elasticity is concerned, both densities obtained increased modulus of elasticity when 0.15% PF was added in both densities. The modulus of elasticity was determined to be 9090 N/mm^2 and 17567 N/mm^2 for densities 1600 kg/m^3 and 1800 kg/m^3 respectively.
6. From the line graphs and bar chart, it is proven that the higher the compressive strength the higher the modulus of elasticity.

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