STUDY ON USE OF POLYMERIC WASTE MATERIALS IN CONCRETE FOR ROAD PAVEMENTS

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Abstract

Concrete is strong in compression but weak in tension and brittle also. Cracks also start forming as soon as the concrete is placed. These 3 drawbacks don't permit the use normal concrete in pavements as they lead to lack of ductility along with fracture and failure. These weaknesses in concrete can be mitigated by using fibers as reinforcement in the concrete mix. Waste materials in the form of polyethylene and tires cause environmental pollution which leads to various health problems. Polyethylene and waste tires can be recycled and used effectively in the concrete as reinforcement in the fiber form. Polyethylene is a synthetic hydrocarbon polymer which can improve the ductility, strength, shrinkage characteristics etc. This paper deals with the effects of addition of polyethylene fiber on the properties of concrete. Polyethylene and tire fibers were cut into the size of 30mm x 6mm and they were used 1.5% each by volume. Grade of concrete used were M30, M35 and M40. IRC 44:2008 was followed for the design of concrete mix. In this study, the results of the Strength properties of Polyethylene fiber reinforced concrete have been presented. 4 point bending test and double shear test were performed in the laboratory for flexure and shear strength determinations. There was seen an increase of 18% in the 28 day compressive strength along with an increase of 39% in flexure and 32% in shear strength. 22% decrease in 4 point bending test and 36% decrease in double shear test in deflection was found out from the experiments. Theoretical analysis of deflection was carried out by the help of energy methods. Practical values were verified with the theoretical values within the permissible limits. Finally it can be concluded that polyethylene and tire can be used effectively in reinforced cement concrete.

1.1 Introduction

For a developing nation such as India, road networks play a crucial role in providing a durable and comfortable surface for vehicles. Pavements are mostly made using bitumen. However, in certain situations concrete pavements are also preferred. Many additives have been explored for beneficial use of concrete as a paving material. A recent research has shown that fiber reinforced concrete (FRC) can be used for the construction of pavements as it is found to be very good in strength and it also exhibits other desirable properties . The definition of FRC given by ACI Committee 544 is "fiber reinforced concrete is a concrete which is made of cements containing fine and coarse aggregates along with water for obtaining cementious properties and discontinuous fibers" . The fibers used are of various types such as steel fibers, polymer or natural fibers etc. As said earlier, fiber reinforced concrete is that form of concrete where fibers are put into the concrete as reinforcement in order to increase the strength characteristics and other mechanical properties of the concrete. Fiber reinforced concrete is not just provided for local strengthening in tensile region but it is provided for obtaining a gain in compression and tension along with reduced deflections and shrinkage and increased ductile property .

Apart from the above mentioned properties, polymeric fibers also help in corrosion reduction. Commonly, Recron 3s, polyester and polypropylene have been used for the purpose of FRC.

1.2 Objective

The present work is aimed at using two polymeric waste materials, such as polyethylene and tire fibers as reinforcement in concrete pavement. The basic objective of this work is to assess the advantages of using such waste materials such as increase in compressive, flexure and shear strength and decrease in deflection characteristics of the resultant concrete and also the determination of the deflection in the laboratory testing then its comparison to the theoretical deflection and check whether the errors are in the permissible limits of 20%.

2. Polymer fibers

Fiber reinforced concrete (FRC) is made by mixing polymer fibers into a conventional concrete mix.

2.1 Role of polymer in pavement

There is a need of improvement in the quality of the pavements as the steady increase of wheel loads, change in climatic conditions, tire pressure & daily wear and tear adversely affect the performance of vehicles over the pavement

Synthetic polymer fibers can be used to overcome the above mentioned problems which are faced in daily life. Modifying the concrete with the polymers can improve the crack arresting capability, fatigue life and many other mechanical prospects of pavement

2.2 Synthetic fibers

Synthetic fibers include polyethylene, polypropylene, acrylic, carbon, aramid, nylon, polyester etc . Synthetic fibers can be further classified into macro-fibers and micro-fibers. Both of these subtypes have different properties with respect to each other. We have used polyethylene and tire in the form of macro-fibers as the reinforcement. Chosen size is 30mm x 6mm.

