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Experimental Studies on Utilisation of Recycled Plastic Materials in Concrete

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ABSTRACT: The introduction of fibres is brought in as a solution to develop concrete with enhanced flexural and tensile strength as the Concrete is acknowledged to be a relatively brittle material. Plastics are commonly used substances that play a major role in every aspect of human lives. The highest usage of plastics causes problem in disposal resulting in serious environmental issues. The widespread of plastics wastes need proper recycling and reuse strategies. PET (Polyethylene terephthalate) is prepared from petroleum hydrocarbons, formed due to the reaction between ethylene glycol, colorless viscous hygroscopic liquid, terephthalic acid and the organic compound. In the year 2015-16, nearly 1,450 KT of PET was produced in India, as compared to 980 KT in the year 2014-15. For making PET bottles, nearly 96-97% of PET resin was required for various applications.

This research work focuses on the utilization of recycled PET in the form of fibres in concrete, so that the performance of concrete in the aspects of mechanical, structural and durability properties can be improved. The addition of fibre in concrete results in increase in cracking resistance, fatigue endurance, shear strength, impact resistance, toughness and long-term ductility of concrete. The PET fibres used in concrete were initially tested for tensile and pull out test to study their characteristics. The concrete made with PET fibres were compared with conventional concrete to study their behaviour. From the average tensile strength of fibres obtained by testing in the UTM and bond strength obtained from the pull-out test, it was observed that the fibres were sufficiently stronger and ductile. The mechanical properties over the different specimens for various tests were studied.

KEY WORDS: PET fibres, environmental issues, recycling and reuse strategies.

I. LITERATURE REVIEW

The concept of utilization of fibres in a breakable matrix was recorded for the first time with the ancient Egyptians who used animal hair and straw as reinforcement for mud bricks and walls in the accommodation. This dates back to 1500 BC (Ezeldin and Balaguru (1992)). Ronald (1997) gives a summary of the history and progress of the reinforced concrete with fibre 30 years ago. Conferring to this report, at the beginning of the 1960s, they had started work on reinforced concrete with fibre. Many researchers have carried out many researches on different modes. But these projects have studied only the fibres of steel. So far, only a few works have studied other fibres like rubber, nylon, natural, and plastic fibres. But these investigations are completely different from the current study since they have been concentrated in the resistance properties of the material and not in its Structural behaviour.

Ghosh et alstudied the tensile strength of the steel fibre reinforced concrete and reported that the inclusion of short steel fibres increases the tensile strength of concrete with low fibre volume fractions. The optimal aspect ratio has been found as 80 and the maximum increase in resistance a tensile load was obtained as 33.14% with a volume fraction of 0.7 %. It has also been reported that the resistance to tensile stress in the cylinder is more consistent and consistent results than the flexural and the direct tensile test.

Sabapathi and Achyutha studied the characteristics of stress and deformation of reinforced concrete with steel fibre under compression. The resistance of fibre reinforced concrete under compression and the initial tangent modulus of elasticity were obtained and also the equation for the stress-strain relationship was also proposed. To determine the tensile strength of reinforced concrete with fibre,

Youjiang et al. proposed the test configuration to replace the expensive direct tensile strength tester.

The test methodology and procedure were also provided and it requires a servo-controlled testing machine.

Ganesan and Ramana determined the deformation behaviour of a short column with and without fibre reinforced. They used the volume fraction of steel fibre as 1.5% with an aspect ratio of 70. The endpoint study was the percentage of strengthening lateral reinforcement. The strain in the maximum loads has increased to a certain extent.

Anbuvelan et al. carried out studies on the properties of the concrete with crushed fibre plastic through re-engineering. Re-engineered fibres are manufactured by re-processing the plastic waste and then laminated it into plastic sheet, which is converted into the fibre with required dimensions. The authors studied compression, split tensile, modulus of rupture, abrasion, and resistance against impact and shrinkage in an earlier stage. It is concluded that the performance of concrete increases with the presence of plastic fibre.

