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Performance of plain pet fibres to enhance the mechanical behavior of concrete under tension and shear

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Abstract— **Concrete is the most widely used construction material in the world due to its high compressive strength, long service life, and low cost. However, concrete has inherent disadvantages of low tensile strength and crack resistance. To improve such weaknesses, the introduction of fibres was incorporated as an alternative to produce concrete with substantial tensile capacity as well as enhanced ductility property. Therefore, the purpose of this study was to investigate the mechanical behavior of fibre reinforced concrete under tension and shear. Polyethylene Tereplthalate (PET-Bottle) synthetic fibres of 40mm long, 1.5 mm width and 0.6mm thickness were added to concrete in various percentages, such as 0.0%, 0.40%, 0.46% and 0.52% as volume fractions. It was observed that workability of concrete reduced with increase in dosage of fibres. A total of 12 numbers cylinder specimens (each size 152mm× 305mm) were casted to investigate splitting tensile strength and for shear strength four beam specimens (each Size 762mm×152mm×152mm) were prepared to investigate the shear capacity. Test results after 28days curing shows that tensile strength and shear strength increased maximum values of about 25% and 70% for the addition of 0.52% and 0.46% respectively, compared to the plain concrete.**

Index Terms— **Balling of fibres , fibres reinforced concrete (FRC), fibres volume fraction, polyethylene terephthalate fibres (PET-fibres), splitting tensile strength test.**

I. Introduction

Plain concrete is brittle material, with low tensile strength and strain capacities. To overcome these problems, the use of fiber in concrete has been increased over the past 40 years [1]. Day by day the implication of concrete has been developed and the limitations of concrete have been slowly but surely eliminated which increase the durability of concrete allowing a higher performance value to be achieved. The introduction of fibers was brought in as an alternative to developing concrete in view of enhancing its flexural and tensile strengths. Although the basic governing principles between conventional reinforcement and fiber systems are identical, there are several characteristic variations; such as fibers are generally short, closely spaced and dispersed throughout a given cross section but reinforcing bars of wires are placed only where required [2].

Polyethylene Terephthalate (PET) is one of the most common consumer plastics used and is widely employed as a raw material to realize products such as blow bottles for soft-drink use and to containers for the packaging of food and other consumer goods. In 2007 it is reported a world's annual consumption of PET drink covers of approximately 10 million tons, which presents perhaps 250 milliards bottles. This number grows about up to 15% every year [3]. On the other hand, the number of recycled or returned bottles is very low. Indeed. PET is reported as one of the most abundant plastics in solid urban waste [4]. Being a non-biodegradable plastic waste, the disposal of Post-consumer PET has huge environmental impacts. A different use implies the use of waste PET bottles as PET fibers to produce fiber reinforced concrete with the aim to increase the toughness of concrete [5].

In 2009, an investigation was carried out by using PET bottle granules as a light weight aggregate in mortar and reported some advantages; such as – reduction in the dead weight of a structural concrete member of a building which help to reduce the seismic risk of the building, reduction in the use of natural resources, disposal of wastes, prevention of environmental pollution and energy saving [6]. The purpose of this study is to investigate the mechanical behaviour of concrete reinforced with plain PET fibres under tension and shear.

II. Experimental Investigation

A. Materials and Mixes

The main components of the polymeric fiber used in the study were Polyethylene Terephthalate (PET) fibers (Fig. 1). This fiber was prepared by cutting the used mineral water bottle with designated size such as - nominal length of 40 mm, average width of 1.5 mm and average thickness of 0.6mm. The fiber had an aspect ratio of 38 and specific gravity of approximately 1. The average tensile strength of the fiber was 100 MPa and tested by performing the Pullout test of briquette specimens. All the fibers used in this experiment were crystalline.

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Fig.1 Macro synthetic plain PET-fibres

Portland composite cement confirming 28 days (ASTM C109) cube strength 41.25MPa, initial setting time (ASTM C191) 126 minutes, final setting time 275 minutes was used as a binding material collected from the local market. Normal consistency was measured 27%. Coarse sand of angular and partially rounded shape having a fineness modulus of 3.31 was used as a fine aggregate. Stone chips maximum particle size of 20mm, well graded, were used as coarse aggregate. Tap water for mixing was used to cast specimens where water/cement ratio of 0.45 was used throughout the research. PET fibers with the fiber volume fractions of 0.0, 0.4, 0.46 and 0.52% were used where fiber containing no fiber was used as reference specimens. Mix ratio was 1:2:2.5:0.45 (Cement: Fine Aggregate: Coarse Aggregate: w/c ratio) in reference specimens. A total of 12 cylinder specimens (each size of 152mm × 305mm) and 4 beams (each size of 762mm × 152mm × 152mm) were cast and then tested in the laboratory.

