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Shear-Behaviour of Plasti-Fibre Reinforced Concrete Beams

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Abstract: Concrete is the most commonly used construction material. Its usage by the communities across the globe is second to water. The construction industries are concentrating on reducing the ecological footprint of concrete by looking at the ways of making it “greener”. On the other hand, accumulation of unmanaged or non-decomposable waste like plastics, rubber, tin, etc., from industries results in an increasing environmental threat .Consequently, the use of non - recyclable materials for preparation of concrete is being actively encouraged. The Past research on the utilization of plastics in construction of flexible pavements reported enhanced mechanical properties. The use of plasti - fibre in cement concrete has not yet been investigated. This paper covers the mechanical properties of plasti-fibre reinforced concrete (PFRC) prepared from hand shredded plasti- fibres of size 10mm x 50mm consisting Polyethylene plastic bags of 40 microns and PET bottles in the ratio of 1:4 and shear behavior of PFRC beams. The use of non-decomposable plastics in concrete mixtures as fibers will not only be its safe disposal method but also enhances the mechanical properties concrete. The compressive strength, flexural strength and tensile strength of M25 grade PFRC were evaluated and compared with the conventional concrete. At the age of 7 days the compressive strength, flexural strength and tensile strength of PFRC was found to increase by 5.18%, 20.88%, 0.81% and 0.38%, 4.66%, 11.19% on addition of 0.25% and 0.5% plasti-fibres by weight of concrete respectively. Similarly at the age of 28days the compressive strength, flexural strength and tensile strength was found to increase by 4.33%, 14.29%, 9.56% and 0.53%, 6.25%, 16.52% on addition of 0.25% and 0.5% plasti-fibres by weight of concrete respectively. It was observed that increase in the dosage of plasti-fibre decreased the compressive strength and flexural strength of PFRC, but the increase in split tensile strength was directly proportional to the increase in percentage of plasti- fibre added. Though the control beams failed in shear, PFRC beams were found to perform well in shear. The PFRC beams failed by forming cracks in the flexural region which was with both lateral and longitudinal reinforcements while the shear portion of the beam consisted of plasti-fibres alone, in the absence of shear reinforcement.

***Keywords:** Plasti- fibres, Fibre reinforced concrete, Shear performance, Waste management*

1. Introduction

Concrete is the most commonly used construction material, its usage by the communities across the globe is second to water. Due to its durability, longevity, and versatility, concrete is well-suited for broad construction applications under diverse loading and exposure conditions [1]. Unfortunately, it is a relatively brittle material and is inherently weak in tension.[2] On the other hand plastic possess high tensile strength and durability. Most of the plastic is non- biodegradable waste which leads to serious environmental threats. The rapid urbanization and industrialization all over the world has resulted in large deposition of waste polymer materials. The world’s annual consumption of plastic materials has increased from around 5 million tons in the 1950s to nearly 100 million tons in 2001[3]. The average annual growth rate of plastics was 15% from 1960 to 1974, and 8% thereafter, from 1974 to 2000, and 2005. According to a recent survey the plastic consumed by India in the year 2013 alone was found to be 56 lakh tones. The plastic consumption is expected to be 20 million metric tons by 2020. Since, the recycling cost of plastics is more than the manufacturing cost of virgin plastics; nearly 93% of total plastics manufactured are dumped on landfills. Thus it is highly efficient and sustainable to use plastic fibres in concrete which in turn enhances the mechanical properties and shear capacity of concrete.

2. Past Research

Konin A [4] has studied the effect of plastic waste content on Physico-Mechanical properties of flexible pavements by using plastic waste instead of cement on the physical and mechanical properties of pavements. The author reports that the use of plastic waste enhances abrasion resistance and slip resistance upto 20% while reducing porosity which is less than 5% of for the pavements, along with it the relationship between content of plastic waste with that of splitting tensile strength and abrasion resistance is also presented.

Md. Mostafizur Rahman et al [5] has partially replaced aggregates for concrete with three types of recycled waste polymeric materials namely expanded polystyrene (EPS) based packaging waste, high density polyethylene (HDPE) and vehicle tire. The authors assess the mechanical, physical and morphological properties of the modified concrete and have reported that the inclusion of waste polymer materials decreases compressive strength, density, porosity and water sorption properties.

