



EVALUATION OF STRENGTH CHARACTERISTICS OF POLYETHYLENE TEREPHTHALATE (PET) STRAP FIBRE REINFORCED CONCRETE BY DIRECT AND IN-DIRECT METHOD OF TESTING

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Abstract

Polyethylene Terephthalate is a synthetic material referred as PET Strapping, which means process of bundling with help of various straps and strapping tools. PET strap is a strong material used for packaging of various goods. PET strap are high resistivity against temperature and high tensile strength. It is most commonly used in all industries for packaging and bundling.

In this experimental work an attempt was made to utilize PET strap in concrete in the form of fibres to pro-

duce PET Strap Fibre Reinforced Concrete. To study the strength behavior of PET strap fibre reinforced concrete the various test specimens were casted such as, cubes, cylinders, prism, plate and L-shaped specimens for the nominal mix proportion of 1: 1: 2 with a w/c ratio of 0.45 and cured for 28 days in normal water for the different aspect ratio of PET strap fibres like 0, 33, 55, 77, 99 and 122 and by keeping percentage addition of fibre 2% as constant. Totally 18 test specimens were casted for each method of test for different aspect ratio of PET strap fibres. Based on the obtained test results by direct and in-direct methods of testing, it was concluded that aspect ratio 55 is the good aspect ratio of PET strap fibres and it can be added upto 2% by weight of cement in the production of PET strap fiber reinforced concrete.

Keywords: Pet Strap Fibre reinforced concrete; Different Aspect ratio; Strength Characteristics.

1 INTRODUCTION

Fibre Reinforced Concrete (FRC) was invented by French gardener Joseph Monier in 1849 and patented in 1867. The concept of using fibres as reinforcement is not new. This can be proved by the following: Fibres have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900s, asbestos fibres were used in concrete, and in the 1950s the concept of composite materials came into being and fibre reinforced concrete was one of the topics of interest. There was a need to find a replacement for the asbestos used in concrete and other building materials once the health risks associated with the substance were discovered. By the 1960s, steel, glass (GFRC), and synthetic fibres such as polypropylene fibres were used in concrete, and research into new fibre reinforced concretes continues today[2]. The concrete is one of the most widely used construction material in developed and developing countries. The performance of concrete depends on its ingredients. It is well known that plain concrete is brittle and weak in tension[3]. The principle reason for incorporating fibres into a cement matrix is to increase the toughness and tensile strength and improve the cracking deformation character-

istics of the resultant composite[1, 13]. Fibers as crack arrestors, bridge the crack and its propagation thereby controlling the crack width of the members[5, 6]. Different fibers like steel, carbon, glass, synthetic organic and natural fibers of various sizes and shapes have been developed for use in FRC to improve the mechanical properties of concrete[2]. Among these fibres, the polypropylene has been one of the most successful commercial applications. Polypropylene fibres have some unique properties that make them suitable for reinforcement in concrete. The fibres have a low density, are chemically inert and non corrosive[4, 10]. Polyethylene Terephthalate famously referred to as PET, is a strong but lightweight form of clear polyester. PET consists of polymerized units of the monomer ethylene terephthalate, with repeating $C_{10}H_8O_4$ units. PET crystallizes readily above its transition temperature. The presence of a benzene ring in the main chain leads to a stiffer chain with the result that the polyester has both a higher glass transition temperature $80^{\circ}C$ and crystalline melting point $254^{\circ}C$ ¹².

PET was first developed for use in synthetic fibres by British Calico Printers in 1941. The patent rights were then sold to DuPont and ICI who in turn sold regional rights to many other companies. Although originally produced for fibres, PET began to be used for packaging films in the mid-1960s much before the technique for blowing bi-axially oriented bottles was commercially developed in the 1970s. It is used to make containers for food and beverages, packing straps, etc. PET is one of the most commonly used plastic today. The majority of the world's PET production is for synthetic fibers (in excess of 60%), with bottle production accounting for around 30% of global demand[9].

