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Experimental Investigation on polymer fiber reinforced engineered cementitious composites under Flexural and Shear Loading

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Abstract

This paper deals with the experimental investigation of flexural and shear strength of Engineered Cementitious Composites (ECC) with polymer fibers viz., polyester and polypropylene. The effects of strain hardening behaviour and toughness of the specimens under flexure are investigated. Shear test is carried out with a newly fabricated double shear test setup. The Experimental results shows that the ECC mixes with polymer fibers yielded higher flexural and shear strength compared to conventional mixes without fiber due to enhanced ductility. The failure pattern of ECC mix under flexure and shear is such that multiple cracks are formed under the load as well as there is a uniform distribution of minor cracks throughout the tested specimen. Polypropylene based ECC leads to relatively higher flexural and shear strength due to its enhanced ductility and higher strain hardening capability compared to Polyester based ECC mix.

The conclusions of the study can be used for the design of ECC with enhanced ductility and toughness with polymer fibers.

Keywords: Engineered cementitious composite (ECC), fiber, polyester, polypropylene, flexure, shear

INTRODUCTION

One of the primary function of fibers is their ability to enhance the strain capacity of the cement composite. The improved strain capacity in tension helps to reduce cracking under restrained conditions. Hence material composition with strain hardening properties named Engineered Cementitious Composites (ECC) is developed for producing high performance, with low volume concentrations of short fibers (2%) in a cementitious material [1]. In high early strength ECC, tailoring the flaw-size distribution in the matrix microstructure is necessary to produce multiple cracking. Beams with ECC mix performs better under shear loading than the high strength concrete beams with dense shear reinforcement [2]. ECC overlay on the conventional concrete improved the load carrying capacity of the beam by imparting ductility to the system [3]. In addition to shear and flexure, ECC has higher fatigue resistance than steel fiber reinforced concrete which causes the crack bridging stress to decrease with increase in repetition of loads [4]. The fatigue characteristics of ECC overlaid beam is not influenced by interfacial property which is an important property in the deformation of the overlaid beams [5]. Ductility of ECC beam is dependent on enhanced workability and fiber dispersion within the concrete [6]. Apart from strength properties, ECC is durable against sulphate and chloride even after an exposure of 200 days [7]. Under a constantly applied tensile load using displacement controlled system, the permeability of ECC is observed to be relatively less than the conventional fiber reinforced concrete (FRC). ECC is made durable against water absorption, permeability, freezing and thawing by coating the surface with super-hydrophobic admixture [8]. The type of fibers used for the production of ECC has influence on the strength properties. Polyvinyl alcohol fibers (PVA) in ECC has high interfacial chemical bond which results in high toughness than PVA in FRC [9]. Self-consolidating PVA ECC has been developed with strain hardening property through proper control on processing and micromechanical parameters [10]. Kong et al. (2003) [11] has studied strength properties of polyethylene based self-consolidating ECC mix by employing micromechanical and rheological design. Application of PVA fiber along with shape memory alloy (SMA) fiber in ECC results in improvement of tensile and flexural capacity by 59% and 97% than ECC with PVA fiber alone [12]. In this study, the polymer fibers such as polypropylene fiber and polyester fibers are taken for studying the flexural and shear strength ECC mix.

PROPERTIES OF MATERIALS:

Cement (C):

The physical properties of ordinary Portland cement tested as per IS: 4031 are given below

i)	Grade	: 53(OPC)
ii)	Specific gravity	: 3.15
iii)	Particle size range	: 31µm to 7.5µm
iv)	Normal consistency	: 28%
v)	Initial setting time	: 110 minutes
vi)	Final setting time	: 260 minutes

Standard sand (G)

The Physical properties of sand used in investigation are given below:

i) Specific gravity : 2.65

ii) Particle size : 0.3mm to 0.6mm (grade II)

0.075mm to 0.15mm (grade II

Silica fume (SF)

The physical properties of silica fume are given below

i) Specific gravity : 2.2

ii) Particle size range : 0.2 to 25μm

iii) Percentage of passing : 92%

Superplasticizer (SP)

In this study structuro-100 superplasticizer which is poly-carboxylic ether based has been used.

Polymer Fibers

Polymer fibers like polyester and polypropylene fibers are used for the study. The properties of the fibers are given in Table 1.

Table 1. Physical properties of fibers

Fiber type	Length(mm)	Density (kg/m3)	Young's modulus (GPa)	Tensile strength (MPa)
Polyester	10	1.34	17.25	897
Polypropylene	20	0.91	3.40	295

a) Polyester fiber **b) Polypropylene**

Figure 1. Fibers for production of ECC

MATERIALS AND MIX PROPORTIONS

ASTM Type I Portland cement, low calcium class F fly ash and Silica fume are used. Large aggregates were excluded in ECC mix design, and only fine standard sand (i.e. grade II) is incorporated. Discontinuous, polyester and polypropylene fibers are used in this study. The fiber dimensions and properties are shown in Table 1. The volume fraction of fibers included in the matrix is 2%. The mix proportions of the matrix taken based on the (Li paper) are given in Table 2. All the mix proportions are by weight of the ingredients.

