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Shear Strength of Waste Plastic (PET) Fiber Reinforced Concrete

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Abstract - In this paper, the shear strength of plastic (PET) fiber reinforced concrete (PFRC) is discussed. The post-consumer PET mineral bottles were manually cut into fiber form after removing neck and bottom, and these fibers were used to reinforce the plain concrete. The concrete of M20 and M30 grades were selected for the study. The PET fibers were obtained from used mineral water bottles, without any processing, of two sizes with aspect ratios 35 and 50. The fibers were added in proportions 0.0 % to 3.0 % at an increment of 0.5%. The concrete specimens were tested after 28 days of curing. The shear resistance of plastic fiber reinforced concrete (PFRC) was found to be increased. The maximum increased in shear strength of PFRC was 27.25% for M20 grade of concrete at 1% fiber volume fraction with aspect ratio 50, over the normal concrete. A model for predicting the shear strength for PFRC is presented, based on the experimental results, in terms of cube compressive strength and fiber volume fraction.

Key Words-Plastic fibers, Grades of concrete, Aspect ratio, Shear strength, Model.

I. INTRODUCTION

Concrete is a miraculous man made material for civil engineering construction. The fibers inclusion in cement base matrix acts as unwanted micro crack arrester and prevents prorogation of cracks under load. Waste disposal is become one of the major environmental, economic and social issues. The waste plastic is being among the most prominent, waste polyethylene terephthalate (PET) bottles are recycled and used for different purposes. The use of plastic in concrete helps to improve the basic properties of concrete. The main advantages of using plastics in concrete is its durability, resistance to chemicals and light in weight but disadvantage of using plastic in concrete is that it has smooth surface, their bond characteristics. Batayneh M. *et al*. [1] have studied the effect of ground plastic on the slump of concrete. They observed decrease in the slump with the increase in the plastic particle content. For a 20% replacement, the slump has been decreased to 25% of the normal concretre. Soroushian P. *et al*. [2] have also reported reduction in slump with the use of recycled plastic in concrete. Ismail Z.Z. and Hashmi E. A. [3] have found that the slump is prone to decreasing sharply with increasing the waste plastic ratio. Al-Manaseer A. A. and Dalal T. R. [4] investigated the effect of plastic aggregates on the bulk density of concrete. They concluded that the bulk density of concrete decreased with the increase in plastic aggregates content. Choi Y. W. *et al*. [5] have discussed the effects of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the compressive strength of concrete. They found that compressive strength of concrete mixtures decreased with the increase in PET aggregates. Marzouk O. Y. *et al*. [6] have presented the innovative use of consumed plastic bottle waste in granule form as sand substitution aggregate within composite materials for building application. The granuales made from Bottles Poly Ethylene Terephthalate (PET) were used as partial and complete substitutes for sand in concrete composites. They reported that substituting sand at a level below 50% by volume with granulated PET, whose upper granular limit equals 5 mm, affected the compressive strength of composites and plastic bottles shredded into small PET particles may be used successfully as sand-substitution aggregates in concrete composites.

Ochi T. *et al.* [7] have investigated development of recycled PET fiber and its application as concrete-reinforcing fiber. They described a method that can be used to produce concrete-reinforcing PET fiber from used PET bottles. The issue of concern in the development of PET fiber was its alkali resistance and they encountered no problems when using these fibers in normal concrete. Kim Sung Bae*et al.* [8] have proved structural performance evaluation of recycled PET FRC. A procedure to recycle waste PET bottles is presented, in which short fibers made from recycled PET were used within concrete. The test results have shown that compressive strength and elastic modulus both decreased as fiber volume fraction increased and cracking due to drying shrinkage was delayed in presence of PET fiber in concrete specimens, compared to concrete specimens without fiber.

Foti Dora [9] have experimented on plastic fiber-reinforced concrete; the improvements in ductility behaviour of the concrete were reported. Nibudey R. N. *et al.* [10, 11, 12, and 13] have optimized the benefits of using post consumed waste PET bottles in the fiber form in concrete. The concrete of M20 and M30 grade with two aspect ratios 35 and 50 of waste plastic fibers were experimented to determine green and harden properties concrete. It was observed that slump, compaction factor and dry density of concrete reduces as compared to normal concrete when fiber content increases and reduction in these values found higher for larger value of aspect ratio. It was observed that, at 1% of fiber content improvement in mechanical properties of plastic fiber reinforced concrete was higher for aspect ratio 50 than aspect ratio 35.