Sekar studied the feasibility of using fibre from the industrial waste in the concrete as reinforcement, it has been reported that the usage of lathe waste and wire windings have significantly improved in the mechanical properties of concrete. It is also claimed that the residues fibres from the wire drawing industry decreased the values of resistance.

The following are the objectives of the present investigations:

1. To study the strength and durability characteristics of concrete with recycled PET bottle waste fibres under static and cyclic loading.
2. To analyze the recycled PET fibre reinforced concrete specimens using the finite element analysis model and compare the same with the experimental results
3. To render suitable recommendations to the construction industry towards the possible utilization of the PET bottle wastes in a suitable form

II. EXPERIMENTAL INVESTIGATION

This experimental research focuses on the utilization of recycled PET fibre in the concrete. This has been conducted by performing various tests to assure the characteristics of PET fibre reinforced concrete. The mechanical properties, workability, strength parameters and various other tests are carried out according to the prescribed IS standards. The slump test, compaction factor, vee-bee and air content tests are conducted to find out the workability of the concrete with the PET fibre reinforcement concrete with varying aspect ratio and volume fraction. The mechanical properties such as compressive strength of cubes, split tensile strength, modulus of rupture and shear strength tests has been performed to check the strength parameter. There is a need to carry out the durability tests to know the performance of the PET fibre reinforced concrete under various environmental conditions. RCPT, acid and chloride attacks are carried over to study the durability parameter of PET fibre reinforced concrete. The static load test on reinforced concrete beam has been carried out for the conventional and the optimum aspect ratio in each volume fraction of PET fibre reinforced concrete. In addition to this beam column joint has been investigated under cyclic loading.

MATERIALS AND MIX

The materials used for this experimental investigation are river sand, crushed rock aggregate, Portland cement, and HYSD bars. This section deals with the properties of materials used in concrete. The river sand collected is a fine aggregate from Cauvery river whereas the coarse aggregate of crushed rock is collected from a quarry. The maximum size of the crushed rock is 20 mm whereas the grade of ordinary Portland cement is grade 43. The high yield steel deformed HYSD bars of 2 nos. of 8 mm diameter at top and 3 nos. of 10 mm diameter bar at bottom used as tension reinforcements for beam. 6 nos. of 12mm diameter HYSD bars and 2 nos. of 12mm diameter at the top and bottom for beam column. The details of the tests conducted to determine the basic properties of constituent materials are also explained.

PET Fibre

Recycled Polyethylene Terephthalate (PET) fibre is used in this research work. Figure.3.1 shows the PET fibre used in fibre reinforced concrete. Physical properties of PET fibre is shown in Table.3.9, tensile strength of PET fibre ranges from 550-700 MPa with excellent elongation index.

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Figure PET Fibre

Recycled PET fibre Properties	Values
Young's modulus (E)	2800-3100 Mpa
Tensile strength(σt)	550-700 Mpa
Elastic limit	50-150%
Notch test	3.6 KJ/m²
Glass transition temperature (Tg)	67-81°C
Linear expansion coefficient (α)	0.00007 per K
Water absorption (ASTM)	0.16
Melting point	>250°C
Boiling point	>350°C (decomposes)
Density	1.38 g/cm³.
Solubility in water Practically	Insoluble
Molar mass	Variable

CASTING AND CURING

The materials for casting the specimens are prepared, proportioned, weighed and mixed as per IS 516-1959 (1989). A laboratory-type concrete mixer machine is used to mix the ingredients of the concrete. Initially, 20 mm size aggregate and sand are mixed dryly for two to three minute and then cement is added the dry aggregates mixers. After two minutes water is added to the dry mix, finally, PET fibres are added to the mix and thoroughly mixed in mixer machine. Allow the ingredients to mix for 5 minutes to distribute the fibres evenly in the concrete. The concrete is manually placed in the respective moulds. All the specimens are well compacted using a tamping rod. The specimens were remoulded after 24 hours and immersed in the water for curing for a period of 28 days. The standard150 mm metallic cubic moulds are used as per IS 10086-1982 for the preparation of test specimen for determining the compressive strength. The standard cylindrical steel moulds measuring 150 mm diameter and 300 mm height are used as per IS 10086-1982 (1995) for the preparation of test specimen for determination of tensile strength and for modulus of rupture standard prism moulds of 500 mm are used as per IS 10086-1982 (1995) for the× 100 mm ×size 100 mm 46 flexural strength test. For rapid chloride penetration test

