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Mechanical Behavior of Recycled Pet Fiber Reinforced Concrete Matrix

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Abstract**—**Concrete is strong in compression however weak in tension. The tensile strength as well as ductile property of concrete could be improved by addition of short dispersed fibers. Polyethylene terephthalate (PET) fiber obtained from hand cutting or mechanical slitting of plastic sheets generally used as discrete reinforcement in substitution of steel fiber. PET fiber obtained from the former process is in the form of straight slit sheet pattern that impart weaker mechanical bonding behavior in the concrete matrix. To improve the limitation of straight slit sheet fiber the present study considered two additional geometry of fiber namely (a) flattened end slit sheet and (b) deformed slit sheet. The mix for plain concrete was design for a compressive strength of 25 MPa at 28 days curing time with a water-cement ratio of 0.5. Cylindrical and beam specimens with 0.5% fibers volume fraction and without fibers were cast to investigate the influence of geometry on the mechanical properties of concrete. The performance parameters mainly studied include flexural strength, splitting tensile strength, compressive strength and ultrasonic pulse velocity (UPV). Test results show that geometry of fiber has a marginal effect on the workability of concrete. However, it plays a significant role in achieving a good compressive and tensile strength of concrete. Further, significant improvement in term of flexural and energy dissipation capacity were observed from other fibers as compared to the straight slit sheet pattern. Also, the inclusion of PET fiber improved the ability in absorbing energy in the post-cracking state of the specimen as well as no significant porous structures.

Keywords**—**Concrete matrix, polyethylene terephthalate (PET) fibers, mechanical bonding, mechanical properties, UPV.

I. Introduction

CONCRETE is known to be weak in tensile strength and crack resistance. Conventionally, steel reinforcement is provided in concrete in order to carry the tensile forces and prevent any cracking. Adding short dispersed fibers could help in enhancing the flexural and tensile strength of the concrete. The main fibers used as concrete reinforcing materials are steel, glass, and polymeric fiber. The polymeric fibers that can be used in concrete reinforcements are nylon, aramid, polypropylene, polyethylene, polyester, etc.

Polyethylene terephthalate (PET) bottles have been replaced glass bottles as a storage container because of its easy handling, storage, and lightweight. Therefore, the productions of PET bottles have increased exponentially. Utilizing these waste bottles in any form would be benefitted not only in the prevention of the environmental pollution but also energy saving in the disposal. Excellent contributions of PET fiber in concrete using a different form of PET fibers have been explored [1]-[4].

Research revealed that PET fiber in concrete has a significant role in term of bonding and strength [1]. Nevertheless, PET fiber has a very weak bond with cement paste. To improve the bond strength, fiber may be drawn into different geometry and size. Hand cutting PET fibers is in the form of straight slit sheet either in a short or long [1], [3]. It was observed that straight slit sheet fibers typically have low bond strength with the concrete matrix as compared to the other geometries. Therefore, in order to improve the mechanical bonding of PET fiber on the concrete matrix different geometries of PET fibers is designed and the study is carried out to observe the effect on mechanical properties.

II. Experimental Design

A. Cement and Aggregates

Ordinary Portland Cement (OPC) of 53 grades conforming to Bureau of Indian Standard (BIS) [5] was considered. Aggregates of about 12 mm size from crushed basalt rock and river sand was used as coarse and fine aggregates. All materials are tested as per relevant BIS codes [6], [7].

B. PET Fibers

By maintaining the same cross-sectional area (7.2 cm^2 approx.) the fibers as shown in Fig. 1 were produced by hand cutting into different geometries as per guidelines provided by ACI [8] for steel fiber. The fibers geometries are (a) Straight slit sheet (b) flattened-end slit sheet and (c) deformed slit sheet.