Lakshmi R [6] et al has observed gain in compressive strength, tensile strength and flexural strength of concrete with E plastic waste as coarse aggregates. On the contrary A. A. Al. Manaseer [7] et al reports decrease in mechanical properties of concrete with increase in percentage of post consumed plastic waste as coarse aggregates.

The past literatures deal with plastic waste as a replacement for aggregates in concrete or a binder for flexible pavements. The type of plastic waste employed were from poly ethylene teraphthalite (PET) or E waste or granular plastic. The current paper covers the use of plastic covers of 40 micron as fibre in concrete.

3. Experimental Investigation

3.1. Materials Used

3.1.1. Cement and Aggregates

53 grade Ordinary Portland cement conforming to IS 12269:1987 with specific gravity 3.15 was used. River sand obtained from Chennai and the locally available blue granite crushed stone aggregates of size 20mm were used as fine aggregates and coarse aggregates respectively in the present investigation. Their physical properties(Table 1) like specific gravity, bulk density, percentage of water absorption and fineness modulus were tested in concurrence with IS: 2386:1963.

Table 1: *Physical Properties of Aggregates*

Type	Fine Aggregate	Coarse Aggregate
Specific gravity (SSD)	2.67	2.6
Fineness modulus	2.36	4.81
Water absorption (%)	0.5	1.21
Bulk density (SSD), kg/m^3	1628	1562

3.1.2. Water

Potable water was adopted as the liquid for mixing and curing of specimens throughout the experimentation.

3.1.3. Plastifibres

Plasti- fibres was prepared from Polyethylene (PE) bags of 40 microns and PET bottles. The plasti- fibres were hand shredded to a size of 10mm x 50mm which comprised of PE bags and PET bottles in the ratio of 1:4. The plasti- fibres were added to concrete at dosages of 0%, 0.25% and 0.5% by weight of concrete to form the Plasti-fibre reinforced concrete (PFRC).

Figure 1: *Hand shredded PE bags of 40 microns*

Figure 2: *Hand shredded PET bottles*

4. Mix Design

Based on the trial mixes the final design mix was prepared for M25 grade of concrete as per IS 10262:2009. The concrete mix proportions were as shown in Table 2. The plasti- fibers were added into dry mix of concrete in the percentages of 0%, 0.25% and 0.5% by weight of concrete.

Table 2: *Mix proportions*

Specimen	OPC	FA	CA	Water
Control	1	1.79	2.92	0.5
PF 0.25%	1	1.79	2.92	0.5
PF 0.5%	1	1.79	2.92	0.5

5. Preparation of Test Specimens

Standard steel moulds were used for casting cubes of size 150mm x 150mm x 150mm, cylinders of 150mm diameter and 300mm height, prisms of size 100mm x 100mm x 500mm and beams of size 100mm x 200mm x1500mm. Nine cube specimens, twelve cylinder specimens, six prism specimens and two beam specimens were cast for each mix. The concrete mixes obtained by means of hand mixing were placed uniformly in three layers and each layer was well compacted using ramming rod. The finishing of top surface was carried out with trowel. These specimens were demoulded 24 hours after casting and were cured under water until the age of testing.

6. Tests for Mechanical Properties

The compression test, flexural test and split tensile tests were carried out as per IS516:1959 [8] and IS5816:1999 [9].

6.1. Compressive Strength

The compressive strength test was performed in a universal testing machine of 200 tones capacity at the age of 7, 14 and 28 days respectively. The reported strengths are the average of three test specimens.

6.2. Flexural Strength

The flexural strength of PFRC was found out by subjecting the prism to two points loading on a compression testing machine of 200 tones capacity at the age of 7 and 28 days.

6.3. Split Tensile Strength

The split tensile test on cylinders was also carried out at the age of 7 and 28 days by placing the cylinders horizontally on a compression testing machine of 200 tones capacity. The reported strengths are the average of three test specimens.