The main objective of this experimental work was to make utilization of PET strap packaging material [13] as fibres in the production of fibre reinforced concrete and check its efficiency in the production fibre reinforced concrete, when they become waste, after use for packaging purpose, also to save energy and environment from pollution.

2 MATERIALS AND METHODS

This part deals about description of materials used in the experimentation and testing methodology on concrete and concrete specimens is outlined, and discussed as per IS Code provision.

Materials Used

53-Grade Cement

The cement used in the experimentation was Ordinary Portland Cement-53 grade, which satisfies the requirements of IS: 12269-1987 specification.

Fine Aggregates

River sand purchased from the supplier was used as fine aggregate. The sand used was having fineness modulus of 3.48 and confirmed to grading zone-III as per IS:383-1970 specification. Physical properties of tested fine aggregate are given in Table.No.1

Coarse Aggregates

The crushed stone aggregate by local quarry purchased from the supplier. The coarse aggregates used in the experimentation were 12.5mm and down size aggregate, tested as per IS: 383-1970 and 2386-1963 (I, II and III) specifications. The aggregates used were having fineness modulus of 1.98. Physical and Mechanical properties of tested coarse aggregates are given in Table.No.2

Fibres

The fibres were obtained by cutting the PET Strap, purchased directly from market shown in Figure.1. The fibres were made into piece for different aspect ratio by using heavy scissor as per the requirement and it was labour oriented shown Figure.2. The thickness of PET Strap fibres was 0.9mm and its breadth was kept 6mm and these fibres were straight. The different aspect ratios of fibres like 0, 33, 55, 77, 99, and 122 were adopted in this work. Fibres were added 2% by weight of cement in the production of PET strap fiber reinforced concrete. Physical properties PET strap fibers and comparison of different straps is given in Table.No.3 and No.4 respectively.

Water

Ordinary potable water free from organic content, turbidity and salts was used for mixing and curing throughout the work.

Super Plasticizer

To impart the additional desired properties, a super plasticizer

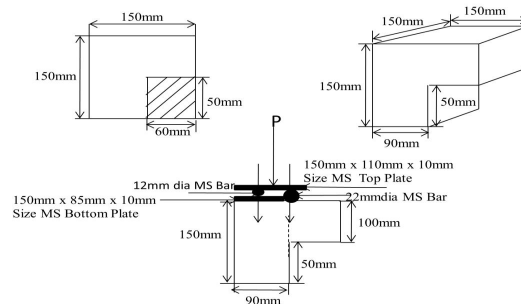


Figure.1: Details of Shear Specimen with Test Set-Up

Table.1: Physical Properties of Fine Aggregate

Properties	Results	Permissible limit as per IS: 2386-1963
Organic impurities	Straw Colour	Colour less /Straw Colour/Dark Colour
Silt content	0.5%	Should not be more than 6-10%
Specific gravity	2.42	Should be between the limit 2.6-2.7
Bulking of sand	16%	Should not be more than 40%
Moisture content	0.72%	-

Table.2: Physical and Mechanical Properties of Coarse Aggregate

Properties	Results	Permissible limit as per IS: 2386-1963
Impact value	14.15 %	Should not be more than 30% used for concrete
Crushing value	13.20%	Should not be more than 30% for surface course and 45% other than wearing course
Specific gravity	2.62	In between range 2.6-2.8
Moisture content	0.2%	-

Table.3: Physical Properties of PET Stap Fibres

Breadth (b) mm	Thickness (t) mm	Percentage of elongation	Tensile strength N	Water absorption	Specific gravity
12	0.9	10-16%	4900 N	Nil	1.32

* Data Taken From the Product Brochure of the Supplier

(Conplast SP- 430) was used. The dosage of super plasticizer adopted in the experimentation was 1% by weight of cement. Super-plasticizer Conplast-430 is a sulphonated naphthalene formaldehyde

Table.4: Comparison of different straps

Characteristics	Polyester Strap	Steel Strap	PET Strap
Strength	Excellent	Moderate	Excellent
Life Range	High	Moderate	High
Resistance to Heat	Fair	Good	Good
Costing	Low	Low	High
Curving Capacity	Good	Poor	Excellent
Environment Hazards	Low	High	Low
Flexibility	Moderate	Poor	Excellent
Machinery Cost	Moderate	High	Low

* Data Taken From the Product Brochure of the Supplier

condensate and it is manufactured by FOSROC chemicals (India) Ltd, Bengaluru.

