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Experimental investigation on the properties of concrete with plastic pet (bottle) fibres as partial replacement of fine aggregates

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ABSTRACT

Plastic bottles are a major issue of solid waste disposal. Several things which were invented for our convenient life are responsible for polluting environment due to improper waste management technique. One of them is plastic which has to be disposed or recycled properly to maintain the beauty of our nature. Polyethylene Terephthalate (PET, PETE or polyester) are routinely used for carbonated beverage and water bottles. This is an environmental issue as waste plastic bottles are difficult to biodegrade and involve processes either to recycle or reuse. In the Modern world, the construction industry is searching for cost-effective materials for enhancing the strength of concrete structures. This work is carried out with the possibility of using the waste PET bottles as the partial replacement of aggregate in Portland cement. Concrete with 1%, 2%, 2.5%, 3% and 5% PET bottle fibers for fine aggregate were produced and compared against control mix with no replacement. Cube specimens, cylinder specimens and prism specimens were cast, cured and tested for 7 day and 28 days strength. Tests such as Compression test, splitting tensile test and flexural strength tests were done and the results were compared with control specimens and results were compared. The observed results revealed an increase in compression and tensile strength hence with the increasing demand for fine aggregate, PET bottle fiber replacements can be adopted. This study was carried to investigate the properties of concrete with plastic pet (bottle) fibres as partial replacement of fine aggregates.

Keywords— *Concrete, Cement, Fine aggregates, Plastic bottles*

1. INTRODUCTION

Plastics are one of the most widely used substances that changed human life for more than six decades ago. Now-a-days, plastics are used in almost every area, from small bottle caps to large containers, such as laundry baskets and garbage pails, in every aspect of life. In today's time, we produce and use 20 times more plastic amount than we did five decades ago [1]. Global production of plastic materials through the last decade has increased dramatically. This growth in plastics manufacturing is due to its many benefits like their lighter weight, durability and lower economic cost when compared to many other material kinds [2]. The recorded growth in the plastic manufacturing industry within the last five years was 4-5% (Plastics - the facts, 2013). An amount of about 107 ton of PET is used every year to produce about 250×109 bottles all over the world. According to a recent study by Smithers Pira (2014), the global consumption of PET packaging is expected to increase at a rate of 5.2% to reach 19.1 m tones by 2017. Its unique properties such as impact resistance, excellent barrier properties, reflective and opaque increased its usage for the bottles for a lot of liquids and drinks. In the total production, about 30 % of the PET is used for the manufacturing of bottles [3]. The mass industrial production of PET bottles in such large quantities has developed huge environmental challenge since these bottles are used for one time only and left to be a plastic waste, which is slow biodegradation in nature. Recycling is one of three methods for utilization and minimization of the huge amount of waste. The others are landfilling and incineration with or without energy recovery [4]. In the field of concrete technology, India, as well as other nation, now is seeking for an alternative for conventional aggregate that may be recognized as using plastic waste, for it might be realized as PET phase capacities. As per the estimates, India produces 500,000 tons of pet waste every year. At present, the total recycling capacity in India is around 145,000 TPA its use in the concrete mix will prove a better option for landfill that, being non-degradable, remain for long years and cause a problem before us. Nowadays, unfortunately, the recycling rate of PET bottles is much less than the sales of virgin PET production for common uses, a possible application is to utilize waste PET pieces as replacement of fine aggregates in concrete. Plastics Packaging totals 42% of total consumption and every year little of this is recycled [5]. Hence an attempt on the utilization of waste Poly-Ethylene Terephthalate (PET) bottle granules [6] as a fine aggregate is done and its mechanical behaviour is investigated.