7. Results and Discussion

7.1. Compressive Strength

Table 3: *Compressive strength*

Specimen	Compressive Strength (MPa)		
	7th day	14th day	28th day
Control	21.25	34.63	35.55
PF 0.25%	22.41	34.92	37.09
PF 0.5%	21.33	28.44	35.74

From Table 3 and Figure 3, PFRC cubes were found to show increase in compressive strength compared to control concrete. At the age of 7, 14 and 28 days the compressive strength of PFRC with dosage of 0.25% and 0.5% of plastifibres were found to be 22.41N/mm^2,34.92 N/mm^2,37.09 N/mm^2 and 21.33 N/mm^2 ,28.44 N/mm^2 ,35.74 N/mm^2 respectively which is 5.18%, 4.1% and 0.38%, 0.53% more than the control concrete respectively. But at the age of 14 days the compressive strength of PFRC with 0.25% and 0.5% of plasti fibres were found to increase by 0.83% and decreasse by 17.87% than the control concrete. Hence it is observed that the PFRC showed decrease in compressive strength with increase in dosage of plasti-fibres as observed by Raghatate Atul M [10]. This may be due to the lack of bonding between the plastifibres and concrete. Also the cracking pattern observed from Figure 4 shows that the fibres present in the cubes prevent shattering and spalling of concrete under compressive stress to a great extent.

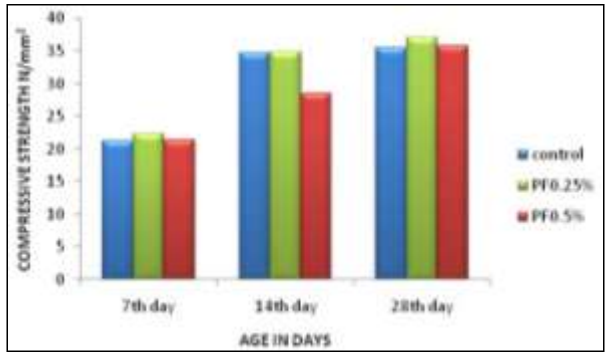


Figure 3:*Compressive strength of PFRC at various ages*

a) 0% Plastifibres

b) 0.25% Plastifibres

c) 0.5% Plastifibres

Figure 4: *PFRC cubes after compression test*

7.2. Flexural Strength

Table 4: *Theoretical and experimental flexural strength*

Specimen	Flexural Strength F_{cr}(MPa)at the age of			
	7th day		28th day	
	Fcr_{Th}	Fcr_{Exp}	Fcr_{Th}	Fcr_{Exp}
Control	3.23	2.18	4.17	3.63
PF 0.25%	3.31	2.75	4.26	4.23
PF 0.5%	3.23	2.28	4.18	3.87

The flexural strength values of the PFRC with o.25% and 0.5% are given in Table 4 as 2.75 N/mm^2, 2.28 N/mm^2 and 4.23 N/mm^2, 3.87 N/mm^2 for 7th day and 28th day respectively which has increased by 21.58%,3.6% and 14.18%, 6.2%. In contrary to results reported by Zainab Z. Ismail [11] at al who partially replaced fine aggregates with granulated plastic waste, flexural strength decreased with increase in dosage of plastifibres which may be due to the lack of bonding between the concrete and plastic as the flexural strength was observed to follow the same trend of the compressive strength,. Also the theoretical flexural strength was calculated as per IS456:2000 [12] clause 6.2.2 and the theoretical results were found to be compatible with the experimental results.

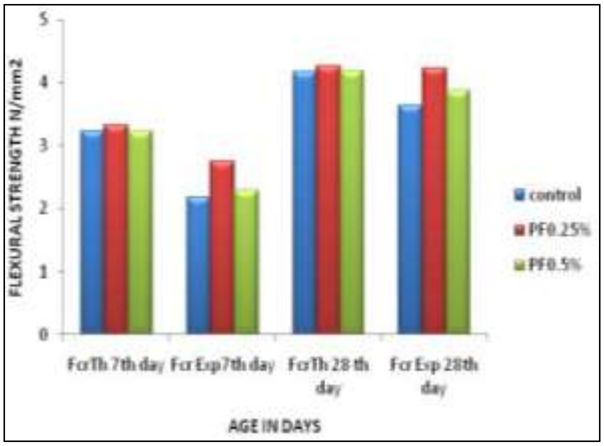


Figure 5: *Flexural strength of PFRC at various ages*

7.3. Split Tensile Strength

Table 5: *Theoretical and experimental tensile strength*

Specimen	Split Tensile Strength F_{ct} (MPa) at the age of			
	7 days		28 days	
	Fsp_{TH}	Fsp_{Exp}	Fsp_{TH}	Fsp_{Exp}
control	2.31	2.51	2.99	3.69
PF0.25%	2.37	2.53	3.05	4.08
PF0.5%	2.31	2.83	2.99	4.42

