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Improvement in tensile and flexural ductility with the addition of different types of polypropylene fibers in cementitious composites

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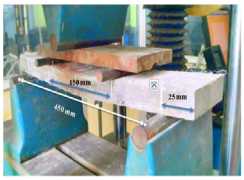
GRAPHICAL ABSTRACT



Flexural test set –up along with sample

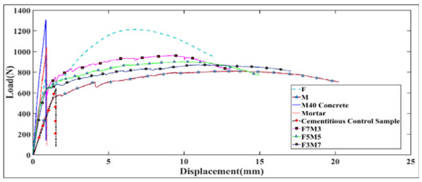


Fig. 1. Flexural load-displacement diagram of different samples

Direct tensile test set –up along with dogbone sample

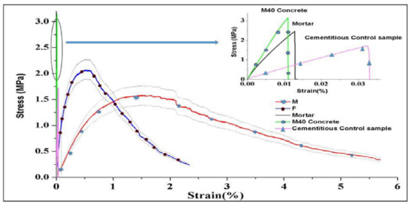


Fig. 2. Uniaxial direct tensile stress-strain diagram of different samples

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ABSTRACT

The influence of addition of fibrillated and monofilament polypropylene fibers to a cementitious composite mix on the tensile strength, flexural strength and ductility characteristics of the sample are being probed in this study. The study demonstrates that addition of fibrillated variety improves the strength of the samples both in tension and flexure in comparison to that of monofilament variety, whereas the addition of monofilament variety improves the tensile and flexural ductility characteristics of the sample. A combination of both these type of fibers improves the tensile strength and ductility characteristics along with improvement in flexural ductility with no significant improvement in flexural capacity.

1. Introduction

Improved tensile and flexural ductility along with lightweight characteristics are typical needs of high-performance concrete and/or cementitious composite materials for use in infrastructure.

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It is well known that certain mechanical properties of concrete and/or cementitious composites can be improved by the addition of reinforcing materials such as steel wires, glass and carbon fibers, synthetic polymeric fibers (polypropylene, polyethylene, polyvinyl alcohol, acrylics, polyamide, polyester). Out of these different synthetic fibers, polypropylene (PP) fibers have been adjudged as the most efficient [1–3] because of their low cost, ductility, ease of dispersal, good anchoring capability, no corrosion, thermal stability (high melting point in comparison to other polymer fibres), being chemically inert and stable under alkaline environment of concrete/cementitious composite material as well as chemically inert and stable under strong acidic environments. In this manuscript, we have considered only cementitious composites with polypropylene fiber as reinforcements.

There is numerous literature on improvement of mechanical performance with the addition of polypropylene fibers in cement concrete mix [4–10] as compared to that in cementitious composites [11–14]. It should be noted that the differences between concrete and cementitious composite are in presence of coarse aggregates. Since the strength and stiffness of coarse aggregates are significantly different from the surrounding matrix, observing the influence of addition of fibers to the matrix becomes difficult in presence of coarse aggregates in matrix. Typically, coarse aggregates are like inclusions in a matrix. The entire matrix along with the inclusions when subjected to load results in development of internal stresses due to the presence of aggregates which might help in the initiation of cracks. On the other hand, fibers are added to control cracks; thereby addition of the two materials: fiber – which helps in crack propagation mitigation and coarse aggregate which results in crack initiation may counter the effect of each other. With this in perspective, the manuscript deals with cementitious composites with polypropylene fiber reinforcements. Generally, polypropylene is available in commercial market as monofilament and/or in fibrillated forms. The study makes an attempt to identify the comparative improvement in mechanical performance with addition of these different forms of polypropylene fibers in the cementitious composites.

In this regard, it should be mentioned that there are related study in literature in which the adherence of polypropylene to the cementitious matrix has been explored through different methodologies such as alkaline and silane treatment [15,16], mechanical modifications such as fibrillation and indentation [17], altering surface polarity [18], altering surface chemistry and morphology [19,20], plasma treatment [21], introducing functional groups through treatment with acids and other chemicals [22–24]. It should be noted that the objective of this paper is not on modification to the properties of commercially available polypropylene fibers so as to improve the mechanical performance. Moreover, most of the methodologies presented in the above references are quite complex to be practiced in the field. The objective of this paper is to use commercially available polypropylene fibers in different forms and observe the mechanical performance improvement if any.

