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Influence of polypropylene fibres on the tensile strength and thermal properties of various densities of foamed concrete

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Abstract. As almost half of the world's population now lives in the urban areas, the raise in temperature in these areas has necessitated the development of thermal insulating material. Conventional concrete absorbs solar radiation during the daytime while releasing it at night causing raise in temperature in urban areas. The thermal conductivity of 2200 kg/m³ density conventional concrete is 1.6 W/mK. Higher the thermal conductivity value, greater the heat flow through the material. To reduce this heat transfer, the construction industry has turned to lightweight foamed concrete. Foamed concrete, due to its air voids, gives excellent thermal properties and sound absorption apart from fire-resistance and self-leveling properties. But due to limited studies on different densities of foamed concrete, the thermal properties are not understood properly thus limiting its use as thermal insulating material. In this study, thermal conductivity is determined for 1400, 1600 and 1800 kg/m³ densities of foamed concrete. 0.8% of Polypropylene fibres (PP) is used to reinforce the foamed concrete and improve the mechanical properties. Based upon the results, it was found that addition of PP fibres enhances the tensile strength and slightly reduced the thermal conductivity for lower densities, while the reverse affect was noticed in 1800 kg/m³ density.

1. Introduction

The increase in migration of people from rural areas to urban cities due to economic benefits, has led almost half of the world's population [1] to dwell in the urban areas. Due to this urbanization, it has become necessary to manage the urban microclimate [2]. Building materials, such as concrete and asphalt used in the construction of pavements, roofs and other building components, have the tendency to absorb significant amount of solar radiation, ultimately causing concentrations of urban roads and buildings [3] to overheat compared to the rural areas during the day.

Urban overheating is a product of global warming, which effects the urban climate and the urban heat island (UHI) effect which occurs mainly in cities [4]. UHI is the phenomenon in which the temperature in the urban areas raises slightly compared to the surrounding rural areas, thus causing urban cities to become heat 'islands'. Though UHI varies from city to city in terms of intensity and magnitude, however it is the measure of difference between the urban and its surrounding rural temperatures [5,6].

The ability of any material to allow heat to flow through it is known as the thermal conductivity. Concrete and asphalt which are extensively used in urban construction, have profound impact on the



urban thermal balance. These building materials absorb the solar radiation which is dissipated by convective and radiative heat transfer into the urban atmosphere and increases air temperature consequently [7]. Type, amount and form of moisture content present in the concrete has considerable influence on its thermal conductivity [8]. The conventional concrete of 2200 kg/m^3 has thermal conductivity of 1.6 W/mK [9]. The greater the value of thermal conductivity, the lesser resistance to heat transfer through the medium. It is therefore become necessity for the tropical countries, where constant hot climate is maintained throughout the year, to use thermal insulating building materials to counter the UHI effect. A good thermal insulating building material is one which has low thermal conductivity value.

Foamed concrete is a potentially thermal insulating material. It has become well-known material in the construction industry due to its ability to resistance the flow of heat through it. Dry density of foamed concrete ranges from 300 to 1840 kg/m^3 [10]. Homogenous pore voids are created with the introduction of air using the foaming agent [11,12] which is also used to control the density of the foamed concrete [13]. The higher the amount of foam used, reduced density of foamed concrete is achieved. The introduction of air voids makes the foamed concrete up to 87% lighter than conventional concrete. This light-weightness achieved by foamed concrete allows it to reduce the self-weight which is another advantage over conventional concrete. Due to the presence of air voids in the foamed concrete, the heat flow is slowed down making foamed concrete, an excellent thermal insulating building material.

Due to reduced density, foamed concrete achieves lower compressive and tensile strengths while also developing micro-cracks. It has been observed that lower densities develop less mirco-cracks than higher densities of foamed concrete [14,15]. Therefore, nowadays concrete is being enhanced with the addition of Polypropylene fibres (PP fibres). PP fibres, which are synthetic organic fibres, are a product of polymerization process in which monomer polymers are turned into long chains of polypropylene. Over the years, various amount of PP fibres has been used in foamed concrete and it was observed that 0.8% of PP fibres are the optimum addition rate for enhancing the properties and performance of concrete [16].

Although the lightweight foamed concrete has been around for years, but it still lacks the study in terms of its thermal ability. Therefore, this study is done to reduce the energy consumption of the building and contribute to mitigation of UHI effect. To enhance the mechanical properties, 0.8% PP fibres are added into the three densities of foamed concrete, 1400 kg/m^3 , 1600 kg/m^3 and 1800 kg/m^3 . The thermal conductivity was also determined to understand the thermal performance of the different densities of foamed concrete with and without the addition of PP fibres.

