Performance of PET Bottle Fiber to Enhance the Mechanical Behaviour of Concrete

Abstract

Concrete is an indisputable material for the construction of various types of structures in the modern advancement of civil infrastructures. Concrete is strong in compression but weak in tension. To eliminate this problem, the introduction of fiber was brought in as an alternative to developing concrete in view of enhancing its tensile strength as well as improving its ductile property. Therefore, the purpose of this study was to investigate the mechanical behaviour of concrete reinforced with Polyethylene Terephthalate (PET-Bottle). Polyethylene Terephthalate (PET) fibers of 40mm long, 1.5mm width and 0.6mm thickness were added to concrete in various percentages, such as 0.0%, 0.3%, 0.5% and 0.75% of fiber as volume fractions. Specific gravity and unit weight of hardened concrete was measured and it was found that both were reduced insignificantly when percentages of PET fibers were increased. A total of 24 number cylinder specimens (each size 150mm×300mm) were cast to investigate compressive and splitting tensile strength. Test results after 28 days of curing reveal that compressive and tensile strength were increased maximum values of about 23% and 20%, respectively for the addition of 0.50% PET fiber volume fractions. Finally, optimum dosages of PET fiber volume fractions; such as 0.47% to attain maximum compressive strength and 0.44% to attain maximum tensile strength were found for the mix.

Keywords: Polyethylene Terephthalate (PET) fibers, Fiber Reinforced Concrete (FRC), Fiber Volume Fraction, Compressive Strength Test, Splitting Tensile Test.

1. Introduction

Concrete and cement based materials have been implemented in structural members since prehistoric times. Day by day the implication of concrete has been developed and the limitations of concrete have been slowly but surely eliminated which increases the durability of concrete allowing a higher performance value to be achieved. However, concrete is strong in compression but weak in tension. To overcome this weakness in concrete, steel reinforcement is used to carry the tensile forces and prevent any cracking or by pre-stressing the concrete so it remains largely in compression under load. Therefore, the introduction of fibers was brought in as an alternative to developing concrete in view of enhancing its flexural and tensile strengths (Banthia N and Sheng J, 1996). 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 or wires are placed only where required (Kosmatka S et al., 2002). For this reason fibers have been used to improve the toughness and ductility of concrete. It is used in industrial floors, tunnelling, mining, security structures, heavy duty pavements, slab types members, runways of airport where conventional reinforcement are impractical (Clarke J et al., 2007).

Polyethylene Terephthalate (PET) is one of the most important synthetic fibers for industrial production. The largest use of PET currently is in containers. In this area, beverage and mineral water bottles are standing in prime position. The current worldwide production of PET exceeds 6.7 million tons/year and shows a dramatic increase in the Asian region due to recent increasing demands in China and India (Kim et al., 2009). Last decade, few studies were done on mechanical behaviour of PET-FRC and fiber itself. Semiha A et al. (2009) investigated PET bottle granules as a light weight aggregate in mortar and reported some advantages; such as – reduction in the death 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. Santos P and Pezzin H (2009) performed an experimental study on recycle PET (r-PET) and observed that the incorporation of r-PET fibers in Polypropylene (PP) is an efficient way to recycle PET as well as enhancing the mechanical properties of PP. Frigione M (2010) carried out an study on r-PET as a fine aggregate and found that the r-PET concretes display similar workability characteristics and compressive strength, but splitting tensile strength slightly lower than the conventional concrete and a moderately higher ductility. Therefore, it has abundant scope to do research on PET fibre in conjunction with concrete as a discrete fibre by the various percentages of fibre volume fractions and carry out the laboratory investigation on the mechanical behaviour of PET-FRC. The purpose of this study is to investigate the mechanical behaviour of concrete reinforced with PET fibres.

2. Experimental Investigation

2.1 Materials and mixes

The main components of the polymeric fiber used in this study were Polyethylene Terephthalate (PET) fibers (Figure 1). This fiber was prepared by cutting the used mineral water bottle with size such as - nominal length of 40 mm, average width of 1.4 mm and average thickness of 0.6mm (Figure 2).The fiber had an aspect ratio of 90 and specific gravity of 1. The average tensile strength of the fiber was 100 MPa.