Table 2: Mix proportions

Mix No	Cement	Flyash	Silica fume	Sand	W/C
I	1	1	0	1	0.44
II	1	0	0.1	1	0.30

PREPARATION OF TEST SPECIMENS

The various ingredients required for the different types of concretes viz., cement, sand, silica fume, water, polymer fibers and superplasticizer were taken by weight. A Hobart type planetary mixer machine (Fig.2) was used for mixing the mixtures. All the dry materials required for the mixtures were placed in the mixer machine and mixed in the dry condition for 30 seconds. The required water and superplasticizer were added and the materials were thoroughly mixed for 5 to 15 minutes till a uniform color was obtained and the mix achieved the required consistency. Fibers were introduced slowly without any bulking and mixed.

Figure 2. Hobart mixer machine

The test specimens required for flexural strength of size 70×70×350mm were cast in steel moulds. The cast specimens were first kept under normal water curing for 3 days and followed by hot water curing at 90ºC for 3 days. The specimens were cured for remaining 28 days in water.

EXPERIMENTAL INVESTIGATION

Flow Characteristics of Fresh Concrete

Workability of ECC mixes are calculated through flow test as per ASTM 230 [13]. The fresh concrete mix placed in the flow table and initial flow was measured. The final flow was measured by giving 25 blows. The values of the flow were tabulated in Table 3. It is observed that polyester based ECC mix has lesser spread values compared to polypropylene based ECC mix which is due to the tendency of polyester fiber to absorb mixing water and leads to relatively lesser spread value.

Table 3: Flow values of Fresh Mix

Mix no	ECC with Polyester fiber	ECC with Polypropylene fiber
I	Initial – 110mm Final - 140mm	Initial – 110mm Final - 220mm
II	Initial – 100mm Final – 160mm	Initial – 120mm Final - 195mm

EXPERIMENTAL PROGRAM FOR FLEXURE

The beam specimen of size 70×75×350mm are tested with standard two-point loading. Both ECC beam with fiber and without fibers were cast and tested. The deflection is measured by dial gauge placed at the mid point. The specimens were tested in universal testing machine with proper test setup (Fig 2). The deflection was measured using dial gauge at mid-point for each load intervals of 0.5 KN.

Figure 2. Flexural Test setup

RESULTS AND DISCUSSION

In the ECC beam specimens, the first crack started inside the mid-span at the tensile face, and multiple cracks developed from the first cracking point and spread to the outside of the mid-span. The multiple cracks in the outside of the mid-span were inclined cracks similar to shear cracks in steel reinforced concrete (RC) beams. As the moment of resistance (MOR) is approached, one of the cracks inside the mid-span started to open up after a large damage zone had been developed. The stress-deflection curves for polyester and polypropylene fiber were shown in Figure 3. The flexural strength of beam specimens obtained from testing is tabulated in the Table 4. The failure mode shows that the polypropylene fiber reinforced concrete undergoes maximum deflection and develops very fine cracks compared to polyester fiber reinforced concrete. The results suggest that the ductility of polypropylene based ECC beam is relatively higher than the ductility of polyester based ECC beam. Flexural strength of both ECC mix with fibers produced nearly 50% increase than the ECC beam without fiber. Polyester based ECC results in relatively higher flexural strength at first crack and has a relatively lesser ultimate flexural strength due to relatively brittle behavior. As the area under the curve of PP based ECC mix is high, toughness of the concrete is higher than PE based ECC mix.

a) Failure pattern of Polypropylene ECC beam

b) Failure pattern of Polyester ECC beam

Figure 3. Typical failure pattern of ECC specimen tested under flexure

Table 4: Flexural strength of different ECC mix

Mix	ECC mix	First crack strength (MPa)	Deflection at first crack (mm)	Flexural Strength (MPa)	Max Deflection (mm)	Increase in strength compared to control concrete (%)
I	ECC with Polypropylene fiber	12.8	0.672	16.355	7.24	155
II		13.4	0.426	17.25	6.15	158
I	ECC with Polyester fiber	13.511	0.624	14.22	3.87	111
II		13.98	0.48	15.24	2.94	153
I	Control concrete (ECC without fiber)	-	-	6.40	-	-
II		-	-	7.12	-	-