2. MATERIALS AND METHODS

2.1 Materials

- Cement: Ordinary Portland cement 43 grade.
- Fine aggregate: River sand.
- Coarse aggregate: 20 to 40 mm – 25%, 12.50 to 20mm- 35%, 4.75 to 12.15mm-40%
- Plastic fibres: Average PET bottles fibers size 2mm approximately
- Water Cement ratio: 0.45

2.2 Methodology

The following flow chart illustrates the methodology of the investigation:

Collection of waste PET bottles and cleaning

↓

Shredding of PET bottles to flakes and Grinding to granules

↓

The casting of test specimens like cylinders, cubes and prisms with various % of plastic waste and testing

↓

Casting and testing of structural specimens and comparison of results

In this experiment, 1%, 2%, 2.5%, 3% and 5% of traditional fine aggregate were replaced in M_{20} grade concrete. The replacement percentage is by volume of total fine aggregate content derived from the mixture proportioned. Cube specimens of size 150 mm× 150 mm×150 mm, cylinder specimens of 150 mm diameter and 300 mm height and prism specimens of size 100 mm×100 mm× 500 mm. Various Specimen types prepared are listed in Table 1.

Table 1: Various specimen types prepared

S. no	Specimen Type	No. of specimens prepared						Total no. of specimens prepared from each type
		PCC	1%	2%	2.5%	3%	5%	
1	Cube	2	2	2	2	2	2	12
2	Cylinder	2	2	2	2	2	2	12
3	Beam prism	1	1	1	1	1	1	6
Total no. of specimens prepared								30

However, Slump test will be conducted on fresh concrete to determine the workability. The tests performed on hardened concrete after 7 and 28 days of curing will be compression test, Split Tensile test and Flexural Test.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

The parameters such as Compressive Strength, Splitting Tensile Strength and Thermal Conductivity are discussed and Comparison between the Control Concrete and PET added concrete is represented as follows:

3.1 Compressive strength

Concrete cubes specimens (150mm×150mm×150mm) of M_{20} grade were cast for computing compressive strength. After casting, the cubes were removed from the mould after 24hrs and then put for curing in the sump for 7 days and 28 days to get respective strengths. Before testing remove the cubes from the sump and dry to the normal atmosphere to get a dry surface. Then check it for compressive strength in compression testing machine to get the result. The test results of 7 and 28 days are listed in table 2 and table 3. The compressive strength is calculated by using the following equations.

$$\text{Compression strength} = P/A$$

P = ultimate load, *A* = cross sectional area

Fig. 1: Cube after compression failure

Table 2: Variation of seven-day compressive strength

S. no	Percentage addition of fibres	Failure load (KN)	The compressive strength of seven days (Mpa)	Percentage change in compressive strength
1	0%	300	13.33	0.00
2	1%	355	15.77	18.3
3	2%	370	16.50	23.7
4	2.5%	345	15.34	15
5	3%	275	12.2	-8.4
6	5%	240	10.6	-20.4

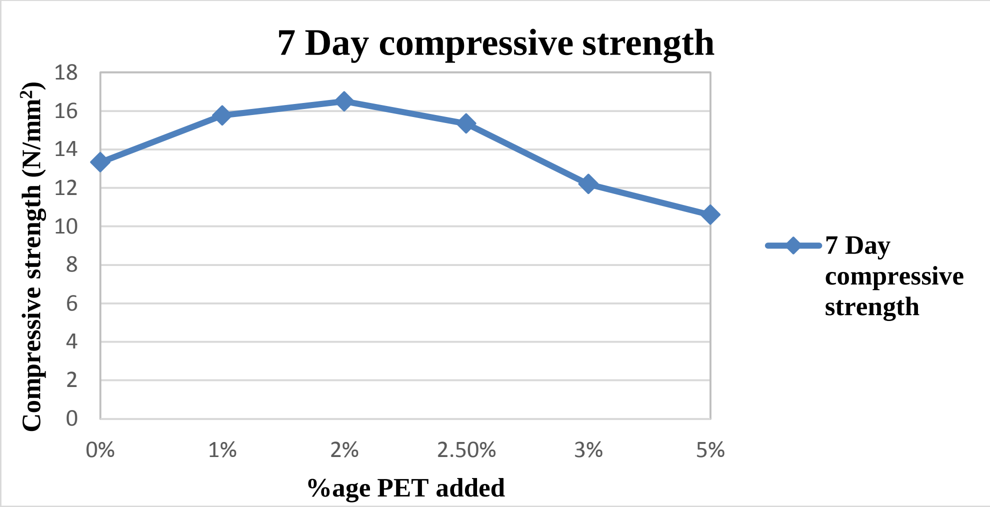

Fig. 2: Graph between seven days compressive strength versus percentage PET added