B. *Mixing Sequence*

A rotary drum mixture machine was used to obtain the good quality of concrete. Firstly the coarse aggregate and fine aggregate were added prior to the PET fibers. These dry ingredients were mixed for about two minutes so that the fibers were evenly distributed throughout the mix. Special care was taken so as to ensure no fiber balls were formed. After that cement was added and these dry ingredients were mixed for about one minute. Water was added after one minute and was mixed for about 5 minutes so that a good mix was achieved. Then to measure the workability, slump test was done for both fresh and fibre reinforced concrete (Fig. 2). After that, concrete was then placed in the molds in three layers and a tamping rod (ASTM C 31/C 31M) of 600mm long and 16mm diameter was used to compact each layer. After finishing the compaction, a trowel was used to make the top surface smooth. The molds were then kept for 24 hours under a temperature of 25^0C to 32^0C to set the concrete. After 24 hours the specimens were demoulded and kept in the water tank for 28 days.

Fig.2 Slump Test

C. *Splitting Tensile Strength Test*

Direct tension tests are not reliable for predicting the tensile strength of concrete, due to minor misalignment and stress concentrations in the gripping devices. An indirect tensile test procedure was carried out in accordance to ASTM C 496/C 496M. In this test, concrete cylinder was placed with its axis horizontal in a compression testing machine.

Fig.3 Splitting tensile strength test

The load (P) was applied uniformly along two opposite lines on the surface of the cylinder through two plywood pads (each 330mm long, 25.4mm wide and 3.175mm thick). The tensile strength was then calculated by the equation (2) as under.

$$T = \frac{2P}{\pi LD} \tag{2}$$

Where, T = maximum splitting tensile strength (MPa),
L = length of cylinder (mm)
D = diameter of the cylinder (mm).

D. *Shear Strength test*

Direct shear test is performed by beam specimen (each Size 762mm × 152mm× 152mm). The shear load was applied by one loading block. The specimen was supported on two rigid blocks 305mm apart. A static load was applied in accordance with the JSCE-SF6 [7]. Mid span deflection was measured by averaging signals from deformation dial gauge attached to the bottom surface of the specimen.

Fig. 4 Shear capacity test of beam.

III. Results and Discussion

A. Workability

From this test it was obtained that workability of PET-fibre reinforced concrete was decreased with the increases of fibre dosages volume fraction. The addition of fibres changes the structure of the aggregate skeleton. In particular, the packing density decreases, requiring higher fines content in order to compensate for this effect. If proper attention was paid to the mix design, FRC can not only have the same workability as plain concrete with the same w/c ratio, but can also be made to be self-compacting. In order to produce self-compacting FRC, careful attention must be paid to the total particle size distribution of the mix, and to the choice of appropriate admixtures, both chemical and mineral if needed.

B. Splitting Tensile Strength test results

Table I below shows the average of indirect tensile strength of three cylinder specimen in each case recorded during the test and the percentage change in tensile strength for all mix batches relative to the control batch.

Table I Splitting Tensile Strength Test Result

Specimen Designation	% fibers volume fractions used	Average Tensile Strength (MPa)	Change in Splitting Tensile Strength (%)
TC	0.0	2.503	Reference Specimen
TPA	0.4	2.703	9
TPB	0.46	2.896	16
TPC	0.52	3.116	25

Fig. 5 below shows a graphical representation of the average indirect tensile strength for concrete containing no fibres and concrete containing different amounts of PET fibres.

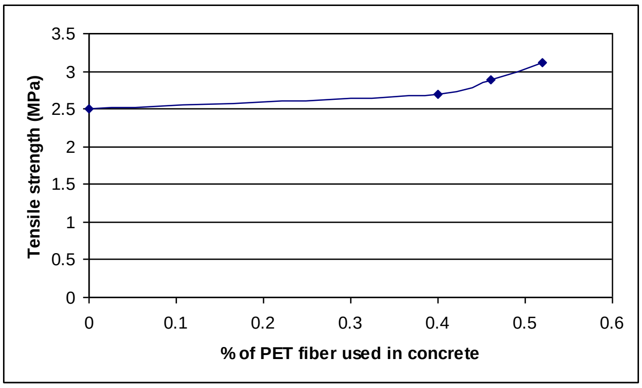

Fig. 5 Variation of tensile strength with different percentage of PET fibres.

Table II and Fig. 5 show that the indirect tensile strength was increased with the addition of plain PET fibers. The tensile strength of the concrete for the cylinder samples TPA and TPC were increased by at least 9% and 25% respectively relative to the sample TC. The maximum tensile strength was recorded as 3.116 MPa for the cylinder with PET-fibre volume fraction of 0.52%.

Fig. 6 Failure Pattern of cylinder specimen.

The reinforced concrete was split apart in the tensile strength test and as a result the load was transferred into the fibres as pull out behaviour when the concrete matrix began to crack where it exceeded the pre-crack state. The specimens containing fibres was not failed suddenly (Fig. 6) once the concrete cracked, while the PET fiber reinforced concrete specimens exhibited cracks but did not fully separate . This shows that the PET fibre reinforced concrete has the ability to absorb energy in the post-cracking state.