The split tensile strength of the concrete cylinders at the 7^{th} day and 28^{th} day were found to be 2.53N/mm^2, 2.83 N/mm^2 and 4.08 N/mm^2,4.42 N/mm^2 with the addition of 0.25%,0.5% plasti- fibres which has shown 0.81%,11.31% and 9.56%, 16.52% increase in tensile strength respectively. Unlike compressive strength, the split tensile strength is in direct proportion with the increase in dosage of plasti- fibres. This may be due to the imparting of tensile strength by the fibre to the concrete. Generally, the splitting tensile strength can be established from compressive strength. National building codes propose various formulas for the splitting tensile strength and compressive strength [13]. In the present study, based on the revised codeACI318-99(1999) the theoretical split tensile strength was taken as

$$Fsp = 0.56(Fck)^{1/2}$$

Where Fsp and Fck are split tensile strength and cylinder compressive strength expressed in MPa.

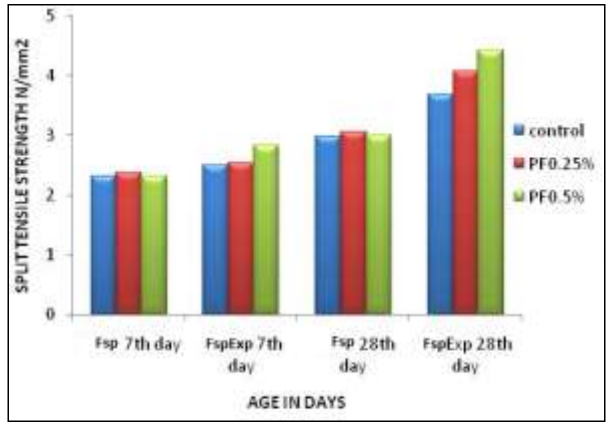


Figure 6:*Split tensile strength of PFRC at various ages*

8. Shear Capacity of PFRC Beams

8.1. Beam Geometry

The test specimens were designed as per the provisions of IS 456-2000. A total of six beams, each with cross section having 150 x 200 mm and length of 1500 mm, were cast. The a/d ratio of the beams was 1.5. All the beams were reinforced with two 12mm diameter rods at the bottom and two 10mm diameter provided at the top of the beam were used as tensile bars and hangar bars respectively. The 8mm diameter transverse reinforcement was provided in the beam at 120mm spacing for a span of 900mm in the centre of the beam (i.e., flexural region) and no transverse reinforcements were provided for a span of 300mm on both ends of the beams(i.e., shear region). The clear cover to the reinforcement is 20mm. The beams were designed to fail in shear. The geometry of the beam specimen is shown in Figure 7

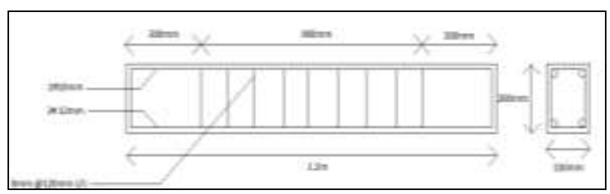


Figure 7: *Geometry of shear beams*

Figure 8: *Reinforcement cage of shear beams*

8.2. Test Procedure

All the specimens were white washed in order to facilitate marking of cracks .The sketch showing the details of the beam setup for the shear test is shown in

Figure 9. Testing was carried out on a loading frame of 40 tons capacity. Before resting the beam on reaction blocks, the beam was centered by using a plumb bob so that its centre lies exactly under the centre of the loading head. The beam was simply supported over a span of 1300 mm, which is considered as the effective span. The beam was supported on the reaction blocks by a hinged plate at one end and roller plate at the other end. The beams were tested under two point static loading. The load was applied on two points, at a distance of 900 mm for a/d ratio 1.5 at centre to center of the load spreader. An automatic data acquisition unit was used to collect the data during the test. Strain gauges were placed at selected locations of the beam. All loads and the deflection data were electronically recorded.