Fig 1.1 Steel fiber (Source: Google images)

Fig 1.2: Polypropylene fiber (Source: Google images)

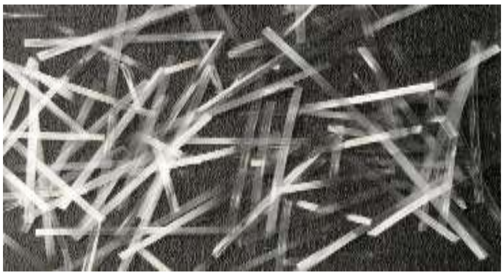


Fig 1.3: Polyethylene fiber (Source: Google images)

BASE MATERIALS

3.1 Basic materials

The basic materials which compose concrete are:

1. Water
2. Cement
3. Fine aggregate
4. Coarse aggregate
5. Admixture

In case of polymer fiber reinforced concrete fibers are added. For this experiment 2 types of fiber are chosen. The fibers to be used in the concrete mix are:

1. Polyethylene fiber
2. Tire (Nylon) fiber

3.2 Material preparation:

The materials used in the concrete mix are:

1. 53 grade OPC.
2. Zone – iii sand as fine aggregate.
3. 10mm and 20mm coarse aggregate.
4. Sikament – 170 admixture

5. Polyethylene fiber
6. Tire fiber

3.2.1 Preparation of fibers

The polythene used in OMFED milk packets is used as raw material for preparation of the fiber. These polythene packets are collected; they are washed and cleaned by putting them in hot water for 3- 4 hours. They are then dried.
Similarly waste tires are collected. The steel wires inside them are striped out of the tires. They are washed in hot

water and then dried.

The dried polyethylene packets and the tires are cut into pieces of size 30mm x 6mm size. This is to ensure that when the fibers are mixed with the cement and aggregate the mixing will be proper and the fibers will be randomly distributed over the concrete matrix evenly.

4.1 Methodology

To study the various parameters of polymeric fiber reinforce concrete that affect the service life of a pavement with minimal maintenance, the following experiments are needed to be carried out:

1. Test of aggregates

a. Abrasion resistance of aggregates

b. Impact resistance of aggregates

c. Crushing resistance of aggregates

2. Test of concrete

a. Physical inspection of concrete

b. 28 day compressive strength test

c. Flexural strength test

d. Shear strength test

Table 4.1: Test on aggregates

L.A. ABRASION TEST	IMPACT VALUE TEST	CRUSHING VALUE TEST
Maximum value allowed in fiber introduced concrete = 30% Test results on average = 23.6%	Maximum value allowed in fiber introduced concrete = 45% Test results on average = 21.8%	Maximum value allowed in fiber introduced concrete = 30% Test results on average = 21.3%

4.2 MIX DESIGN

The design mixes M30, M35 and M40 are carried out in accordance to codes IRC 44:2008.

Table 4.2: Mix design

GRADE OF CONCRETE	WATER	CEMENT	FINE AGGREGATE	COARSE AGGREGATE (10mm)	COARSE AGGREGATE (20mm)	ADMIXTURE
M30	0.45	1	2.1	3.06	0.34	0.019
M35	0.43	1	1.6	2.7	0.3	0.022
M40	0.4	1	1.8	2.7	0.3	0.023

Specific gravity of polyethylene = 0.94

Specific gravity of tire without steel wires = 1.114

Therefore,
For cubes of size 150mm x 150mm x 150mm

I. Polyethylene fiber used = 47.56gms

II. Tire fiber used = 57.65gms

For beams of size 500mm x 100mm x 75mm

I. Polyethylene fiber used = 64.125gms

II. Tire fiber used = 52.875gms

Figure 3.1(a): OMFED Polyethylene used
Figure 3.1(b): Shredded polyethylene

Figure 3.2: Steel wires taken out (top) and tire cut in 30mm x 6mm (bottom)

4.3 Casting and curing

Standard sized cubes (150mm x 150mm x 150mm) are casted for compression test of concrete. The beams casted are however different than standard size. The beams are casted with dimension 500mm x 100mm x 75mm.
Total 18 numbers of cubes and 36 numbers of beams are casted. They are allowed to stay in the mould for 24 hours. Then they are immersed in water for curing. After 28 days they are taken out from water, dried and then tested.