C. Casting and Curing of Specimens

The mix for ordinary concrete was design for a compressive strength of 25 MPa at 28 days curing time with a water-cement ratio (*w/c*) of 0.5. PET fiber with fiber volume fractions of 0.5% was considered. A conventional step of mixing was adopted. Test specimens were designated as SP1, SP2, SP3, and SP4 as illustrated in Table I. Concrete containing no fiber was used as reference specimens (SP1). The specimens were demoulded after 24 hours of casting and were kept in the water tank for 28 days curing period.

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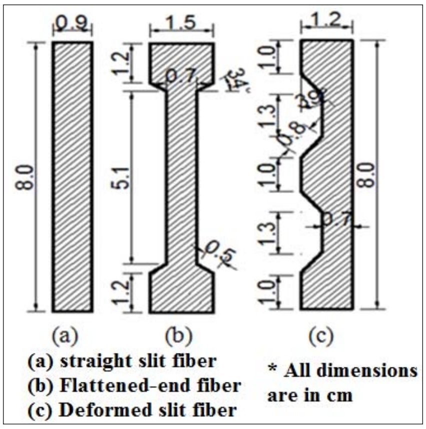
(a)

(b)

(c)



(d)

Fig. 1 Fiber geometry obtained by hand cutting from PET bottle (a) Straight slit sheet fiber (b) Flattened end slit sheet fiber (c) Deformed slit sheet fiber (d) Fiber Dimensions

TABLE I
SPECIMENS DESIGN

Specimen	Size (mm)	Testing Methodology	Characteristics
SP1	Beam: 100x100x400	Flexural and Ultrasonic pulse velocity (UPV)	Concrete with 0% fiber
	Cylindrical: 150x300	Compressive and splitting tensile	
SP2	Beam: 100x100x400	Flexural and UPV	Concrete with 0.5% straight slitsheet fiber
	Cylindrical: 150x300	Compressive and splitting tensile	
SP3	Beam: 100x100x400	Flexural and UPV	Concrete with 0.5% flattened end slit sheet fiber
	Cylindrical: 150x300	Compressive and splitting tensile	
SP4	Beam: 100x100x400	Flexural and UPV	Concrete with 0.5% deformed slit sheet fiber
	Cylindrical: 150x300	Compressive and splitting tensile	

IV. Results And Discussion

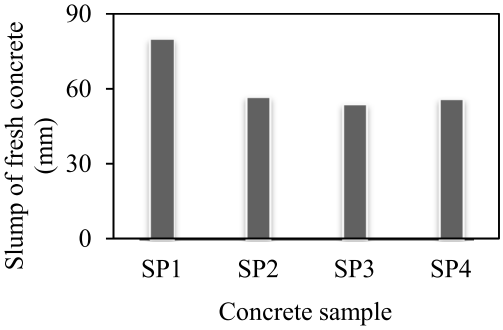
A. Fresh Concrete Properties

In fresh concrete – concrete should be a workable state so that desired shape can be moulded. Thus, the workability of concrete indicates the degree of fluidity or mobility and surface finishing without detachment. The workability measuring is called a slump. The slump was measured at each stage of the mixes as per guidelines of BIS [9]. Fig. 2 shows a typical measurement process and value of slump attained by concrete specimens. It can be observed that for a *w/c* of 0.5%, a medium degree of workability was achieved for concrete with and without fibers. Further, a comparable slump values were also observed for fiber concrete of different geometry. Thus, it can be concluded that the shape of the fiber has a small significant effect on the workability of concrete.

B. Compressive Strength

The compressive strength test was carried out in accordance to BIS [10]. Fig. 3 shows the variations of strength for different concrete design. The increase in strength for specimens SP3 and SP4 was attributed to the good mechanical bonding of fiber in the concrete matrix in comparison to specimen SP2 where straight slit sheet fiber impart comparably weaker bonding to the concrete matrix. Fig. 4 shows the pattern of failures of the specimen during the compressive test. As presented in Figs. 4 (a) and (b), a similar failure pattern was observed for specimen SP1 and SP2 in which the specimens were crushed and possessed a brittle failure. However, a typical wedge failure mode was observed for specimens SP3 and SP4as shown in Fig. 4 (c). It reveals that shape of fibers has a significant effect on the failure of the specimens.