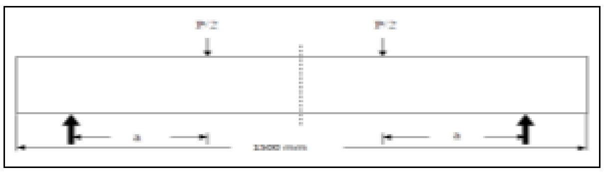


Figure 9: *Test set up sketch*

8.3. Crack Pattern and Failure Mode of Control Beams

At early load stages, flexural cracks appeared in the constant bending moment zone. At later load stages, shear cracks appeared at the shear span and gradually spread towards the support portion of the beam and the loading point. The flexural cracks propagated towards the compression zone under increasing load. The failure occurred by the crushing of concrete in the compression zone. Concrete spalling at the compression zone was observed after the ultimate load. As the load increased existing cracks propagated and new cracks developed along the span. The spacing of cracks varied along the span. The crack patterns of the beams varied significantly as shown in Figure 10. Thus the control beams failed due to diagonal tension failure.

Figure 10: *Crack pattern of control beams*

8.4. Crack Pattern and Failure Mode of PFRC Beams

The failure of the PFRC beams containing 0.25% plasti-fibres was indicated by the Flexural failure. The cracks were found to develop at the tension zone in the bottom and extended to the compression zone. At the compression zone crushing of concrete clearly indicated a flexural failure. In the shear span only slight tensile cracks were formed at the bottom tension zone. Though hair line shear crack developed in shear span, these cracks once initiated did not extend with increasing load. Also, the Initial cracks were not formed in the shear span.

The crack pattern of the PFRC beams with 0.5% plasti-fibres was also indicated by flexural failure. The cracks were observed to develop in the tension zone at the bottom of the beam and extended to the compression zone resulting in crushing of concrete. In the shear span inclined cracks were formed, but did not contribute to the ultimate failure of beam. The shear cracks were found to develop above 100kN, but the crack width and length did not increase considerably with increasing load. Also, the Initial cracks were not formed in the shear span. The crack pattern of the PFRC beams is shown in Figure11.

Figure 11: *Crack pattern of PFRC beams*

9. Shear Mechanism in Beams without Stirrups

In the absence of transverse reinforcements in beams, the shear transfer mechanism forms the shear resistance. The factors assumed in contributing to shear mechanism are as shown in Figure 12.

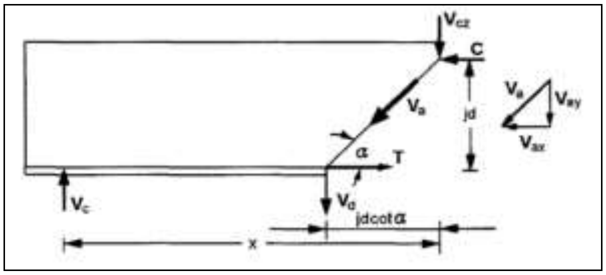


Figure 12: *Beam action[14]*

The occurrence of the inclined cracks in concrete was followed by the Dowel shear resistance (Vd), Aggregate shear resistance (Va), and Compression zone shear (Vc). These three factors beget beam action; in addition to these three resistances, arch action also has its contribution to the shear resistance. Transfer of shear through intact concrete such as the compression region in a beam contributes to Vc. It was observed that as inclined cracks widen in the concrete, the shear resistance, Va decreases while Vc and Vd increase. Finally when the aggregate interlock mechanism fails and develops breach, large shear force will be transferred rapidly to the compression zone causing sudden and often explosive failure while arch action contribution is low. It is obvious that the Shear resistance caused by dowel action increases as shear reinforcement decreases. As a result, it has a significant effect in members, where no shear reinforcement is prevalent. When inclined cracks cross the longitudinal reinforcement bar, the forces act on the dowel due to deflection at the face of intersection of the crack and reinforcement. The aggregates around the reinforcement try to resist the deflection by interlocking with each other and those entire forces sum up as total shear resistance of dowel action.

It is generally believed that aggregate interlock transfers a large part of the total shear force to the supports. Width of the cracks, aggregate size and concrete strength are the most important variables which influence the shear transfer mechanism in beams without shear reinforcement.