2. Materials and Methodology

2.1 Materials

Ordinary Portland cement (OPC), sand, water and foaming agent were used for the making of foamed concrete [17] while PP fibres were also added. The foaming agent is used to control the density and obtain the three different densities of foamed concrete used in this study. The foaming agent was used in a ratio of 1:20 with water. The mix proportion of foamed concrete was taken as 1:2 cement-sand ratio, with 0.55 water-cement ratio. Cylindrical specimens of 0.3 m length and 0.15 m diameter were cast to determine the splitting tensile strength. For the thermal properties, panels of 0.3 m x 0.3 m x 0.05 m were cast and thermal conductivity test was conducted.

2.2 Properties of Polypropylene fibres

Fibrillated PP fibres were used in this study. The characteristics of the PP fibres are shown in table 1.

Table 1. Characteristics of polypropylene fibres [18]

Composition	100% Polypropylene fibre
Configuration	Fibrillated/Multi-Filament
Fibre Length	19 mm
Specific Gravity	0.9
Melting Point	160°C - 170°C
Tensile Strength	45-60 ksi (0.31 – 0.42 kN/mm ²)
Thermal Conductivity	Low
Electrical Conductivity	Low
Absorption	None
Modulus of Elasticity	0.5 × 10 ksi (3.5 kN/mm ²)

The permeability as well as the plastic shrinkage is decreased when the fibrillated PP fibres are used in the concrete, while it is also known to enhance the impact resistance, cohesiveness and abrasion resistance fatigue [19]. In this study, dosage of 0.8% of PP fibres is added into each sample of foamed concrete with densities 1400 kg/m³, 1600 kg/m³ and 1800 kg/m³.

2.3 Experimental Procedures

OPC, sand, water, foam and PP fibres were mixed together in the mixer and poured into moulds and kept for 24 hours. Afterwards these were unmoulded and kept for air curing for 28 days. The splitting tensile test was conducted using the Universal Testing Machine according to the BS EN 12390-6:2009 [20].

Panels of the three densities were used in the thermal conductivity test. The test was conducted according to BS EN 12664:2001 [21]. Four holes were drilled on the surface of sample with the depth of 10, 15, 20 and 30 mm to insert with the thermocouples. The panels were then placed on the container of the thermal conductivity apparatus that was attached with cold plate on top and hot plate on bottom. The initial temperature was controlled as for hot plate was set at 40°C by using power system while cold plate set at 18°C by using chiller system. The temperature of hot and cold plates was recorded at every 10 minutes interval for 24 hours. Thermal conductivity value can be determined based on the calculated data recorded from the computer.

3. Results and Discussion

3.1 Splitting Tensile Strength

The results of splitting tensile test conducted on cylinder specimens after 28 days curing is shown in table 2 and figure 1 shows the tensile strength vs. PP fibres for the three densities of foamed concrete.

Table 2. Average splitting tensile of various densities of foamed concrete

Target Density (Kg/m³)	% of PP Fibres	Splitting Tensile (MPa)
1400	0% controlled	0.69
	0.8%	1.00
1600	0% controlled	1.20
	0.8%	1.54
1800	0% controlled	2.60
	0.8%	2.10

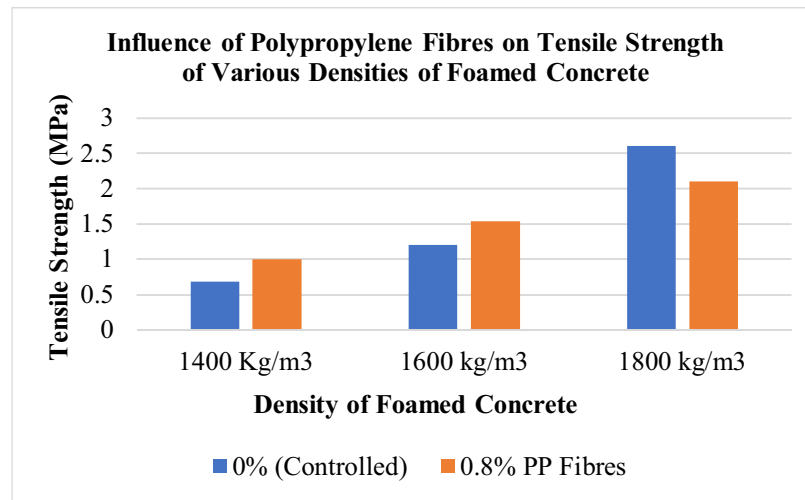


Figure 1. Average splitting tensile of various densities of foamed concrete

From the results, it can be observed that 0.8% PP fibres increases the tensile strength by 44.93% in 1400 kg/m³ density foamed concrete while 28.33% increase was achieved in 1600 kg/m³. But for the 1800 kg/m³ density foamed the addition of PP fibres had adverse impact, it lost 19.23% of its tensile strength compared to the controlled sample.