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cylindrical disc specimen of size 100 mm diameter and 50 mm thickness are used. The beam mould of size 2.1 metres in length, 100 mm in breadth and 150 mm in depth is used for casting RCC beams. The average of the three concrete specimen values in each test is considered to determine the compressive strength, split tensile strength, modulus of rupture, shear strength, rapid chloride penetration test, chloride attack and acid attack. For the loaddeflection test on RCC beams, the value of only two specimens is considered. Figures 3.9 shows the fresh concrete mix in a steel mould to study the mechanical properties.

Figure Fresh Concrete Mix in Mould

MIX PROPORTIONS

Mix Proportions for Concrete

The mix proportion for the concrete is the grade of M20. The IS 10262 – 2009 guidelines are followed to achieve the concrete grade of M20. The designed and adopted mix proportion is 1:2.28:3.50 and a constant water-cement ratio of 0.5 is used. The quantities of different ingredients per cubic meter of concrete are given in Table 3.10 and Table 3.11 shows the different volume fraction and aspect ratio used in the concrete mixes.

Table 3.10 Mix Design for M20 Grade Concrete

Ingredients	Ratio	Quantity/cum
Cement	1	320-kgs
Sand	2.28	730-kgs
Coarse-Aggregate	3.5	1120-kgs
Water/Cement-Ratio	0.5	160-Ltr

Table 3.11 Mix Proportion of the various PET Fibre Reinforced in Concrete Mix

Specimen-ID	Fibre-Volume-Fraction	Aspect-Ratio-of-Fibre
CC	-	-
PFC1	0.50%	15
PFC2	0.50%	30
PFC3	0.50%	45
PFC4	1.00%	15
PFC5	1.00%	30
PFC6	1.00%	45
PFC7	1.50%	15
PFC8	1.50%	30
PFC9	1.50%	45
PFC10	2.00%	15
PFC11	2.00%	30

PFC12	2.00%	45

III. TESTS ON FRESH CONCRETE

Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The fresh concrete properties include workability, bleeding and segregation of it. These properties are obtained only in the fresh state of concrete, hence it is named as fresh concrete properties. Several test methods are there to find out these properties of concrete, but the concentration is only on workability which would indirectly be related to the other passing ability and flowability properties of plastic concrete. The workability of concrete is defined in ACI 116R-90 as the "property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished". The workability properties for the totally 13 mixes comprises of different volume fraction and aspect ratio of PET fibre reinforced concrete. The workability tests for fresh concrete used in the investigations is listed below,

- Slump Cone Test
- Compaction Factor Test
- Vee-Bee Consistency Test
- Air Content

IV. RESULTS AND DISCUSSIONS

This chapter deals with the results which are obtained from the experimental study. The experimental part contains the following aspects of test such as workability, mechanical and durability properties over the various standard specimen and structural behaviour over the beam of conventional and PFC specimens under static loading, cyclic loading over the beam-column joint have been discussed. The recycled PET fibres are added with four volume fractions of 0.5%, 1.0%, 1.5% and 2.0% along with three different aspect ratios of 15, 30 45 for the concrete of grade M20. The concrete has 0.5% volume fraction and the aspect ratio of 15 is named as PFC1. Similarly, 0.5% volume fraction and the aspect ratio of 30 is named as PFC2, 0.5% volume fraction and the aspect ratio of 45 is named as PFC3, 1.0% volume fraction and the aspect ratio of 15 is named as PFC4, 1.0% volume fraction and the aspect ratio of 30 is named as PFC5, 1.0% volume fraction and the aspect ratio of 45 is named as PFC6, 1.5% volume fraction and the aspect ratio of 15 is named as PFC7, 1.5% volume fraction and the aspect ratio of 30 is named as PFC8, 1.5% volume fraction and the aspect ratio of 45 is named as PFC9, 2.0% volume fraction and the aspect ratio of 15 is named as PFC10, 2.0% volume fraction and the aspect ratio of 30 is named as PFC11 and 2.0% volume fraction and the aspect ratio of 45 is named as PFC12. Totally 13 varieties of mixes are prepared. The workability and mechanical properties tests are done for the all mixes. From the test results, it has been observed that the PET fibres with 2% of volume fraction did not perform well in the fresh concrete tests and mechanical properties tests. So, that mix was removed from the durability properties study.