From previous research works it is clear that the post consumed Poly Ethylene Terephthalate (PET) bottles in fiber form can be used in concrete. The use of plastics in fiber form has given better results than any other forms. In this paper behaviour of plastic fiber reinforced concrete (PFRC) under shear strength and models for prediction of shear strength of PFRC in terms of cube compressive strength and fiber volume fraction is presented.

II. EXPERIMENTAL PROGRAMME

A. Materials Used

1. Cement

Portland Pozzolana Cement (Fly Ash based) was used in this experimentation conforming to IS: 1489-1991 (Part I) [14]. The physical properties of cement used in the study were as follows - Fineness (specific surface) = 322 m2/kg, Standard consistency = 32 %, Initial setting time = 210 minute, Final setting time = 330 minute, Soundness (Le-Chat.) = 1.5 mm and 28 days compressive strength = 50.7 MPa.

2. Aggregates

The natural sand obtained from river was used as fine aggregate, having specific gravity 2.53, water absorption 1.2 %, bulk density 1718.52 kg/m3, fineness modulus 2.65, silt content 0.61% and conformed to grading zone- II as per IS: 383-1970 [15]. The crushed stone aggregates were used of 20 mm and 10 mm size and tested as per IS: 383-1970 and 2386-1963 (Part I,II and III) specifications[16]. The physical properties of coarse aggregates were as shown in Table 1.

Table 1 Physical properties of coarse aggregates

Properties of aggregates	20 mm	10 mm
Specific gravity	2.85	2.83
Water absorption (%)	1.15	1.23
Bulk density (kg/m^3)	1564.2	1694.8
Fineness modulus	7.05	6.06

3. Water

Potable water was used for mixing and curing of specimens.

4. Super Plasticizer

To impart workability a super plasticizer AC-PLAST-BV-M4 conforms to IS: 9103-1999 was used in the experimentation.

5. Plastic fibers

The post consumed PET mineral water bottles of single brand were collected from local restaurants and the fibers were cut after removing the neck and bottom of the bottle. The aspect ratio (AR) of waste plastic fibers were 35 (AR-35) and 50 (AR-50). The specific gravity of plastic fibers was 1.34.

B. Experimental Methodology

1. Concrete mix

Based on the trial mixes for different proportion of ingredients final mix proportion was selected as per IS 10262:2009. [17] The concrete mix proportions were as shown in Table 2.

Table 2The concrete mix proportions

Grade	Water	Cement	Fine aggregates	Coarse aggregate, 20 mm (60%)	Coarse aggregate, 10 mm (40%)
M20	0.52	1	1.60	2.31	1.54
M30	0.48	1	1.42	2.13	1.42

2. Specimens and Tests

The cubes of 150 mm size were casted for compressive strength, with 0.0 to 3.0% fiber volume fraction at an increment of 0.5%, of PET fibers. The cubes were tested after 28 days of curing under compression testing machine of capacity 2000 kN as per IS 516-1959[18].

The shear test was carried out on push off type (double 'L' type) specimen. The overall size of specimen was 200 x 350 mm with the two gaps of 25 mm. To ensure the failure of concrete in shear at predefined plane, the steel reinforcement was placed vertically away from shear failure plane to avoid any other failures like flexure or compression. This is a single shear failure test as the failure will occurs at one plane. The specimen was tested under universal testing machine of capacity 400 kN. The peak load was considered for calculating shear strength of the specimen. The schematic and experimental shear test setup is as shown in figure 1.The following equation was used from the strength of material theory to determine the shear strength of concrete.

$$\tau_{max} = \frac{P_S}{A_s}$$

where,

τ_{max} = ultimate shear strength in MPa, P_s= peak shear load applied in kN, A_s= shearing area, 100 x 100 mm.

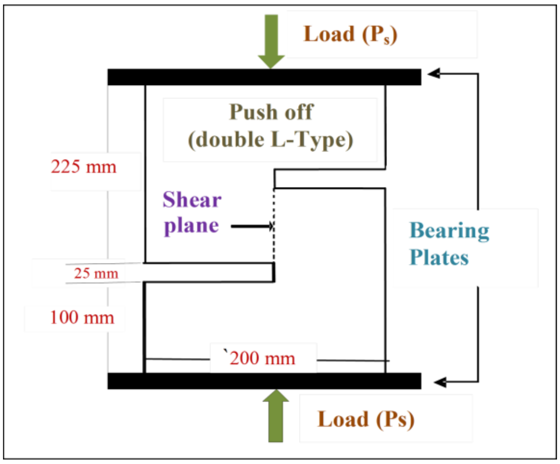

Figure 1 Schematic and experimental shear test setup

The six specimens for 0.0 % and three specimens for other volume fractions of fibers were casted and tested. The concrete filled moulds were vibrated on table vibrator in the laboratory and average values of strengths are considered for representations.