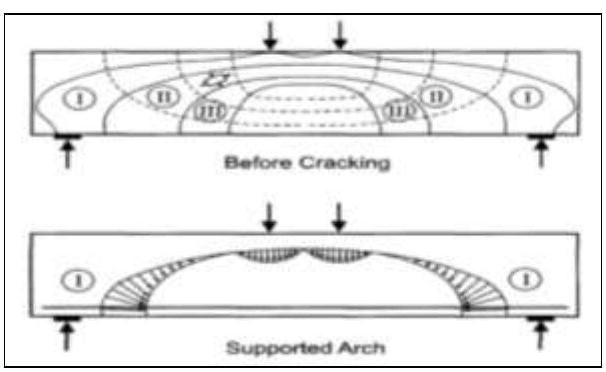


Figure 13: *Internal arches in a RC beam [14]*

When flexure-shear interaction takes place in beams i.e., when bending moment and shear force occur simultaneously, the shear resistance developed consists of two different mechanisms, beam and arch mechanism. When the arch action is predominant of the beam action, the member can take up more loads preventing the formation of diagonal cracking. When arch action administers the failure mechanism, shear-compression failure can be expected and diagonal-tension cracks appear thanks to beam action. It were noticed that two kinds of diagonal cracks were developed in the beams as a result of shear forces: web-shear cracks that originated near mid depth of an un-cracked section and diagonal tension cracks that grew from the tip of an already existing flexural crack and propagated diagonally toward an adjacent point load.

10. Shear Mechanism in PFRC Beams

The collective action of Dowel shear resistance Vd, Aggregate shear resistance Va, Compression zone shear Vc and Tensile Strength of plastic fiber takes place in PFRC. These four factors pave way to beam action, in addition to which arch action also contributes to the shear resistance. Plasti- fibers were found to procrastinate the propagation of shrinkage microcracks within concrete by bridging the cracks. Slender fibers of high aspect ratio and relatively fine diameter are recommended for reinforcement of concrete. Such fibers provide more surface area for bonding to concrete and offer relatively high pullout resistance. By addition of plasti- fibres with high aspect ratio, aggregate interlock has been noticed to increase to a large extent. The fibres present in the shear span around the aggregates increases the interlocking effect by the stitching property of plasti- fibres in the cracking zone. When inclined cracks cross the longitudinal reinforcement bar, the forces act on the dowel due to deflection at the face of intersection of the crack and reinforcement. The aggregates around the bar and plasti-fibres try to resist the deflection by interlocking with each other and those entire forces sum up as total shear resistance of dowel action. Presence of plasti- fibres prevents crack widening and extension of initial flexural cracks into shear cracks extending into shear zone as loading increases. Under increasing load a reinforced concrete beam transform into a comb like structure. In tensile zone, the flexural crack creates more or less vertical concrete teeth, while the compressive zone represents the back bone of concrete comb. As the load was applied to the beam, a vertical crack initiated in the extreme tension fibre in the maximum moment region, while other flexural-shear cracks were formed in the shear region. The vertical crack in the maximum moment region started propagating upward as the load was gradually increased. Failure finally occurred because concrete reached its ultimate compressive strain and crushed.

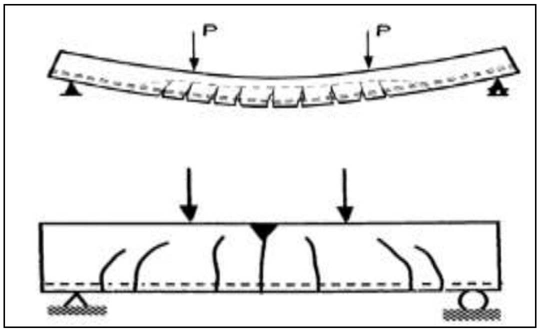


Figure 13: *Teeth formation and flexural failure [15]*

11. Load–Deflection Curve

The deflections of the beams were found out with the help of dial gauges placed at various positions. The addition of plasti- fibers to the beams resulted in a ductile, nonviolent, and slow failure with no shattering or spalling of the concrete which is evident from the load deflection graphs (Figure 14 and 15). From the central deflection graph it is clearly evident that deflection is small for control beams when compared to beams which had plasti- fibres. But the maximum load carrying capacity of most of the beams was same in comparison with control beams. Hence, there is no reduction in load carrying capacity for the PFRC beams. This can be understood from Table 6 and Figure 16