Mix Proportion

Nominal mix proportion of 1: 1: 2 with a w/c ratio of 0.45, which is correspond to M25 grade of concrete was used for the production of PET strap fiber reinforced concrete.

Casting of Concrete Specimens

The concrete ingredients namely cement, fine aggregate (sand) and coarse aggregate (jelly) were weighed according to their proportion and they were dry mixed on non-absorbent plat form. To this, PET Strap fibres were added in the dry mix at the rate of 2% by weight of cement and mixed thoroughly in dry state. To this dry mix, the calculated quantity of water was added and mixed rigorously. Superplasticizers were added at the end to the wet mix by weight of cement followed by remixing homogeneously. Soon after this, the workability tests were conducted for fresh concrete. Before any fresh concrete was poured into the concrete moulds, all concrete moulds were cleaned from the existing concrete stain and oil was applied inside the moulds. The fresh concrete was placed into the mould with the help of scoop. The moulds were filled with concrete in workability condition in three layers each layer being compacted by using standard tamping rod thoroughly and vibrated using table vibrator to achieve an adequate compaction for 2 minutes. After adequate compaction, the specimens were finished smooth and left under wet gunny bags. After 24 hours, the

specimens were demoulded and transferred to curing tank, where in they were allowed to cure for 28 days. The various test specimens were casted to evaluate strength characteristics PET Strap Fibre reinforced Concrete, for compressive strength cube specimens of size 150mm x 150mm x 150mm, in-direct tensile strength cylindrical specimens of size 300mm x 150mm, prism specimens for flexural strength of size 100mm x 100mm x 500mm, impact strength specimens of plate size 250mm x 250mm x 30mm and shear strength test specimens (L-shaped) were casted as proposed by Bairagi. N. K and Modhera. C. D using concrete cube moulds of size 150mm x 150mm x 150mm by inserting a wooden block of size 60mm x 50 mm in cross section and 150 mm high into the cube moulds before casting of concrete. All the strength tests were performed after the concrete specimens were cured for 28 days in surface dry condition shown in Figure 1 to 10.

3 EXPERIMENTAL PROCEDURE

Testing of Concrete Specimens

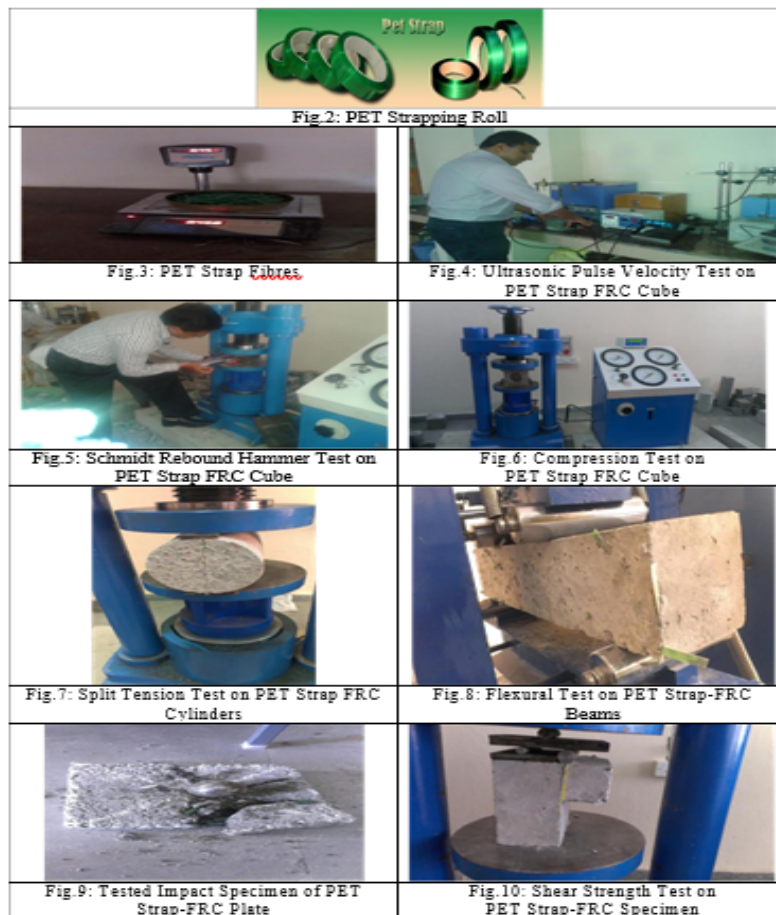
The main objective of this experimental work was to study the effect of different aspect ratio of PET Strap fibres on workability and strength characteristics of fibre reinforced concrete by direct and indirect method of testing as shown Figure 1 to 10.