C. Shear Strength test results

Table II below shows the shear strength of beam specimen in each case recorded during the test and the percentage change in shear strength for all mix batches relative to the control batch.

Table II Shear Capacity Test Result

Specimen Designation	% fibers volume fractions used	Shear Capacity (kN)	Change in Shear Capacity (%)
CB	0.0	20	Reference Specimen
SB-I	0.4	26	30
SB-II	0.46	34	70
SB-III	0.52	30	50

Fig. 7 below shows a graphical representation of shear strength capacity for concrete containing no fibres and concrete containing different amounts of PET fibres.

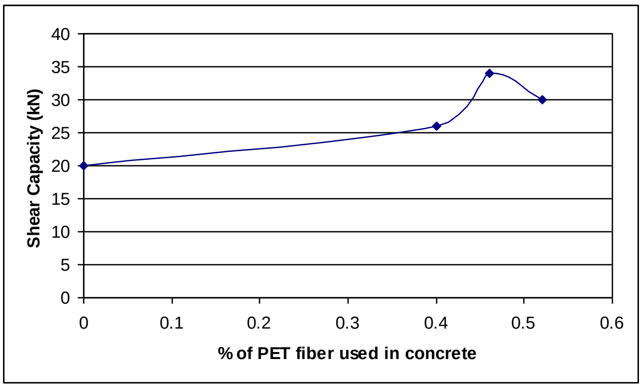

Fig. 7 Variation of shear capacity with different percentage of PET fibres.

Test results reveal that the addition of PET-fiber in concrete enhance shear capacity of the specimens. It was improved by at least 30% for the specimen SB-I and gradual improvement was found maximum value by at least 70% for the specimen SB-II relative to control specimen. Beyond the dosages of 0.52% PET-fiber volume fraction, it was declined. Hence for the specimen SB-III, shear capacity was declined to 20% relative to SB-II specimen. Fig. 8 shows the variation of Shear capacity with resection various percentages of fibre used. It was observed that fibre enhanced the shear capacity up to the inclusion of 0.52% PET fiber volume fraction. The reduction beyond this percentage may be due to the weak bonding of fiber of fiber to concrete matrix. The fiber may not have sufficient paste volume so that in can coat itself and strengthen the fiber- matrix interaction.

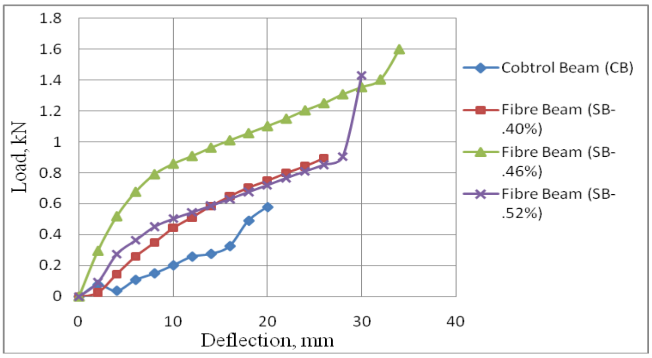

Fig. 8 Load versus deflection curves from direct shear test.

From load versus deflection curve, the maximum deflection was found for 0.46% fibre volume fraction (SB-II). But for 0.46% fibre volume fraction the peak deflection was downward than 0.52% fibre. The reason for this downward trend for specimen may be due to the inadequate concrete's workability for higher dosages and full compaction may not have been achieved. It can be improved by a slight increase of fine aggregate to have sufficient paste volume.

IV. Conclusions

The conclusions and specific findings of the research are summarized as follows

- From this slump test it was obtained that workability of plain PET-fibre reinforced concrete was decreased with the increases of % fibre volume fraction. Proper attention need to be paid to the mix design to have same workability as plain concrete with the same w/c ratio.
- From the laboratory test results it is shown that the tensile strength was increased with increases of fibres with the concrete. For maximum 0.52% volume fractions of PET-fibres, tensile strength increased by 25% compared to the plain concrete reference cylinders. Optimal tensile strength was not obtained beyond the fibre volume fraction of 0.52%. Moreover, the control batch specimens containing no fibers failed suddenly once the concrete cracked, while the PET-fiber reinforced concrete specimens were still remain as a unique.
- The addition of plain PET-fibers to concrete improved shear capacity. Shear capacity of concrete beam increased by 30%, 70% and 50% due to addition of PET-fibers of 0.40%, 0.46%, and 0.52% respectively, compared to the plain concrete specimen. These results indicate the fact that macro synthetic fiber reinforcement enhanced the shear capacity although the 0.46% fiber volume fraction is seems to be optimal. The reduction beyond this percentage may be due to the weak bonding of fiber of fiber to concrete matrix.

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