Mixes	Fibre Volume Fraction	Aspect Ratio of Fibre	Slump (mm)	Compaction Factor	VeeBee (sec)	Air Content (%)
CC	-	-	110	0.98	3.5	2.8
PFC1	0.50%	15	100	0.96	4.6	3.8
PFC2	0.50%	30	94	0.92	5.8	4.1
PFC3	0.50%	45	90	0.89	6.1	4.3
PFC4	1.00%	15	98	0.95	4.6	4.1
PFC5	1.00%	30	94	0.9	5.9	4.3
PFC6	1.00%	45	90	0.87	6.2	4.6
PFC7	1.50%	15	98	0.92	4.8	4.3
PFC8	1.50%	30	93	0.88	5.5	4.5
PFC9	1.50%	45	89	0.83	6.4	4.8
PFC10	2.00%	15	95	0.86	7.3	4.6
PFC11	2.00%	30	90	0.81	7.9	4.9
PFC12	2.00%	45	84	0.73	8.6	5.2

The mechanical properties such as compressive strength test, split tensile test, modulus of rupture and shear strength over the hardened concrete of grade M20 are elaborated and the test results are shown in Table 5.2 and Table 5.3. Table 5.2 Compressive and Split Tensile

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strength test results of Conventional and PET fibre reinforced concrete

Mixes	Fibre Volume Fraction	Aspect Ratio of fibre	Compressive Strength (fck)	Split Tensile Strength (MPa) (ft)	√fck	ft/√fck	Theory as per author	Deviations
CC	-	-	23.82	2.8	4.88	0.57	-	-
PFC1	0.50%	15	26.58	3.8	5.16	0.74	3.84	1.08
PFC2	0.50%	30	25.81	3.3	5.08	0.65	3.36	1.73
PFC3	0.50%	45	24.98	2.9	5.00	0.58	2.93	1.00
PFC4	1.00%	15	26.53	3.9	5.15	0.76	3.84	-1.61
PFC5	1.00%	30	26.41	3.4	5.14	0.66	3.40	-0.13
PFC6	1.00%	45	25.51	3	5.05	0.59	2.96	-1.33
PFC7	1.50%	15	27.36	4	5.23	0.76	3.90	-2.58
PFC8	1.50%	30	26.85	3.6	5.18	0.69	3.42	-4.89
PFC9	1.50%	45	24.97	3.1	5.00	0.62	2.93	-5.53
PFC10	2.00%	15	24.7	3.60	3.6	0.72	-	-
PFC11	2.00%	30	23.11	3.2	-	-	-	-
PFC12	2.00%	45	20.7	3.0	-	-	-	-