Ultrasonic Pulse Velocity Test

This test was done to assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part I) 1992 specification shown in Figure 4 and results were tabulated in Table 5. The method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc.

Interpretation of results

The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc, indicative of the level of workmanship employed, can thus be assessed using the guidelines as given by Leslie Cheesman, IS: 13311-Part-I, NCBM, CWPR, which have been evolved for characterizing the quality of concrete in structures in terms of the ultrasonic pulse velocity.



Rebound Hammer Test

Rebound hammer test was done to find out the compressive strength of concrete by using rebound hammer as per IS: 13311 (Part II)1992 shown in Figure 5 and results were tabulated in Table 5

Interpretation of results

The rebound reading on the indicator scale has been calibrated by the manufacturer of the rebound hammer for horizontal impact, that is, on a vertical surface, to indicate the compressive strength. When used in any other position, appropriate correction as given

by the manufacturer is to be taken into account.

Experimental Test Results-The following Tables give the details of the experimental results.

Non-Destructive Method Test results-The following Table.No.5 give the test results of PET Strap fibre reinforced concrete for different aspect ratio of fibres by using Ultrasonic Pulse Velocity and Rebound Hammer Techniques.

Compressive Strength Test

The test procedure was carried out accordance with Indian standard: 516-1959 specification, shown in Figure.6 and results were tabulated in Table.No.6

Indirect Tensile Strength Test

The test procedure was carried out accordance with Indian standard: 5816-1999 specification, shown in Figure.7 and results were tabulated in Table.No.7

Flexural Strength Test

The test procedure was carried out accordance with Indian standard: 516-1959 specification, shown in Figure.8 and results were tabulated in Table.No.8

Impact Strength by Drop Weight Method as per ACI committee 544

The impact test was carried out under controlled conditions shown in Figure.9 and results were tabulated in Table.No.9. A mild steel ball was dropped from a height of one meter on the impact specimen, which was kept on the floor. Care was taken to see that the ball was dropped at the centre point of specimen every time. Number of blows required to cause first crack and final failure were noted. From these numbers of blows, the impact strength was calculated as follows:

$$\text{Impact energy} = mghN = w/g \times g \times h \times N = whN \text{ (N-m)}$$

Where, m = mass of the ball w = weight of the ball

g = Acceleration due to gravity h = Height of the drop =1m

N = Average number of blows to cause the failure.