(a)



(b)

Fig. 2 (a) Measurement of slump (b) Variation of slump values

C. Splitting Tensile Strength Test

Splitting tensile strength of the specimens was carried out as per standard guidelines of BIS [11]. It was observed that the reference specimens without fibers suddenly split out once the concrete cracked as shown in Fig. 5 (a). However, the PET fiber concrete specimen exhibited cracking but did not fully separated out. This shows that PET fiber reinforced concrete has the ability in dissipating the energy in the post cracking state. Variations of tensile strength for different concrete designs are shown in Fig. 5 (b). The improvement in the tensile strength of fiber concrete over the conventional one was found to be better for specimen SP3 and SP4 as compared to SP2. This behavior was also attributed to the mechanical bonding due to shape effect.

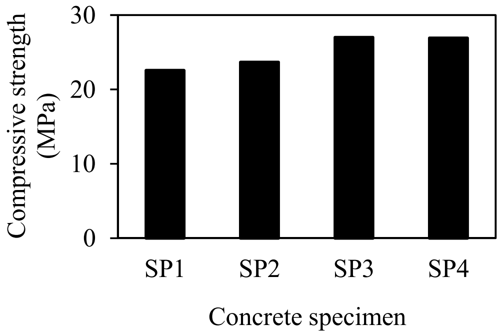


Fig. 3 Variation of compressive strength

(a) SP1

(b) SP2

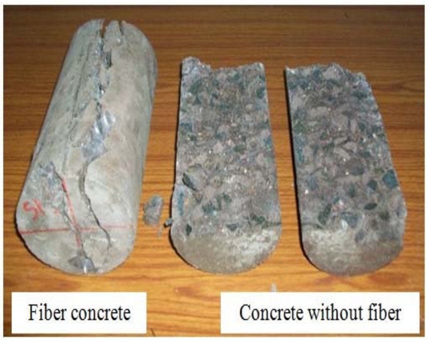
(b) SP3 and SP4

Fig. 4 Typical failure of specimens

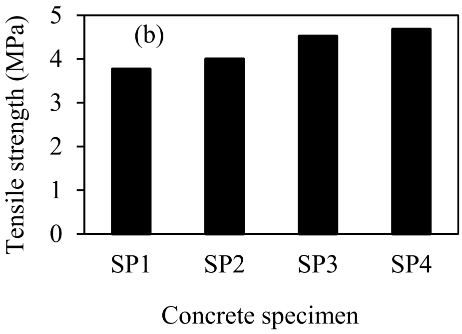
D. Flexural Strength

Testing of the specimens was carried out as per standard guidelines of BIS [10]. Fig. 6 (a) shows the testing arrangement of the specimens. All loads in the flexural test were applied till the specimens attained approximately the same displacement level or collapsed whichever occurred earlier. This procedure is adopted to facilitate the comparative study of their behavior. The failure of the specimen at the end of the test are shown in Fig. 6 (b). Failure of the specimen with fiber presents better performances as compared to the reference specimens without fiber (SP1). On the other hand specimens, SP3 and SP4 show significant improvement over SP2 for the same displacement level. This behavior is attributed to the good mechanical bonding between the fiber and the concrete matrix.

The typical load versus displacement curves from the flexural test on beam prism incorporating different fiber geometry is shown in Fig. 7. The curves depict that addition of PET fiber enable a greater capability of resisting more tensile stress, especially at the post cracking stage. Due to the brittle behaviour of concrete specimens without fiber, specimen SP1 failed suddenly and collapsed at low loads. However, fibers concrete specimen's shows significant improvement. The plot also depicts that curves of SP3 and SP4 lie above SP2. This shows that the fiber geometry has a key role on the performance of the concrete.