The PP fibres can enhance the split tensile strength as the fibre can provide a bridging effect with the foamed concrete matrix. Shear stress acted can be transferred from the interface to the fibres and consequently the entire load can be supported. The transfer of stress helped in improving the tensile strain capacity which resulted in the increase of splitting tensile strength for foamed concrete added with PP fibres. Sudden reduction of split tensile strength at density of 1800 kg/m³ can be due to the non-uniform distribution of the fibres that may occur during the mixing process.

3.2 Thermal Conductivity

The thermal conductivity values of the three densities were obtained and are shown in table 3 while figure 2 shows thermal conductivity value vs. percentage of PP fibre added for various densities of foamed concrete.

Table 3. Average thermal conductivity of various densities of foamed concrete

Target Density (Kg/m ³)	% of PP Fibres	Thermal Conductivity, k (W/mK)
1400	0% controlled	0.66
	0.8%	0.64
1600	0% controlled	0.71
	0.8%	0.70
1800	0% controlled	0.82
	0.8%	0.84

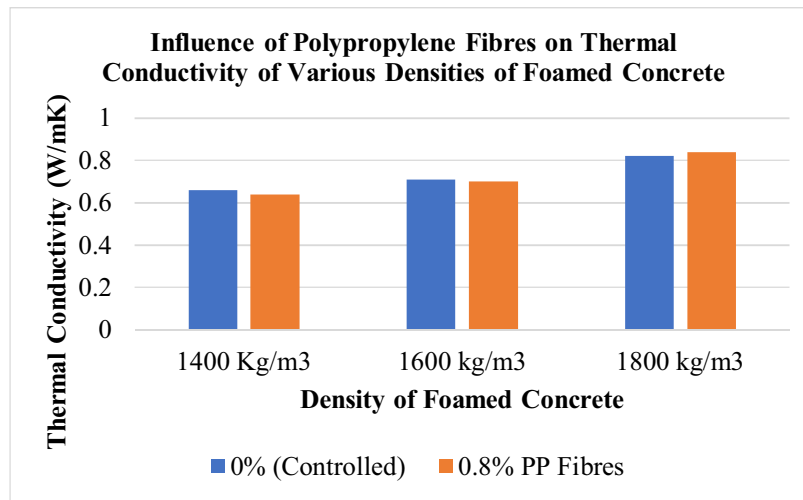


Figure 2. Thermal conductivity of various densities of foamed concrete

Lower the value of thermal conductivity makes the material to resist the heat transfer through it. The thermal conductivity for the controlled sample of 1400 kg/m³ was recorded to be 0.66 W/mK but when the addition of 0.8% PP fibres were added, 0.64 W/mK thermal conductivity was achieved, which is approximately 3.03% reduction. The decrease in thermal conductivity value was also noticed with the addition of PP fibres in 1600 kg/m³ density foamed concrete, reducing the thermal conductivity value from 0.71 W/mK (controlled sample) to 0.70 W/mK (0.8% PP fibres) with reduction of 1.41%. Interestingly the thermal conductivity increased 2.43% from 0.82 W/mK to 0.84 W/mK for the 1800 kg/m³ density foamed concrete when PP fibres were added.

PP fibres being hydrophobic, retain water, during the thermal conductivity test, the water attained with PP fibres may dry out leaving the voids to be occupied by air. The air voids trap the heat and slow down the transfer. So theoretically, the thermal conductivity value should decrease with the addition of PP fibres. From the results, this is visible for both the lower densities of foamed concrete. The gain in 1800 kg/m³ can be explained due to the non-uniform distribution of fibres or due to other factors such as variation in hole depth which are drilled to place the thermocouples to measure the internal temperatures.

4. Conclusion

Based upon the results obtained, the following conclusion are drawn:

1. Splitting tensile strength is higher when the density of foamed concrete increase as the amount of pore and voids decrease in higher density.
2. The addition of PP fibres enhances the tensile strength of 1400 kg/m³ and 1600 kg/m³ density foamed concrete, achieving significant increase strength. But the higher density of foamed concrete, 1800 kg/m³, however showed decrease in tensile strength upon the addition of PP fibres.
3. The PP fibres also had a positive impact on thermal conductivity, reducing the value slightly for both 1400 kg/m³ and 1600 kg/m³ while the value was increased in 1800 kg/m³ density foamed concrete when PP fibres were added.
4. The loss in splitting tensile, and slight gain in thermal conductivity can be associated to the non-uniform distribution of fibres in the 1800 kg/m³.
5. The effect of PP fibres increases in lower densities of foamed concrete, which is evident from the splitting tensile and thermal conductivity of all the three densities of foamed concrete.

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