Figure 1: PET(mineral water) bottle ***Figure 2: PET fibers produced from bottle***

Portland composite cement confirming 28 days (ASTM C109) cube strength 40 MPa, initial setting time (ASTM C191) 126 minutes, final setting time 250 minutes was used as a binding material. Washed river sand of angular and partially rounded shape having a fineness modulus of 3.18 was used as a fine aggregate. Stone chips maximum particle size of 20mm, well graded, fineness modulus of 8.38 were used as coarse aggregate. Tap water for mixing was used to cast specimens where water/cement ratio of 0.42 was used throughout the research. PET fibers with the fiber volume fractions of 0.0%, 0.3%, 0.5% and 0.75% were used where fiber containing no fiber was used as reference specimens. Mix ratio was 1:2:2.5:0.42(Cement: Fine Aggregate: Coarse Aggregate: w/c ratio) in reference specimens.

2.2 Mixing sequences

A rotary drum mixture machine was used to get the good quality of concrete. In the mixer machine, at first the coarse aggregate and fine aggregate were added prior to the PET fibers. Then fiber was added and 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. Concrete was then placed in the moulds in three layers and a tamping rod (ASTM C 31/C 31M) of 600mm long and 16mm diameter was used to compact each layer. The number of roddings was 25 and falling height was 300mm from top surface of layer. After finishing the compaction, a trowel was used to make the top surface smooth. The moulds were then kept for 24 hrs under a temperature of 25^0C to 32^0C to set the concrete. After 24 hrs the specimens were demoulded and kept in the water tank for 28 days curing period.

2.3 Instrumentation and testing of hardened concrete

2.3.1 Compressive strength test

Compressive strength test procedure was carried out in accordance to ASTM C 39/C 39M. The prepared cylinders were capped so that load can transmit uniformly. Specimen to measure the compressive strength was instrumented as shown in Figure 3 and then test was performed by the compression testing machine.

Figure 3: Instrumentation of Cylindrical Specimen to Test the Compressive Strength

A maximum crushing load (P) was measured. Compressive strength was then calculated by the equation, $f'_c = \frac{4P}{\pi D^2}$ Where f'_c = compressive strength (MPa), P = maximum crushing load resisted by

the specimen before failure (N), D = diameter of the cylinder (mm).

2.3.2 Splitting tensile strength test

An indirect tensile test procedure was carried out in accordance to ASTM C 496/C 496M. The prepared cylinders were marked (Figure 4) after completing 28 days curing and instrumented as shown in Figure 5. In this test, concrete cylinder was placed with its axis horizontal in a compression testing machine.

Figure 4: Marking the Cylinders in Progress

Figure 5: Test Setup for Splitting Tensile Strength

The load was applied uniformly along two opposite lines on the surface of the cylinder through two plywood pads (each 325mm long, 25mm wide and 3mm thick). The tensile strength was then calculated by the equation $T = \frac{2P}{\pi LD}$; where T = maximum splitting tensile strength (MPa), L= length of cylinder

(mm) and D = diameter of the cylinder (mm).

2.4 Results and discussion

2.4.1 Specific Gravity and Unit Weight of Hardened Concrete

Average value of specific gravity and unit weight of hardened concrete is shown in Table 1.

Table 1: Specific Gravity and Unit Weight of Hardened Concrete (Room Temperature 29.4^{0}C)

Percentage of PET Fibers Used as volume fractions	*Average Specific Gravity*	*Average Unit Weight (kg/m^3)*
0.0%	*2.424*	*2461*
0.3%	*2.415*	*2445*
0.5%	*2.395*	*2422*
0.75%	*2.342*	*2294*

From Table 1, it can be demonstrated that inclusion of PET fiber in concrete reduced both specific gravity and unit weight of hardened concrete. However, the reduction was varying within small ranges, such as - 0.35% to 3.35% for specific gravity and 0.65% to 6.75% for unit weight. As a result, addition of PET fiber made the concrete slightly lightweight compared to the specimen containing no PET fibers.

2.4.2 Compressive strength test result

A total 12 numbers of cylinder with each size of 150mm × 300mm, four different percentages of PET fiber volume fractions, such as 0%, 0.3%, 0.5% and 0.75% were tested. Table 2 shows the average compressive strength test results and the change in compressive strength for each type of specimens.