Table 3: Variation of 28-day compressive strength

S. no	Percentage addition of fibres	Failure load (KN)	Compressive strength of 28 days (Mpa)	Percentage change in compressive strength
1	0%	510	22.67	0.00
2	1%	595	26.44	16.62
3	2%	625	27.77	22.50
4	2.5%	580	25.77	13.67
5	3%	465	20.66	-8.86
6	5%	410	18.22	-19.63

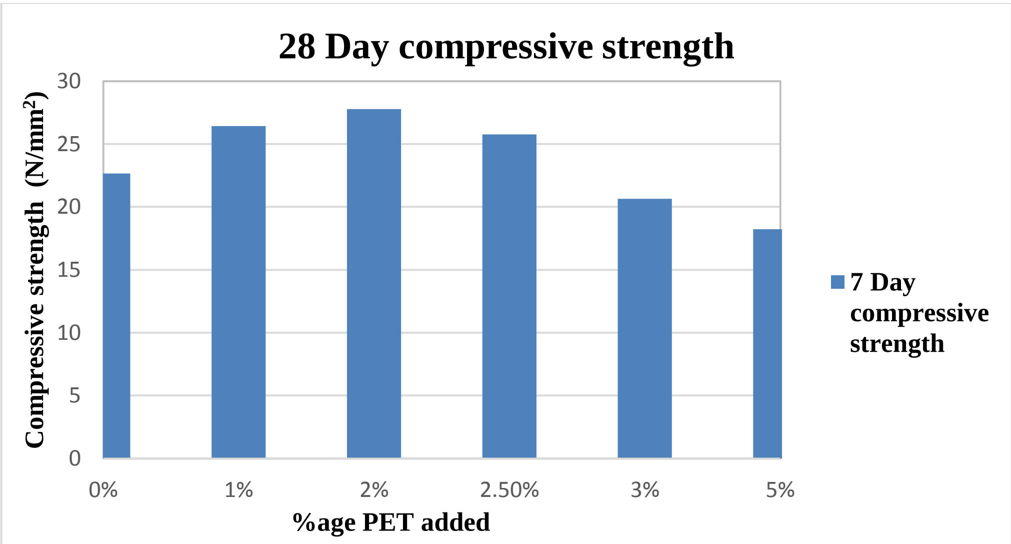

Fig. 3: 28 days compressive strength v/s percentage increase of PET

It was noticed that the compressive strength increases with increase in the percentage of PET both in 7 and 28-day tests up to 2% replacement of the fine aggregate with PET bottle fibres and then decrease for 2.5%, 3% and 5% replacements. The compressive strength of 2% polyester fiber reinforced concrete has found to be 22.5% increase in strength when compared to that of Conventional concrete. This may be because when PET is added to the mixture in order to partial replacement of sand, the silica content reduces and equivalent carbon content replaces it. The Si-Si bond is weaker than C-C is simply that because the Si atom is bigger than the C atom the electrons forming the bond are farther from the nuclei and don't lower their energy as much by forming the bond but if PET is added beyond 2% the compressive strength decreases because all free carbon is bonded or the increase in fiber content decreases bond strength between fibers until some admixture are added to increase the bond strength between fibers. Hence replacement of fine aggregate with 2% replacement will be optimum.