Shear Strength Test

The shear strength test was carried out on inverted L-shaped shear test specimens as proposed by Bairagi. N. K and Modhera. C. D. Figure.1 and 10 clarifies the details of shear strength specimen with test set-up and loading pattern and results were tabulated in Table.No.10. The specimens were placed on compression testing

machine, a 150 x 85 x 10 mm size MS plate was placed on left side portion of 90mm face. Mild steel bar of 12 mm diameter was placed over the centre of the plate; another MS bar of 22 mm diameter was placed at the edge of the plate, over these bars, another MS plate of size 150 x 110 x 10 mm was placed. Load was applied on the top plate which forms single

4 EXPERIMENTAL RESULTS

The following Table. No. 5 to 11 gives the details of experimental test results

Compressive Strength Test Results

The following Table.No.5 and 6 gives the UPV, shear plane below the centre of 22 mm diameter bar. The loading was continued until the specimen failure. The shear strength of concrete can be calculated using the following formula:

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

Where, P = Maximum load applied to the specimen.

A = Cross sectional area (150 x 90 = 900mm²) of the specimen.

RH and compressive strength test results of PET Strap fibre reinforced concrete for different aspect ratio of fibres.

Table.5: UPV, RH and compressive strength Test Results of PET Strap Fibre Reinforced Concrete for Different Aspect Ratio of Fibres

Different Aspect Ratios	Specimen Identification	Ultrasonic Pulse Velocity m/s	Concrete Quality Grading as per Suggestions	Average Schmidt Rebound number	Strength as per Calibration Chart of Schmidt Rebound Hammer	Average Strength from Schmidt Rebound Hammer
			Leslie & Cheesman, IS:13311-Part-I, NCBM, CWPR			
0 (Ref mix)	A	4658.6	Excellent	44.6	50	49.6
	A	4717	Excellent	43.85	48	
	A	4620.3	Excellent	44.95	51	
33	B	4550	Excellent	46.05	53	51.6
	B	4797	Excellent	46.95	57	
	B	4792	Excellent	45.5	51	
55	C	4792	Excellent	48.25	58	56.3
	C	4702	Excellent	49.2	59	
	C	4777	Excellent	45.85	52	
77	D	4859	Excellent	46.05	54	51.33
	D	4702	Excellent	44.3	50	
	D	4843	Excellent	44.6	50	
99	E	4870	Excellent	41.8	44	48
	E	4870	Excellent	44	50	
	E	4881	Excellent	44.1	50	
122	F	4950	Excellent	43.15	48	42
	F	4875	Excellent	35.45	36	
	F	4934	Excellent	40	42	

Table.6: Compressive Strength Test Results of PET Strap Fibre Reinforced
Concrete for Different Aspect Ratio of Fibres.

Different Aspect Ratio Of Fibres	Specimen identification	Weight of specimen (N)	Density (kN/m^3)	Average Density (kN/m^3)	Failure load (kN)	Compressive strength (MPa)	Average compressive strength (MPa)	% increase or decrease of compressive strength w. r. t reference mix
0 (Ref. mix)	A	80.933	23.976	23.766	871	38.711	33.363	-
	A	79.461	23.544		689	30.622		
	A	80.246	23.779		692	30.756		
33	B	79.461	23.544	23.367	1037	46.089	46.637	+39.79
	B	78.088	23.132		1044	46.4		
	B	79.069	23.426		1067	47.422		
55	C	81.57	24.169	23.987	937	41.64	47.11	+41.2
	C	79.755	23.631		1123	49.91		
	C	81.472	24.139		1120	49.78		
77	D	80.393	23.819	24.012	890	39.556	41.141	+23.31
	D	82.028	24.538		1067	47.422		
	D	80.54	23.858		820	36.444		
99	E	82.5	24.447	24.65	704	31.289	37.111	+11.23
	E	84.562	25.055		861	38.267		
	E	82.502	24.447		940	41.778		
122	F	82.649	24.486	24.241	643	28.578	35.882	+6.65
	F	82.6	24.476		940	41.778		
	F	80.197	23.76		839	37.289		

Tensile Strength Test Results

The following Table.No.7 gives the tensile strength test results of PET Strap fibre reinforced concrete for different aspect ratio of fibres.

Table.7: Tensile Strength Test Results of PET Strap Fibre Reinforced Concrete for Different Aspect Ratio of Fibres.