Table 2: Compressive Strength Test Result

Specimen Designation	*% fiber volume fractions used*	*Average Compressive Strength (MPa)*	*Change in Compressive Strength (%)*
C_1	*0.0*	*37*	*Reference Specimen*
C_2	*0.3*	*41*	*11.5*
C_3	*0.5*	*44*	*20.2*
C_4	*0.75*	*34*	*-6.5*

Test results reveal that addition of PET fiber in concrete enhanced the compressive strength of the specimens. It was improved by at least 11% for the specimen C_2 and gradual improvement was found maximum value by at least 20% for the specimen C_3 relative to control specimen. Beyond the dosages of 0.5% PET fiber volume fractions, it was declined. Hence for the specimen C_4, compressive strength was declined to 6.5% relative to reference specimen.

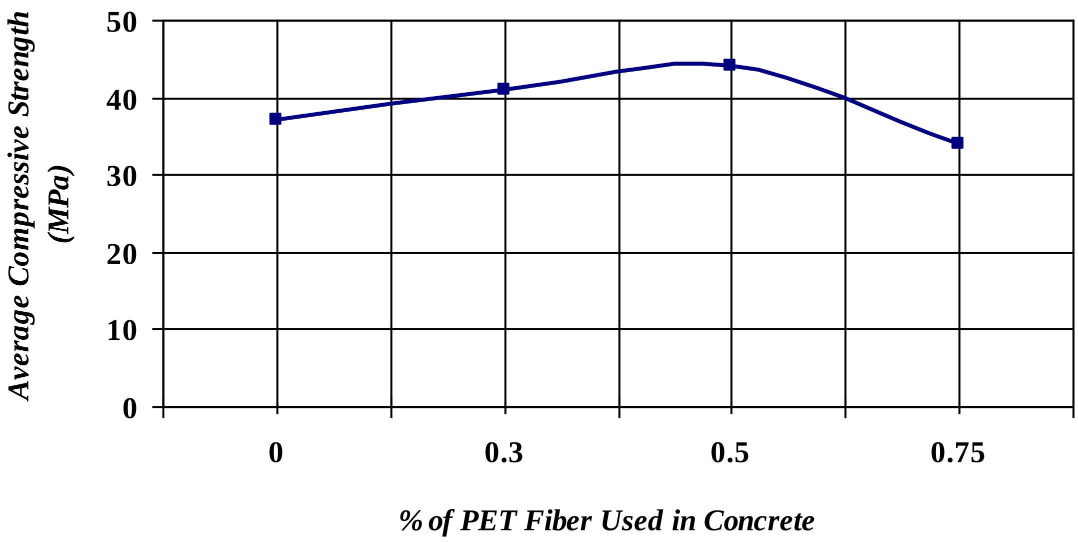

Figure 6: Compressive strength relative to the specimens of various % fiber volume fractions used

Figure 6 shows the variation of compressive strength with respect to various percentages of fiber used. It was observed that fiber enhanced the compressive strength up to the inclusion of 0.5% PET fiber volume fraction. The reduction beyond this percentage may be due to the weak bonding of fiber to concrete matrix. The fiber may not have sufficient paste volume so that it can coat itself and strengthen the fiber-matrix interaction.

Figure 7: Brittle failure of specimen C_1

Figure 8: Wedge failure were observed in specimen C_2 and C_3

Figure 9: De-bonding of fiber-matrix of specimen C_4

Failure pattern of the specimen in the Figure 7 shows that concrete without PET fiber failed suddenly and combined failure was found. However the strength value is acceptable when low to moderate strength is required. Wedge type failure was observed for specimen C_2 and C_3 (Figure 8). The specimens in this case did not fully separate. On the other hand, debonding of the fiber matrix had happened due to the slip of fiber when compressive strength of C_4 specimen was tested (Figure 9).

2.4.3 Splitting Tensile strength test result

Table 3 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 3: Splitting Tensile Strength Test Result

Specimen Designation	*% fibers volume fractions used*	*Average Tensile Strength (MPa)*	*Change in Splitting Tensile Strength (%)*
T_1	*0.0*	*3.77*	*Reference Specimen*
T_2	*0.3*	*4.52*	*20*
T_3	*0.5*	*4.63*	*23*
T_4	*0.75*	*4.01*	*7*

Figure 10 below shows a graphical representation of the average indirect tensile strength for concrete containing no fibers and concrete containing different amounts of PET fibers.