III. RESULTS AND DISCUSSIONS

The results of fresh and hardened concrete for normal concrete for two grades (M20 and M30) and two aspect ratios (AR) (35 and 50) are represented in Tables and graphs.

A. Workability

The following Table 3 shows the results of slump and compaction factor of normal concrete for M20 and M30 grades. The Figures 2 and 3 show the behavior of fresh PFRC in slump and compaction factor test results at different fiber volume fractions. The workability of green concrete found decreases as fiber content increases in both tests, and it was due presence of fibers. It was observed that workability decreases for higher aspect ratio for both M20 and M30 grades. The more surface area of plastic fibers was available at higher aspect ratio, at same volume fraction, which causes an adhesion and holding of other ingredients of concrete.

Table 3 Slump, Compaction factor normal concrete

Grade of concrete	Slump (mm)	Compaction Factor
M20	83	0.913
M30	67	0.877

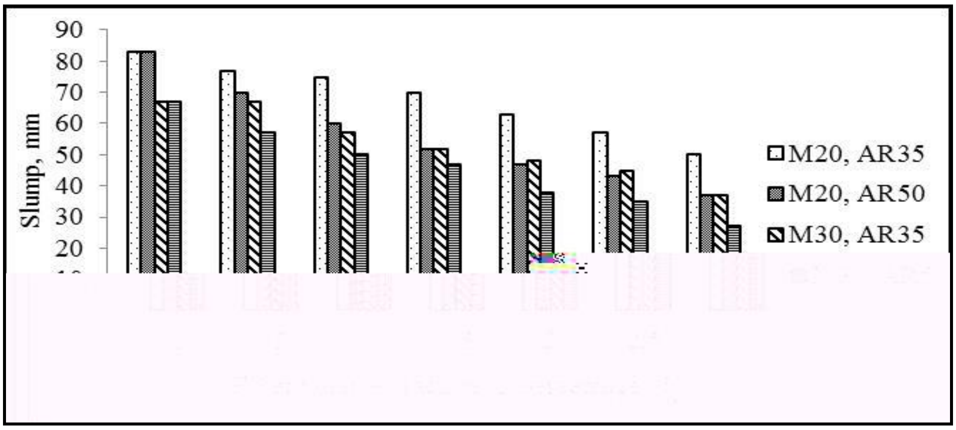

Figure 2 Slump in mm

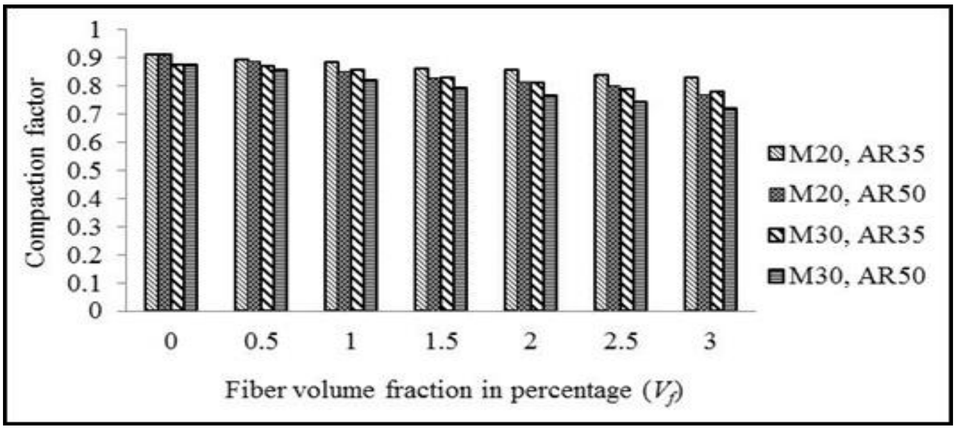

Figure 3 Compaction factor

B. Compressive Strength

The cube compressive strengths for NC and PFRC and percentage increase and decrease in strengths with respect to normal concrete are represented in Figure 4. The cube compressive strength was increased as fiber volume fraction increased from 0.0 to 1.0%, thereafter decreased in compressive strength was observed. The maximum increase in cube compressive strength was observed 7.35% at 1.0% of fiber volume fraction of aspect ratio 50 in M20 grade of concrete. The ductility of normal concrete was found higher in PFRC during cube compression test, as normal concrete cubes were failed suddenly and cubes were broken into pieces, but PFRC cubes were not broken suddenly.