Table 4.3: Compressive strength of conventional concrete cubes

GRADE OF CONCRETE	SPECIMEN NO.	FAILURE LOAD (Tons)	COMPRESSIVE STRENGTH (N/mm2)	MEAN COMPRESSIVE STRENGTH (N/mm2)
M30	1	83	36.88	37.18
	2	84	37.33	
	3	84	37.33	
M35	1	95	42.22	42.66
	2	97	43.11	
	3	96	42.66	
M40	1	104	46.22	46.96
	2	108	48	
	3	105	46.66	

Table 4.4: Compressive strength of fiber introduced concrete cubes

GRADE OF CONCRETE	SPECIMEN NO.	FAILURE LOAD (Tons)	COMPRESSIVE STRENGTH (N/mm2)	MEAN COMPRESSIVE STRENGTH (N/mm2)	STRENGTH GAIN (%)
M30	4	99	44	43.85	17.93
	5	99	44		
	6	98	42.56		
M35	4	111	49.33	49.48	15.98
	5	112	49.78		
	6	112	49.78		
M40	4	124	55.11	54.57	16.1
	5	122	54.22		
	6	122	54.22		

4-Point bend test (2-Point load test)

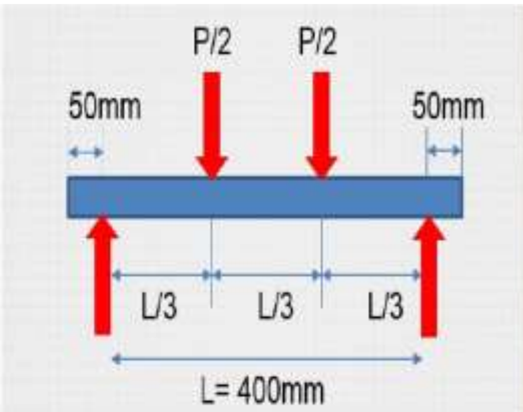


Fig-4.2(a) and 4.2(b): 4 Point bend test

The results for 4-point bend test for conventional concrete cubes and fiber introduced concrete cubes are tabulated in table-4.5 and table-4.6 respectively.

Table 4.5: Flexural strength of conventional concrete beams

Grade of concrete	**Specimen number**	**Failure load (KN)**	**Flexural strength (N/mm²)**	**Mean flexural strength (N/mm²)**	**Deflection (mm)**	**Mean deflection (mm)**
M30	1	5.41	3.85	3.91	0.088	0.09
	2	5.5	3.91		0.091	
	3	5.6	3.98		0.091	
M35	1	5.66	4.02	4.03	0.086	0.085
	2	5.57	3.96		0.086	
	3	5.76	4.10		0.083	
M40	1	5.77	4.10	4.11	0.079	0.077
	2	5.65	4.02		0.077	
	3	5.91	4.20		0.076	

Table 4.6: Flexural strength of fiber introduced concrete beams

Grade of concrete	**Specimen number**	**Failure load (KN)**	**Flexural strength (N/mm²)**	**Mean flexural strength (N/mm²)**	**Deflection (mm)**	**Mean deflection (mm)**
	4	7.53	5.35		0.071	
M30	5	7.57	5.38	5.37	0.071	0.07
	6	7.58	5.39		0.068	
M35	4	7.92	5.63	5.63	0.065	0.065
	5	7.93	5.64		0.064	
	6	7.92	5.63		0.066	
M40	4	8.07	5.74	5.74	0.061	0.061
	5	8.08	5.72		0.063	
	6	8.12	5.77		0.06	

The percentage gain in strength and percentage reduction of deflection due to incorporation of fibers in concrete is calculated and tabulated. The data obtained from the calculations are shown in the table 4.7.

flection reduction in fiber introduced concrete beams

Grade of concrete	Mean flexural strength (N/mm^2)	Gain in flexural strength (%)	Mean deflection (mm)	Reduction in deflection (%)
M30	5.37	37.34	0.07	22.22
M35	5.63	39.70	0.065	23.53
M40	5.74	39.66	0.061	20.78

The load and deflection co-ordinates for beams of conventional and fiber introduced concrete beams are tabulated in table 4.8, 4.9 and 4.10.