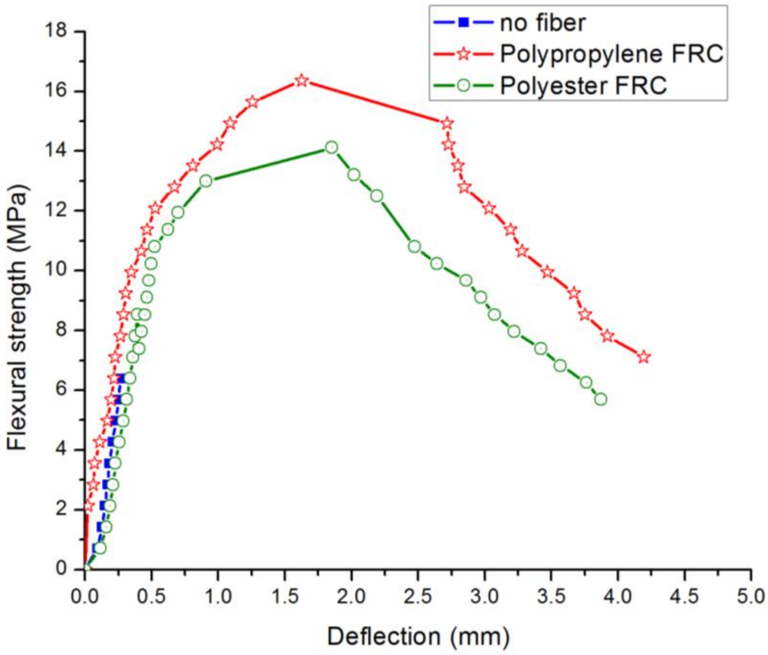

Figure 4. Variation of flexural strength with deflection of ECC mixes

CONCRETE ELEMENTS SUBJECTED TO SHEAR

The test setup for double shear testing is shown in the Figure 5. The experimental setup is being fabricated for this purpose since there is no standard method for testing shear capacity of the beam specimens.

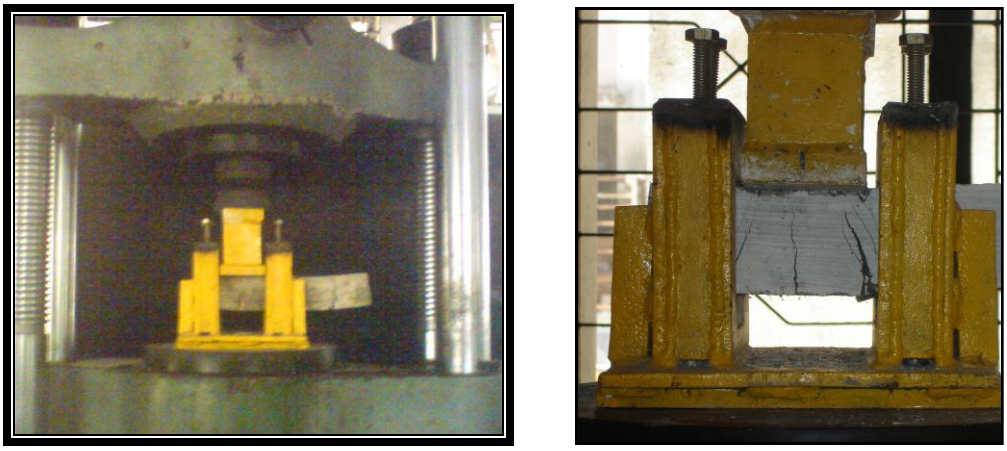

Figure 5. Double shear Test setup

After first crack strength, the ram load continued to increase till the ultimate shear strength is reached. The pseudo strain-hardening behavior of PP based ECC revealed itself in the form of multiple diagonal cracks with small crack widths of less than 0.1 mm even up to ultimate load. In contrast, the PE based ECC beam fails shortly after first crack load with relatively less number of crack opening as the crack width increased at continuously softening load. The tested specimen shows diagonal cracks near the support for both ECC mixes. The average shear strength of ECC specimens tested under shear is given in Table 5. The ECC mix with fibers resulted in nearly 60% higher shear strength than the ECC mix without fibers. The ultimate shear strength of PP based ECC mixes are nearly 20% higher than PE based ECC mixes.

Table 5. Shear strength of various ECC mix

Mix	ECC mix	Shear strength (N/mm^2)	Increase in strength compared to control concrete (%)
I	ECC with Polypropylene fiber	14.5	170
II		15.89	167
I	ECC with Polyester fiber	11.4	163
II		12.48	158
I	Control concrete (ECC without fiber)	4.25	-
II		5.18	-

CONCLUSION

The flexural and shear strength of PP and PE based ECC mixes are studied and the following conclusions are arrived.

i) Polypropylene based ECC leads to relatively higher flexural strength due to its enhanced ductility and higher strain hardening capability compared to Polyester based ECC mix.

ii) Shear strength is calculated with newly fabricated double shear test setup yielded better results with multiple shear cracks in both ECC mixes.

iii) PP based ECC resulted relatively higher shear strength values compared to PE based ECC.

iv) Toughness of PP based ECC mix is higher than PE based ECC mix

v) It is observed that PP based ECC mix resulted in better concrete properties in terms of flexure and shear testing.

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