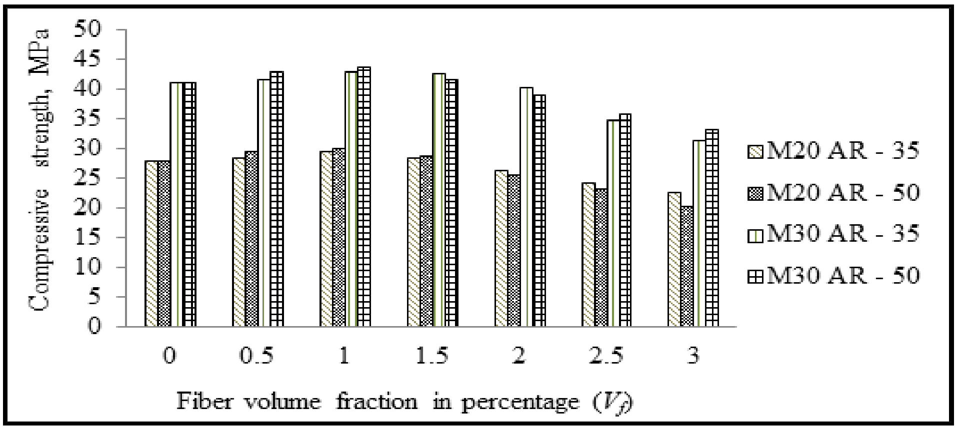

Figure 4 Compressive strength

C. Shear strength

The shear strengths for NC and PFRC, and percentage increase or decrease in strengths with respect to normal concrete are presented in Table 4. It is observed that shear strength of PFRC mix increases at 1.0 % volume fraction of plastic fibers thereafter strength reduction is observed. The maximum increase in shear strength was 27.25% at 1.0% fiber volume fraction of aspect ratio 50 in M20 grade of concrete. The graphs of shear strength of PFRC / square root of cube compressive strength of NC ($\tau_{maxf} /\sqrt{f_{cu}}$) verses fiber volume fractions (V_f) and is shown in Figure 5.

Table 4 Shear strength of NC and PFRC concrete

Mix	Average shear strength in MPa	Increase or decrease in shear strength in %	Mix	Average shear strength in MPa	Increase or decrease in shear strength in %
20NC	3.67	0.00	30NC	4.83	0.00
20M35-0.5	4.13	+12.53	30M35-0.5	5.13	+06.21
20M35-1.0	4.53	+23.43	30M35-1.0	5.60	+15.94
20M35-1.5	4.27	+16.35	30M35-1.5	5.20	+07.66
20M35-2.0	3.93	+7.08	30M35-2.0	4.87	+00.83
20M35-2.5	3.67	00.00	30M35-2.5	4.53	-06.21
20M35-3.0	3.20	-12.81	30M35-3.0	4.13	-14.49
20M50-0.5	4.27	+16.35	30M50-0.5	5.40	+11.80
20M50-1.0	4.67	+27.25	30M50-1.0	5.87	+21.53
20M50-1.5	4.40	+19.89	30M50-1.5	5.47	+13.25
20M50-2.0	4.13	+12.53	30M50-2.0	5.13	+06.21
20M50-2.5	3.73	+1.63	30M50-2.5	4.60	-04.76
20M50-3.0	3.07	-16.35	30M50-3.0	4.20	-13.04

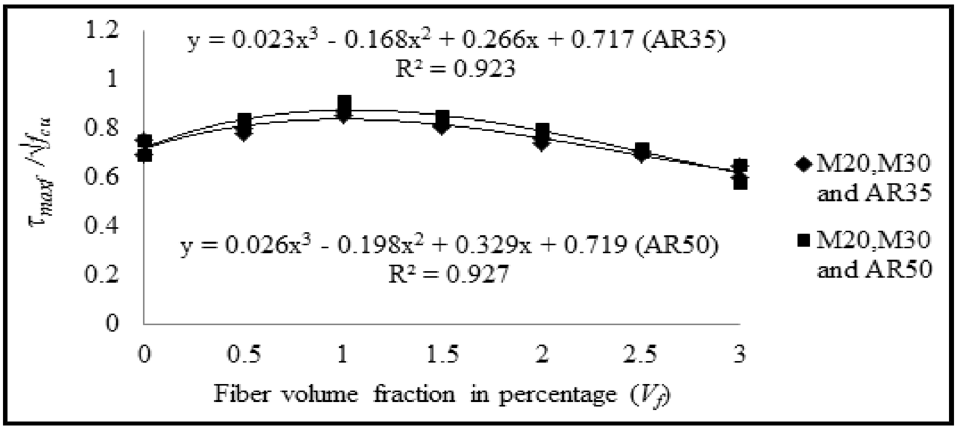

Figure 5 **Shear strength of PFRC/√cube compressive strength of NC verses fiber volume fractions**