The graph between load and deflection is plotted using graph software. The co-ordinate points are first plotted on the plane and joined by 2D cubic spline approach. The load vs deflection graph for M30, M35 and M40 concrete beams are shown in fig-4.2(c), 4.2(d) and 4.2(e) respectively.

Table 4.8: Load and deflection of conventional concrete and fiber introduced concrete beams (M30)

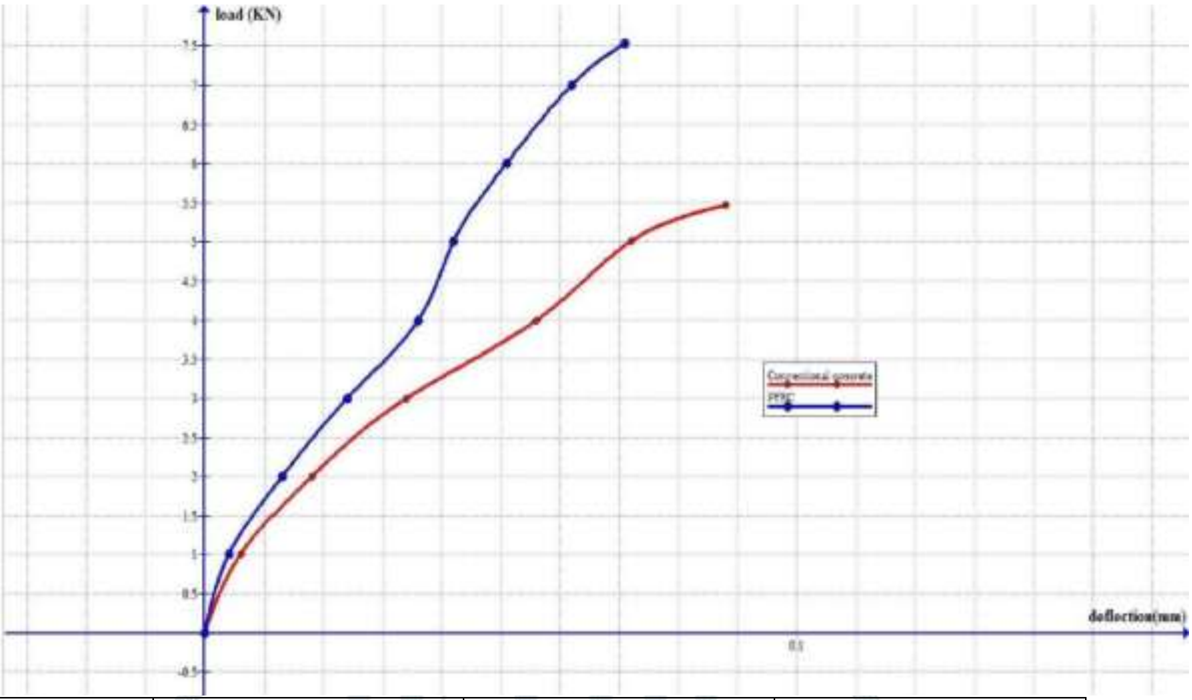
Conventional concrete		fiber introduced concrete	
Load (KN)	**Deflection (mm)**	**Load (KN)**	**Deflection (mm)**
0	0	0	0
1	0.006	1	0.004
2	0.018	2	0.013
3	0.034	3	0.024
4	0.056	4	0.036
5	0.072	5	0.042
5.47	0.088	6	0.051

Table 4.9: Load and deflection of conventional concrete and fiber introduced concrete beams (M35)

Conventional concrete		fiber introduced concrete	
Load (KN)	**Deflection (mm)**	**Load (KN)**	**Deflection (mm)**
0	0	0	0
1	0.018	1	0.008
2	0.032	2	0.017
3	0.044	3	0.026
4	0.061	4	0.031
5	0.078	5	0.037
5.66	0.086	6	0.044

Table 4.10: Load and deflection of conventional concrete and fiber introduced concrete beams (M40)

Conventional concrete		fiber introduced concrete	
Load (KN)	**Deflection (mm)**	**Load (KN)**	**Deflection (mm)**
0	0	0	0
1	0.011	1	0.007
2	0.018	2	0.013
3	0.031	3	0.024
4	0.048	4	0.031
5	0.063	5	0.038