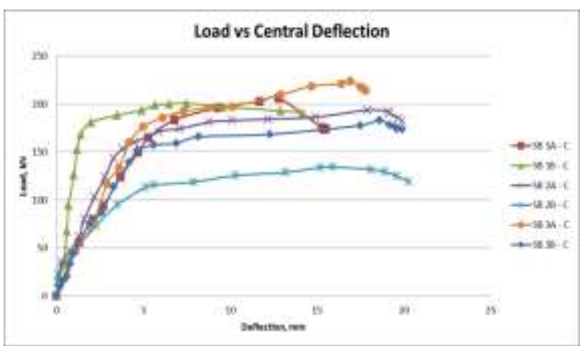
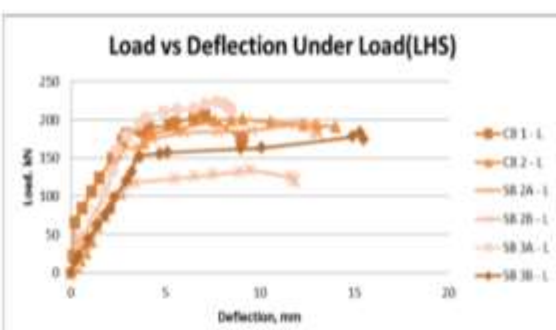
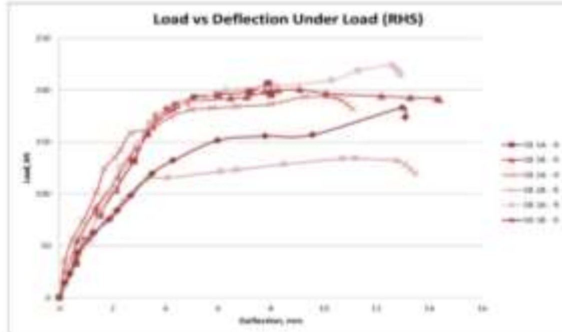


Figure 14: *Load – Central deflection curve*



a) Deflection under LHS loading



b) Deflection under RHS loading

Figure 15: *Load – deflection under load curve*

Figure 16: *Initial and final crack loads*

Table 6 *Initial and final crack loads*

Beam ID	Initial crack load kN	Final crack load kN
SB1A	57.6	204.3
SB1B	69.5	198.7
SB2A	62.8	193.5
SB2B	39.6	121.6
SB3A	63.6	224
SB3B	43.7	177

The initial cracking of the beams were observed to occur in the flexural zone only. Since the plasti - fibres were added only in the shear span, ductility in the flexural span was not governed by plastic - fibres. The final cracks of the control beams were found to be in shear span, on the contrary the final crack of the PFRC beams never appeared in the shear span. This was due to the increased ductility caused by the plasti- fibres in the shear zone.

12. Conclusions

1. The use of unmanaged or non-decomposable plastics in concrete mixtures as fibers has not only paved way for its safe disposal method but also it has enhanced the mechanical properties concrete.
2. The compressive strength, flexural strength and tensile strength of M25 grade PFRC prepared from hand shredded plasti- fibres of size 10mm x 50mm

consisting Polyethylene plastic bags of 40 microns and PET bottles in the ratio of 1:3 and shear behavior of PFRC beams were evaluated and compared with the conventional concrete.

3. At the age of 7 days the compressive strength, flexural strength and tensile strength of PFRC was found to increase by 5.18%, 20.88%, 0.81% and 0.38%,4.66%,11.19% on addition of 0.25% and 0.5% plasti-fibres by weight of concrete respectively.
4. Similarly at the age of 28days the compressive strength, flexural strength and tensile strength was found to increase by 4.33%, 14.29%,9.56% and 0.53%,6.25%, 16.52% on addition of 0.25% and 0.5% plasti-fibres by weight of concrete respectively.
5. It was observed that increase in the dosage of plasti-fibre decreased the compressive strength and flexural strength of PFRC which was due to the lack of bonding between the concrete and plasti-fibres, but the increase in split tensile strength was directly proportional to the increase in percentage of plasti- fibre added which was due to the tensile strength of the fibre that got imparted to the concrete.
6. Though the control beams failed in shear, PFRC beams were found to perform well in shear. This resulted from beam action and arch action.
7. The PFRC beams failed by forming cracks in the flexural region which was with both lateral and longitudinal reinforcements while the shear portion of the beam consisted of plasti – fibres alone, in the absence of shear reinforcement. This was because of the increased ductility caused by the plasti- fibres in the shear zone.

Hence, the use of non-decomposable plastics as plasti-fibres in concrete enables a march towards sustainability via efficiently and qualitatively improved concrete.

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