2. Casting methodology

Two different types of polypropylene fibers have been considered in this study – fibrillated and monofilament. Both the fibers have been tested in the laboratory for their mechanical properties. The fibrillated fibers (F) have tensile strength of 670 MPa, modulus of elasticity as 7.52 GPa and a contact angle of 71.31^0; whereas monofilament fibers (M) have tensile strength of 550 MPa with modulus of elasticity as 5.5 GPa and contact angle of 45.18°. Typically, it is reported that polypropylene fibers are hydrophobic (with contact angle greater than 90°), however the supplied fibers from the manufacturer were hydrophilic in nature. The fibers were supplied by the companies typically used for infrastructural purposes, where spinning oil coating (trade name of Encimage) of the fiber is done. This is because when fibers are cut, due to high abrasion resistance the cutters are heated up which might damage the fibers since the melting point of the fibers is around 165 °C. When the fibers are extruded, they are passed through spin-finish oil which along with water, dissipate the heat. This helps the individual fibers to form a bunch thereby helping in cutting operation. It was also mentioned that these fibers are used for infrastructural applications and because of the hydrophobic nature they tend to agglomerate and thereby disrupting dissipation [25]. Both the fibers (fibrillated and monofilament) has a specific gravity of 0.91, with 12 mm cut length and 34 μm average diameter. The percentage of polypropylene fiber content in the cementitious mix has been kept as 2% by volume.

Ordinary Portland cement (OPC 53 grade conforming to IS: 12269–1987 [26]) has been used in preparing the cementitious mix and the physical properties of cement have been determined in the laboratory. The physical properties of OPC as estimated are: specific gravity = 3.15, normal consistency = 30%, initial setting time = 147 min, final setting time = 273 min, soundness by Le-Chatelier apparatus = 0.20 mm, fineness by dry sieving = 4% also by Blaine apparatus = 399 m^2/Kg. The oxide compositions of OPC have also been estimated in the laboratory using X-ray Fluorescence spectrometer which are as follows: CaO = 64.60%, SiO_2 = 17.83%, Al_2O_3 = 5.04%, Fe_2O_3 = 3.34%, K_20 = 0.40%, MgO = 1.44%, TiO_2 = 0.33%, SO_3 = 2.63%, P_2O_5 = 0.18%.

The fly ash (conforming to IS 3812-Part I [27]) used in the mix has the following properties which are estimated in the laboratory: specific gravity = 2.20 and fineness by Blaine apparatus = 730 m^2/Kg. The oxide compositions of the fly ash as determined in the laboratory are as follows: CaO = 1.84%, SiO_2 = 53.71%, Al_2O_3 = 25.17%, Fe_2O_3 = 9.59%, K_20 = 2.70%, MgO = 0.24%, TiO_2 = 4.10, % SO_3 = 0.8%, P_2O_5 = 1.07%. Another ultrafine pozzolanic material (apart from fly ash) that has been added to the mix is silica fume (specific gravity = 2.20) having spherical particles less than 1 μm in diameter, with an average being about 0.15 μm. The oxide compositions of silica fume as determined from X-ray Fluorescence spectrometer are as follows: CaO = 2.82%, SiO_2 = 92.90%, Al_2O_3 = 0.70%, Fe_2O_3 = 0.08%, K_20 = 0.60%, MgO = 0.10%, TiO_2 = 0.01%, SO_3 = 1.80%, P_2O_5 = 0.86%. As per IRC:SP:46-2013 [28] and ACI 226-1987 [29], the percentage by volume of fly ash is kept around 35% of the OPC cement in this study. As per ACI 234R-2000 [30], the percentage by weight of Silica fume is kept around 15% of the OPC in this study.

Ultra-fine sand (specific gravity = 2.66) having particle size less than 150 μm has been used as a component of the mix. The proportion of sand to binder material (cement + pozzolonic materials like fly ash and silica fume) is kept as 0.1 by weight in this study. In this regard, it should be noted that previous literature prescribes sand to cement ratio as 0.5 or lower [31] and sand to binder ratio as 0.3 [32]. Ultra fine sand has been used as per specifications for the manufacture of strain-hardening cementitious mortars, which is known to act as a good filler material. Polycarboxylate based superplasticizer has been added to the mix to maintain the consistency level (slump value = 150–175 mm) with the specified water/cementitious material ratio of 0.3. Viscosity modifying agent (VMA) has been utilized to maintain the viscosity of the green cementitious mix such that proper dispersion of fibers is ensured. It should be noted that the amounts of VMA and superplasticizer utilized are negligible compared to the volume and/or the weight of the other components in the mix.

The methodology used for mixing of the cement composite material is as follows: at first cement, sand and fly ash are mixed for a couple of minutes to get a uniform dry mix. Half of the total amount of water, superplasticizer and VMA are then added to the