5.91	0.079	6	0.046

Fig-4.2(c): 4 Point bend test Load vs Deflection for M30 concrete

Fig-4.2(d): 4 Point bend test Load vs Deflection for M35 concrete

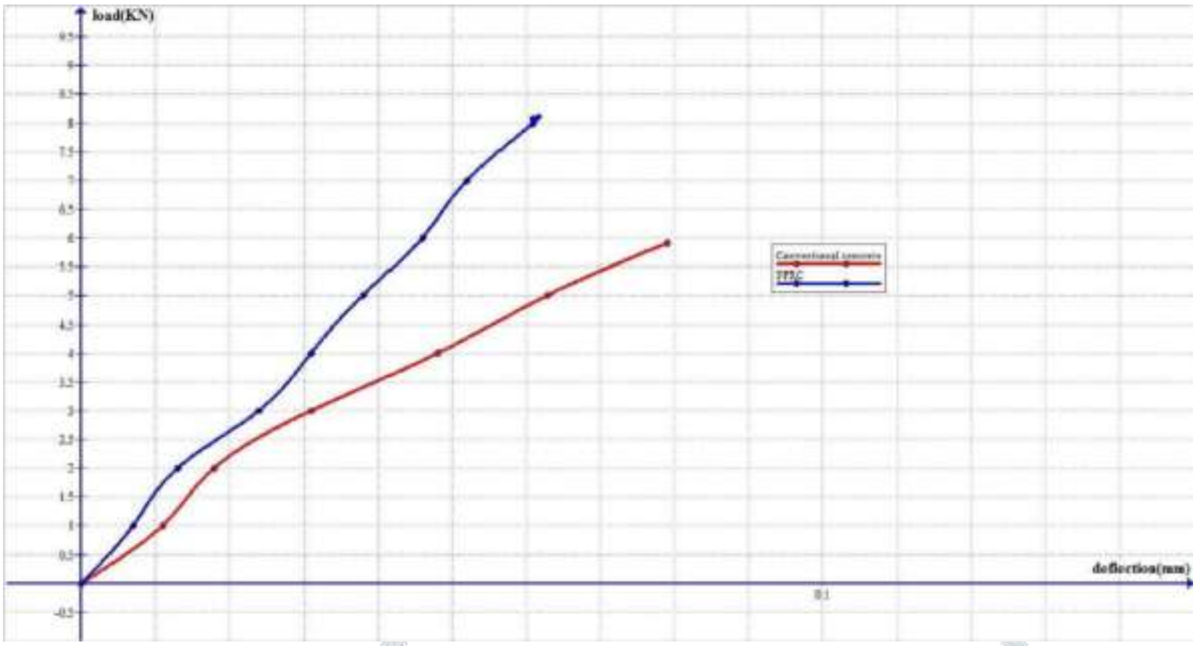


Fig-4.2(e): 4 Point bend test Load vs Deflection for M40 concrete

Double shear test

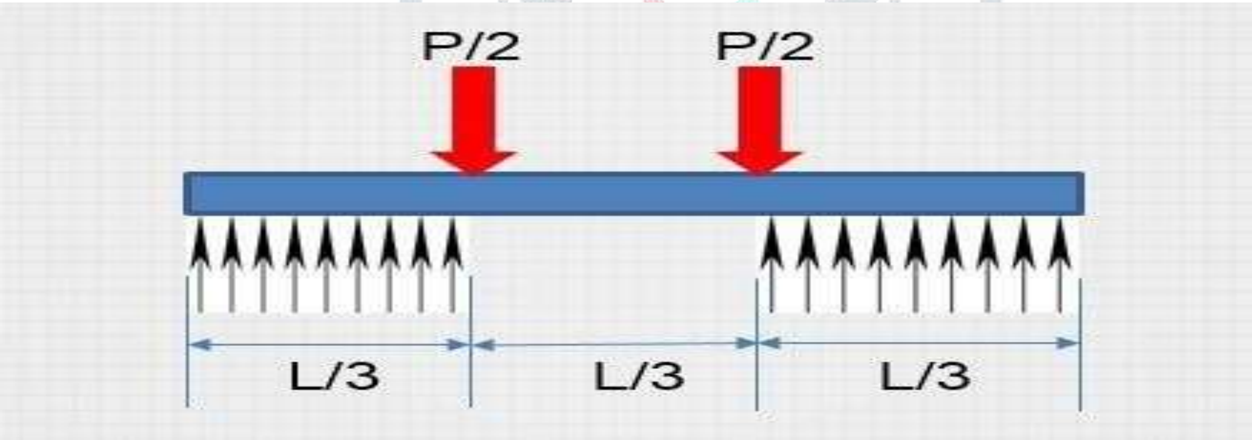


Fig-4.3(a): 4 Double shear test

The results for double shear test for conventional concrete cubes and fiber introduced concrete cubes are tabulated in table-4.11 and table-4.12 respectively.