(a)



(b)

Fig. 5 (a) Specimens failures during splitting tensile test (b) Variation of splitting tensile strength

E. Energy Dissipation

The ability of a structural member to resist the fracture during loading depends to a large extent on its capacity to dissipate its energy. The area form represents the energy absorbed by the specimen by the load vs. displacement curves. As seen in Fig. 7 the load-deflection curves plotted for fiber concrete (SP2 to SP4) are larger than that of the reference concrete (SP1) without fiber. This shows that PET fiber concrete dissipated higher amounts of energy. Fig. 8 illustrated the energy dissipation capacity of the specimens. Specimens SP3 and SP4 shows higher energy dissipation over SP2 that reflect better performance in energy dissipation capability.

F. Ultrasonic Test

Assessments of the quality of concrete beam specimens were carried using ultrasonic pulse velocity (UPV) according to BIS [12]. Fig. 9 shows the typical location of transducers on the specimen. Observed test results revealed that UPV values of fiber concrete specimens, as well as reference concrete, are in the range of 3.5 km/sec to 4.5 km/sec. Thus, it indicated that the quality of UPV values falls in the "good" scale as per quality assessment.

(a)

(b)

Fig. 6 (a) Flexural test of concrete beam and (b) Failure pattern of specimens

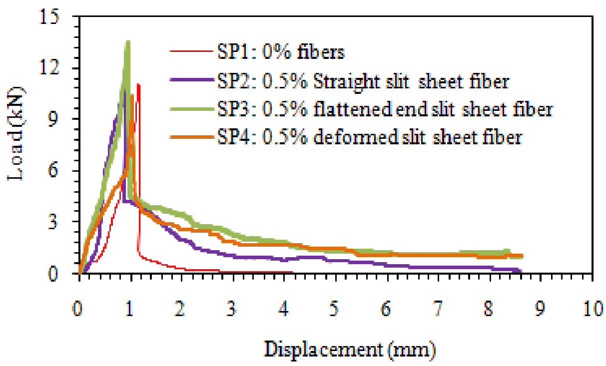


Fig. 7 Load-displacement curves

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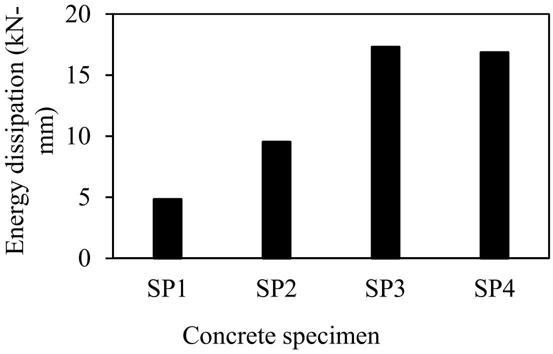

Fig. 8 Energy dissipation capacity

Fig. 9 Typical locations of transducers on the specimen

V. Concluding Remarks

In this paper, comparative studies were carried out to investigate the influence of different fiber geometries of PET materials on the physical and mechanical properties of concrete. The following conclusions were drawn.

1. For water cement ratio of 0.5 the workability of fresh concrete was slightly decreased with the inclusion of 0.5% PET fibers. However, the geometry of the fiber has a small, significant result on the workability of concrete.
2. The addition of 0.5% PET fiber in concrete enhanced the compressive strength of specimens and varied with the fiber geometry.
3. Tensile strength test results demonstrated that the inclusion of 0.5% PET fiber enhanced the tensile strength. The inclusion of PET fiber improved the tensile property and showed the ability in absorbing energy in the post-cracking state of the specimen.
4. Results from the flexural strength test show that inclusions of 0.5% PET fiber in the concrete increase the flexural strength. The load vs. displacement curves shows a ductile behavior for PET fiber concrete. The increases in flexural strength of concrete containing PET fiber, however, vary with the geometry of fiber. Flattened end slit sheet fiber and deformed slit sheet fiber shows significant improvement over the straight slit sheet fibers in term of load carrying capacity and energy dissipation capability.
5. The mixture of 0.5% PET fibers in concrete shows no sign of porous structures. Since an expected range of UPV value (3.5 km/sec to 4.5 km/sec) were obtained.

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