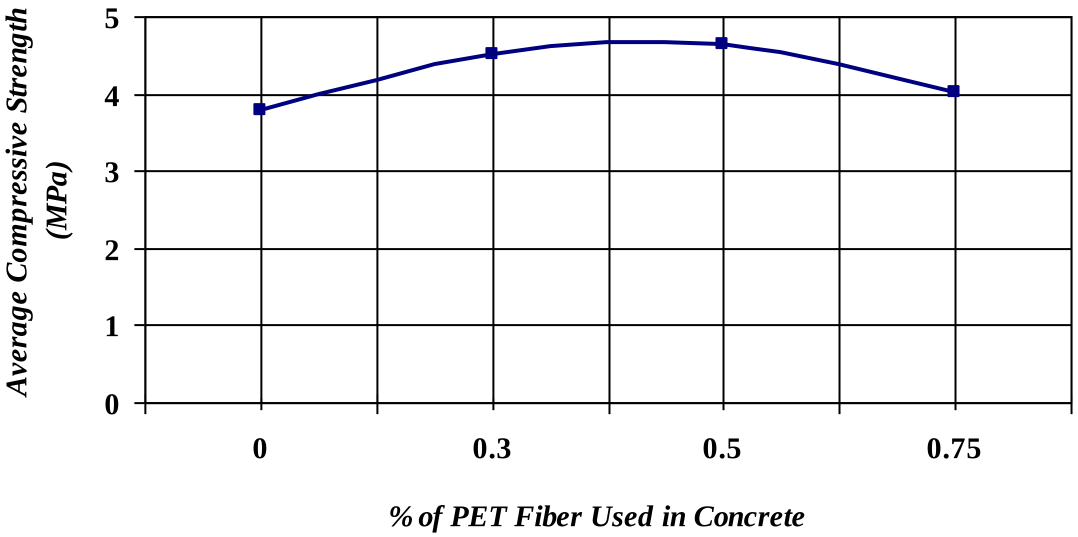

Figure 10: Variation of Splitting Tensile Strength with different percentage of PET fiber used in concrete

Table 3 and Figure 10 show that the indirect tensile strength was increased with the addition of PET fibers. The tensile strength of the concrete for the cylinder samples T_2 and T_3 were increased by at least 20 and 23%, respectively relative to the sample T_1. The maximum tensile strength was recorded as 4.63 MPa for the cylinder with PET fiber volume fraction of 0.5%. This increase in tensile strength was due to the fiber bridging properties in the concrete. The reinforced concrete was split apart in the tensile strength test and as a result the load was transferred into the fibers as pullout behavior when the concrete matrix began to crack where it exceeded the pre-crack state.

Figure 11: Brittle failure of specimen T_1

Figure 12: Fiber bridging of specimens T_2, T_3 and T_4

The control batch specimens containing no fibers failed suddenly (Figure 11) once the concrete cracked, while the PET fiber reinforced concrete specimens exhibited cracks but did not fully separate (Figure 12). This shows that the PET fiber reinforced concrete has the ability to absorb energy in the post-cracking state. However, the tensile strength of the cylinder specimen was increased for the sample T_4 7% compared to the reference specimen T_1. The reason for this downward trend for T_4 specimen may be due to the inadequate concrete's workability (fibers are known to decrease 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 for coating the fibers and the addition of super plasticizer to offset the possible reduction in the slump, particularly for the mixtures with high fiber content.

3. Conclusion

The conclusions as well as specific findings of the research are summarized as follows:

- PET fiber tends to reduce the specific gravity and unit weight insignificantly, such as 0.35 to 3.35% for specific gravity and 0.65 to 6.75% for unit weight compared to the reference specimen.

- Compressive strength was increased by at least 20% to the inclusion of 0.5% PET fiber volume fractions. Moreover, cylinder specimen without PET fiber showed brittle failure where as inclusion of PET fiber enhanced the crack bridging properties of the specimen.

- Indirect tensile strength test result demonstrate that inclusion of 0.5% PET fiber volume fraction enhanced tensile strength a maximum value by 23%. Again, cylinder specimen without PET fiber was failed suddenly and separated into two parts. Therefore, inclusion of PET fiber enhanced the tensile property and showed the ability to absorb energy in the post-cracking state of the specimen.

- The trend curve on both cases revealed that gradual improvement on strength can be possible up to the limit by 0.5% PET fiber volume fractions. However, from the graphs optimum fiber dosages were found slightly lower than 0.5% which was by 0.47% for compressive strength test and by 0.44% for indirect tensile strength test. Hence by performing statistical analysis, it would be feasible to identify the optimum dosages precisely in between these two values.

- The empirical assumption that tensile strength of concrete is approximately one-tenth of compressive strength was verified. Hence precision of laboratory works might be agreed.

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