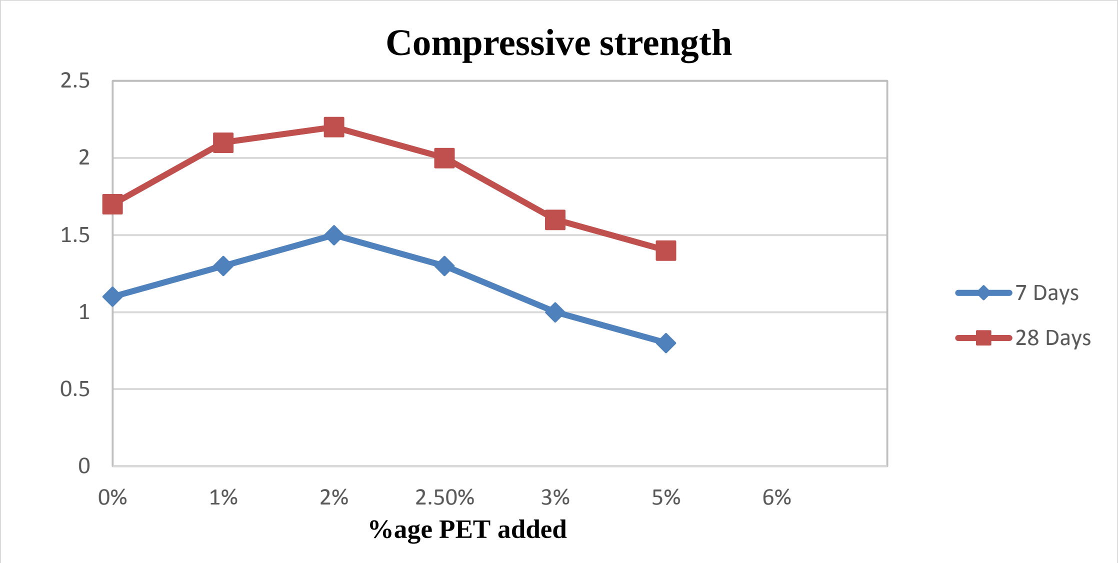

Fig. 4: Comparison between 7 and 28-day compression strength v/s percentage PET added

3.2 Flexural strength

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three-point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress.

The test method for conducting the test usually involves a specified test fixture on a universal testing machine. The value of modulus of rupture (extreme fibre stress in bending) depends upon the dimensions of beam and manner of loading. In case of symmetrical two-point loading, the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum.

Fig. 5: Flexure strength test set up

Table 4: Variation of 28-day Flexural Strength

S. no	%age PET added conventional concrete	Curing days	Flexural strength (N/mm^2)
1	(0%)	28	3.21
2	1%	28	3.82
3	2%	28	4.34
4	2.5%	28	4.85
5	3%	28	4.72
6	5%	28	3.51

The flexural strength of the specimens with the replacement of the fine aggregate with the PET bottle fibres increases gradually with the increase in the replacement percentage up to 2.5%, but it may fall for more replacement percentage. This may be because when PET is added to the mixture in order to partial replacement of sand, the silica content reduces and equivalent carbon content replaces it. The Si-Si bond is weaker than C-C is simply that because the Si atom is bigger than the C atom the electrons forming the bond are farther from the nuclei and don't lower their energy as much by forming the bond but if PET is added beyond 2% the compressive strength decreases because all free carbon is bonded or the increase in fiber content decreases bond strength between fibers until some admixture are added to increase the bond strength between fibers. Hence replacement of fine aggregate with 2.5% replacement will be optimum.

3.3 Split tensile strength test

It is difficult to measure the tensile strength of concrete directly. However, splitting test gives fairer results and are believed to be closer to the true tensile strength of concrete. The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of a compression testing machine and the load is applied until failure of the cylinder along the vertical diameter occurs. The loading condition produces high compressive stress immediately below the two generators to which the load is applied. But the larger portion corresponding to depth is subjected to uniform tensile stress acting horizontally. It's estimated that the compressive stress is acting for about $1/6^{th}$ of depth and the remaining $5/6^{th}$ of depth is subjected to tension.