Different aspect ratio of fibres	Specimen identification	Failure load (kN)	Tensile strength (MPa)	Average tensile strength (MPa)	Percentage increase or decrease of tensile strength w. r. t reference Mix
0 (Ref.mix)	A	260	3.68	2.901	---
	A	194	2.745		
	A	161	2.279		
33	B	240	3.397	3.274	12.86
	B	220	3.114		
	B	234	3.312		
55	C	260	3.68	3.397	17.09
	C	172	2.435		
	C	288	4.076		
77	D	237	3.355	3.011	3.79
	D	161	2.279		
	D	240	3.4		
99	E	218	3.084	2.967	2.28
	E	215	3.043		
	E	196	2.773		
122	F	210	2.971	2.961	2.07
	F	211	2.985		
	F	207	2.928		

Flexural Strength Test Results

The following Table.No.8 gives the flexural strength test results of PET Strap fibre reinforced concrete for different aspect ratio of fibres.

Table.8: Flexural Strength Test Results of PET Strap Fibre Reinforced Concrete for Different Aspect Ratio of Fibres.

Different aspect ratio of fibres	Specimen Identification	Failure load (kN)	Flexural strength (MPa)	Average flexural strength (MPa)	Percentage increase or decrease of flexural strength w. r. t reference mix
0 (Ref. mix)	A	2	0.302	0.266	---
	A	2	0.23		
	A	2	0.23		
33	B	2.5	0.392	0.442	66.16
	B	3	0.563		
	B	2.5	0.37		
55	C	3	0.52	0.564	112
	C	3	0.585		
	C	3	0.588		
77	D	2	0.4	0.384	44.36
	D	2	0.367		
	D	2	0.385		
99	E	2.5	0.423	0.335	25.94
	E	2	0.223		
	E	2.5	0.36		
122	F	2	0.365	0.328	23.308
	F	2	0.365		
	F	2	0.291		

Impact Strength Test Results

The following Table.No.9 gives the impact strength test results of PET strap fibre reinforced concrete for different aspect ratios of fibres.

Table.9: Impact Strength Test Results of PET strap Fibre Reinforced Concrete for Different Aspect Ratio of Fibres

Different aspect ratio of fibres	Specimen identification	Number of blows required to cause		Average number of blows required to cause		Impact strength (N-m) required to cause		Percentage increase or decrease of impact strength w. r. t reference mix	
		first crack	final failure	first crack	final failure	first crack	final failure	first crack	final failure
0 (Ref. mix)	A	6	12	6.67	11.67	5.87	10.23	---	---
	A	6	13						
	A	8	10						
33	B	12	72	13.33	80	11.73	70.4	99.83	588.17
	B	12	72						
	B	16	96						
55	C	13	78	14	84	12.32	73.92	109.88	622.58
	C	15	90						
	C	14	84						
77	D	9	72	9.67	73.33	8.51	64.53	44.97	530.79
	D	10	70						
	D	10	78						
99	E	9	64	8	58	7.04	51.04	19.93	398.92
	E	8	58						
	E	7	52						
122	F	7	62	5.67	51	4.99	44.88	-17.64	338.71
	F	5	61						
	F	5	30						

Shear Strength Test Results

The following Table.No.10 gives the shear strength test results of PET strap fibre reinforced concrete for different aspect ratios of fibres

Table 10: Shear strength test results of PET strap fibre reinforced concrete for different aspect ratio of Fibres

Different aspect ratio of fibres	Specimen identification	Failure load (kN)	Shear strength (MPa)	Average shear strength (MPa)	Percentage increase or decrease of Shear strength w. r. t reference mix
0 (Ref. mix)	A	92	10.21	10.08	---
	A	86	9.56		
	A	94	10.47		
33	B	111	12.33	11.67	15.77
	B	102	11.35		
	B	101	11.33		
55	C	110	12.12	12.67	25.69
	C	124	13.78		
	C	109	12.11		
77	D	104	11.56	12.29	21.92
	D	117	12.98		
	D	111	12.33		
99	E	85	9.46	10.41	3.27
	E	103	11.45		
	E	93	10.32		
122	F	93	10.33	10.12	0.39
	F	95	10.56		
	F	85	9.46		

Workability Test Results

The following Table.No.11 gives the overall test results of workability of PET Strap fibre reinforced concrete for different aspect ratio of fibres.