Mathematical model for prediction of shear strength (MPa) of PFRC (Figure 5) is as follows.

$$\tau_{maxf} = \sqrt{f_{cu}}(0.023V_f^{\,3} - 0.168V_f^{\,2} + 0.266V_f + 0.717), \text{[AR-35]}$$

$$\tau_{maxf} = \sqrt{f_{cu}}(0.026V_f^{\,3} - 0.198V_f^{\,2} + 0.329V_f + 0.719), \text{[AR-50]}$$

The experimental average values and corresponding predicted values of shear strength (equations for AR35 and AR50, respectively) of PFRC are presented in Table 5. The validity of experimental values with 90 to 95% confidence for shear strength is shown in Figure 6.

Table 5 Experimental and predicted values of shear strength

Mix	Expt. values (MPa)	Predicted values (MPa)	Mix	Expt. values (MPa)	Predicted values (MPa)
20NC	3.67	3.80	30NC	4.83	4.60
20M35-0.5	4.15	4.29	30M35-0.5	5.13	5.19
20M35-1.0	4.53	4.44	30M35-1.0	5.6	5.37
20M35-1.5	4.27	4.31	30M35-1.5	5.2	5.22
20M35-2.0	3.93	4.02	30M35-2.0	4.87	4.86
20M35-2.5	3.67	3.65	30M35-2.5	4.53	4.41
20M35-3.0	3.17	3.29	30M35-3.0	4.13	3.98
20M50-0.5	4.27	4.44	30M50-0.5	5.4	5.37
20M50-1.0	4.67	4.64	30M50-1.0	5.87	5.61
20M50-1.5	4.4	4.51	30M50-1.5	5.47	5.46
20M50-2.0	4.13	4.16	30M50-2.0	5.13	5.03
20M50-2.5	3.73	3.68	30M50-2.5	4.6	4.45
20M50-3.0	3.07	3.17	30M50-3.0	4.2	3.84

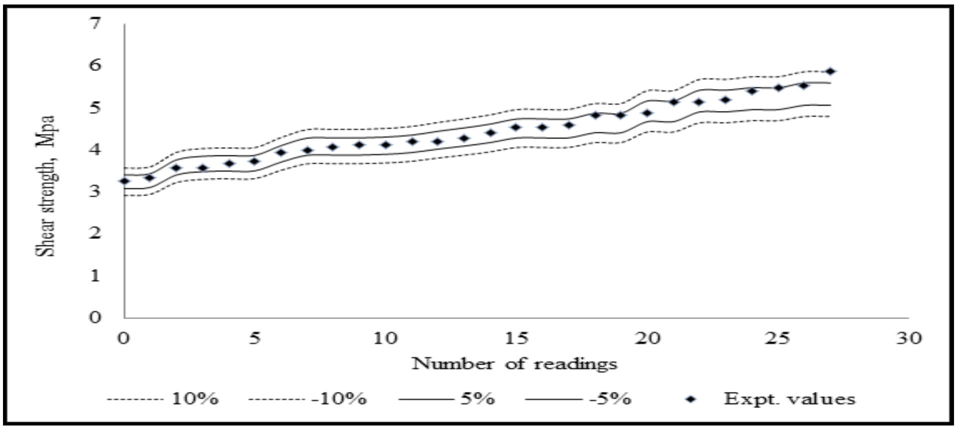

Figure 6 Validity of mathematical model with 90% to 95% confidence

IV. CONCLUSIONS

The major conclusions based on the results obtained in the study are as follows.

a. The maximum percentage increase in compressive strength of PFRC was at 1 % fiber volume fraction.
b. The ductility of normal concrete was found higher in PFRC during test as normal concrete was failed suddenly and cubes were broken into pieces, but PFRC cubes were not broken suddenly.
c. The maximum improvement in shear strength of PFRC is 27.25 % at 1% fiber volume fraction of aspect ratio 50 in M20 grade of concrete.
d. The mathematical model works within 90% confidence limit for predicting shear strength of PFRC
e. The inclusion of PET fibers obtained from waste mineral water bottles appears to be low cost materials which helps to resolve disposal problems and improves mechanical properties of concrete.

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