The split tensile strength of the cylinder specimen is calculated using the following formula:

$$\textit{Split Tensile Strength} = 2P/\pi Ld \ N/mm^2$$

Where, P = Load at failure in N
L = Length of the Specimen in mm
d = Diameter of the Specimen in mm

Fig. 6: Split tensile test failure

Table 5: Variation of 7-day Tensile Strength values

Percentage addition of fibres	Tensile Strength of 7 days (Mpa)	Percentage change in tensile strength
0%	1.11	0.00
1%	1.31	18
2%	1.38	24.3
2.5%	1.28	15.3
3%	1.02	-8
5%	0.88	-20.7

As we know that concrete is weak in tension still the Tensile Strength comes out to be maximum when 2% PET is added to the concrete. So both the compression and tension strengths are maximum at 2% PET. This may be because when PET is added to the mixture in order to partial replacement of sand, the silica content reduces and equivalent carbon content replaces it. The Si-Si bond is weaker than C-C is simply that because the Si atom is bigger than the C atom the electrons forming the bond are farther from the nuclei and don't lower their energy as much by forming the bond but if PET is added beyond 2% the compressive strength decreases because all free carbon is bonded or the increase in fiber content decreases bond strength between fibers until some admixture are added to increase the bond strength between fibers. Hence replacement of fine aggregate with 2% replacement will be optimum.

4. DISCUSSIONS OF RESULTS

All the tests were conducted on green and hardened concrete as per relevant standards. The results were obtained experimentally after7 and 28 days of curing of each specimen. The results of fiber reinforced concrete are compared with the normal concrete.

4.1 Workability

The workability of green concrete was measured in terms of a slump. From the different types of test performed, at each time it was observed that the workability increases when the fiber percentage increases. This is because PET absorbs very less water and more water is available to the mix.

4.2 Compressive strength

The compressive strength of control concrete was 22.67 MPa. The compressive strength was increased to 27.77 MPa at 2% of fiber content in concrete. Thereafter the compressive strength was reduced to 18.22 MPa at 5%. The reasons for the increase and decrease in compressive strength has already been described in section 6.2 of this chapter. The test details and results of 7-day strength variation are represented in table 2 and figure 2 respectively and the 28-day compression test details and results are represented in table 3 and figure 3 respectively. Also, the graph between compression strength versus percentage increase in PET of 7 and 28 days are shown in figure 4.

4.3 Split tensile strength

The tensile strength of control concrete was 1.74 MPa after 28 days curing. The tensile strength increases to 2.03MPa and 2.17 MPa at 1% and 2% respectively after 28 days of curing of fiber content in concrete. Thereafter the tensile strength was reduced to 1.40 MPa at 5% PET. The reasons for the increase and decrease in tensile strength have already been described in section 6.4 of this chapter.

4.4 Flexural strength

The flexural strength of control concrete was 3.21 MPa. The flexural strength was increased to 23.7MPa at 2.5% of fibre content in concrete. Thereafter the flexural strength was reduced to 3.51 MPa at 5% of fibre content in concrete. The reasons for the increase and decrease in flexural strength has already been described in section 6.3 of this chapter.

5. CONCLUSION

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

- The inclusion of fibers content increases the flow properties of concrete. The density was also affected but made concrete slightly lighter weight.
- The maximum compressive, and split tensile strength were at 2% of fiber content were 22.50 %, and 24.3% respectively over control concrete (0% fibers content). Also, the maximum flexural strength was at 2.5% of fiber content were 51.1% more than control concrete. The significant improvements in strengths were observed with the inclusion of plastic fibers in concrete. The optimum strength was observed between 2 to 2.5% of fiber content for all types of strengths, thereafter reductions in strength were observed.
- The concrete with PET fibres reduces the weight of concrete and thus mortar with plastic fibres can be made into lightweight concrete based on unit weight.
- While testing control cement concrete cube the spalling of concrete was observed. However, the failure mode of fiber concrete was bulging in the transverse direction
- The mode of failure was changed from brittle to ductile failure due to the inclusion of plastic fibers into the concrete.
- From this experimental investigation, the PET bottles would appear to be low-cost materials which would help to resolve solid waste problems and preventing environmental pollution.

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