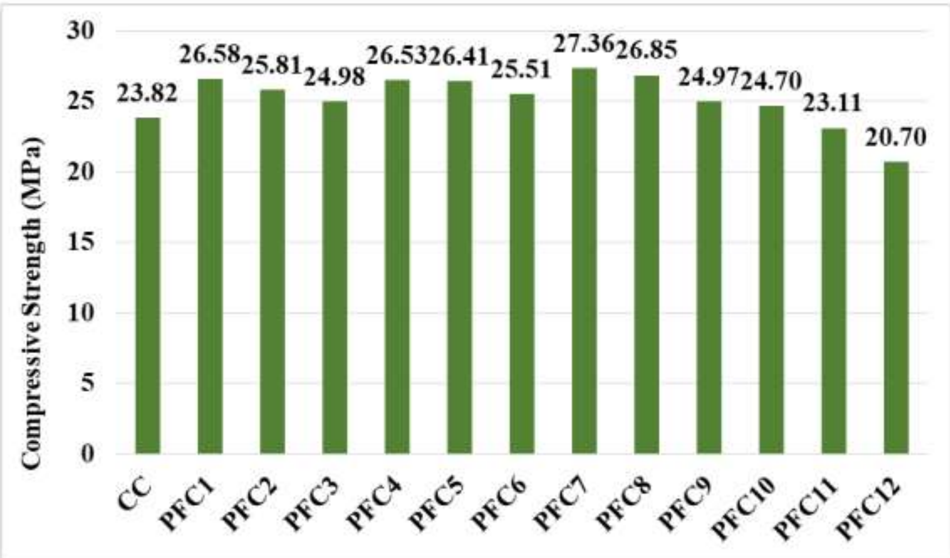

Figure 5.1 Compressive strength of Conventional and PET fibre reinforced concrete

The split tensile strength was found to increase with fibre volume of 1.5% with the aspect ratio of 15. It is observed that the tensile stress was transferred to the fibres, which improves the bond between the concrete and also the ductile behaviour of the specimen. The fibres resist the propagating of macrocracks because of the bonding and substantially improve the splitting tensile strength. This is also interlinked with the surface contact area and the volume of fibres present in the concrete.

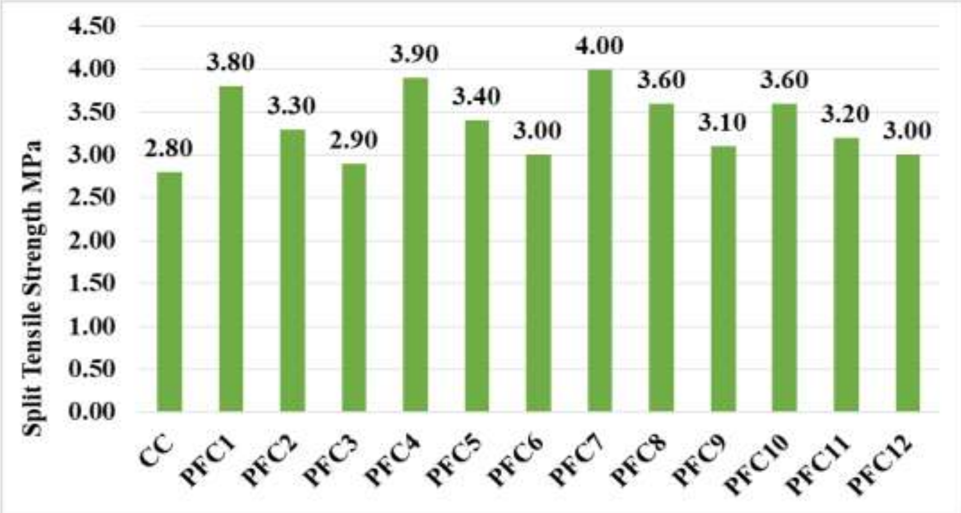

Figure 5.2 Split tensile strength of Conventional and PET fibre reinforced concrete

V. CONCLUSIONS

Plain concrete has good resistance against compression but weak in carrying tension. For the improvement, reinforcement has been embedded in it to carry the tension. Even though reinforcements are provided in concrete the development of micro cracks cannot be restricted due to the application of loads.

From the extensive experimental and analytical investigations, the following important conclusions were obtained. When fibres are used in concrete, the fibres create segregation and restriction to the flow of fresh concrete. The workability of concrete gets affected, if the PET fibre volume fraction and aspect ratio of the fibres are increased. From the pull-out test, it was observed that the PET fibres were sufficiently stronger against slip. From the tensile test on fibre, the average tensile strength of fibre at its failure was found to be 651 N/mm2 , which denotes that, the fibre was stronger and had enhanced ductile property. From the different tests conducted on PET fibre reinforced concrete with the four different volume fractions and three different aspect ratio of PET fibres to study the mechanical properties, it was found that as the volume fraction of fibres increases above 1.5% and the aspect ratio of the fibres increases, the strength of the concrete reduces due to the bundling of fibres. This restricts the making of concrete with greater volume fraction of fibres and with greater aspect ratio of fibres.

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