Table.11: Workability of PET Strap Fibre Reinforced Concrete for Different Aspect Ratio of Fibres

Different aspect ratio of fibres	Workability through			
	Slump (mm)	Compaction factor	Percentage flow	V B Consistometer
0 (Ref. mix)	0	0.91	19	3
33	0	0.92	17	4
55	0	0.97	15	5
77	0	0.95	15	7
99	0	0.93	14	9
122	0	0.92	13	10

5 OBSERVATIONS, DISCUSSION AND CONCLUSIONS

Based on the experimental results the following observations were made

1. It has been observed that the PET Strap fibre reinforced concrete shows an increasing trend in the strength characteristics from zero aspect ratio to 55 aspect ratio. After an aspect ratio of 55 the strength starts decreasing in all the tests.

The higher compressive strength can be achieved for the aspect ratio of 55 and the percentage increase in compressive strength is 41.20

a. Relation between Pulse Velocity and Compressive strength

It is has been observed from the Table No. 5 and .6 the variation in pulse velocity with respect to strength. However, the variation in pulse velocity is relatively more with respect to variation in strength of concrete may be due to quality of production.

b. Relation between Rebound Number and Compressive strength

It is observed from the Table No. 5 and .6 that Rebound number increases

with variation in compressive strength. It is also observed that the Rebound number depends on surface hardness and age of concrete.

c. Relation between Pulse Velocity and Rebound Number

It is observed from the Table No. 5 and .6 that pulse velocity depends on Rebound number.

2. The higher tensile strength can be achieved for the aspect ratio of 55 and the percentage increase in tensile strength is 17.09
3. The higher flexural strength can be achieved for the aspect ratio of 55 and the percentage increase in flexural strength is 112
4. The higher impact strength can be achieved for the aspect ratio of 55 and the percentage increase of impact strength for first crack and for final failure are 109.80
5. The higher shear strength can be achieved for the aspect ratio of 55 and the percentage increase of shear strength is 25.69
6. The higher workability can be achieved for the aspect ratio of 55. This may be due to the fact that beyond an aspect ratio of 55, the waste plastic fibres may obstruct the flow with inconvenience of interlocking with the aggregates.
7. Even, waste PET Strapping material after used in packaging goods can be reutilized to improve the mechanical properties of concrete. The use of PET Strap Fibers as reinforcement of cement concrete products is a quality assured material for developing sustainable materials to be used in the construction industry. Concrete with waste PET Strap fibers can produce more economic and sustainable building material in the future. Hence, PET Strap Fibres can be effectively used in the production PET Strap fibre reinforced concrete as an environmental friendly building construction material.

6 CONCLUSION

Based on the obtained results, the following conclusions can be drawn

1. It can be concluded that an aspect ratio of 55 is a good aspect ratio for the production of PET Strap fibre reinforced concrete and it yields maximum strength characteristics and good workability
2. It can be concluded that based on the evaluation of obtained

results, the addition of PET Strap Fibres as reinforcement in concrete, which, enhances the modification in plain concrete as a ductile material with increased load carrying capacity of cement concrete matrix. Hence, PET Strap Fibres can be used as a cost effective material to replace synthetic fibre products in many applications.

3. The use of PET Strap Fibers as reinforcement of cement concrete products is a quality assured material for developing sustainable materials to be used in the construction industry. Concrete with waste PET Strap fibers can produce more economic and sustainable building material in the future. Hence, PET Strap Fibres can be effectively used in the production PET Strap fibre reinforced concrete.

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