Table 4.11: Shear strength of conventional concrete beams

Grade of concrete	Specimen number	Failure load (KN)	Shear strength (N/mm^2)	Mean shear strength (N/mm^2)	Deflection (mm)	Mean deflection (mm)
	1	64.2	8.56		0.66	
M30	2	64.29	8.575	8.575	0.72	0.72

	3	64.36	8.58		0.84	
	1	64.52	8.60		0.64	
M35	2	64.61	8.61	8.61	0.69	0.69
	3	64.71	8.63		0.76	
	1	65.03	8.67		0.66	
M40	2	65.10	8.68	8.68	0.66	0.66
	3	65.16	8.69		0.66	

Table 4.12: Shear strength of fiber introduced concrete beams

Grade of concrete	Specimen number	Failure load (KN)	Shear strength (N/mm^2)	Mean shear strength (N/mm^2)	Deflection (mm)	Mean deflection (mm)
	4	84.32	11.24		0.42	
M30	5	84.44	11.26	11.26	0.45	0.44
	6	84.56	11.27		0.46	
	4	85.38	11.38		0.45	
M35	5	85.68	11.42	11.42	0.44	0.44
	6	85.96	11.46		0.44	
	4	86.32	11.51		0.51	
M40	5	86.40	11.52	11.52	0.53	0.43
	6	86.49	11.53		0.56	

The percentage gain in strength and percentage reduction of deflection due to incorporation of fibers in concrete is calculated and tabulated. The data obtained from the calculations are shown in the table 4.13.

Table 4.13: Shear strength gain and deflection reduction in fiber introduced concrete beams

Grade of concrete	Mean shear strength (N/mm^2)	Gain in shear strength (%)	Mean deflection (mm)	Reduction in deflection (%)
M30	11.26	31.33	0.44	38.69
M35	11.42	32.56	0.44	36.23
M40	11.52	32.72	0.43	33.75

The load and deflection co-ordinates for beams of conventional and fiber introduced concrete beams are tabulated in table 4.14, 4.15 and 4.16.

The graph between load and deflection is plotted using graph software. The co-ordinate points are first plotted on the plane and joined by 2D cubic spline approach. The load vs deflection graph for M30, M35 and M40 concrete beams are shown in fig-4.3(b), 4.3(c) and 4.3(d) respectively.

Table 4.14: Load and deflection of conventional concrete and fiber introduced concrete beams (M30)

Conventional concrete		fiber introduced concrete	
Load (KN)	**Deflection (mm)**	**Load (KN)**	**Deflection (mm)**
0	0	0	0
10	0.12	10	0.06
20	0.24	20	0.11
30	0.31	30	0.17
40	0.44	40	0.21
50	0.56	50	0.26
60	0.61	60	0.31
64.2	0.66	70	0.36

nventional concrete and fiber introduced concrete beams (M35)

Conventional concrete		fiber introduced concrete	
Load (KN)	**Deflection (mm)**	**Load (KN)**	**Deflection (mm)**
0	0	0	0
10	0.08	10	0.03
20	0.18	20	0.08
30	0.3	30	0.13
40	0.44	40	0.19
50	0.53	50	0.25
60	0.60	60	0.31
64.52	0.64	70	0.37

Table 4.16: Load and deflection of conventional concrete and fiber introduced concrete beams (M40)

Conventional concrete		fiber introduced concrete	
Load (KN)	**Deflection (mm)**	**Load (KN)**	**Deflection (mm)**
0	0	0	0
10	0.13	10	0.04
20	0.22	20	0.1
30	0.34	30	0.15
40	0.47	40	0.21
50	0.56	50	0.27
60	0.62	60	0.38
65.03	0.66	70	0.43

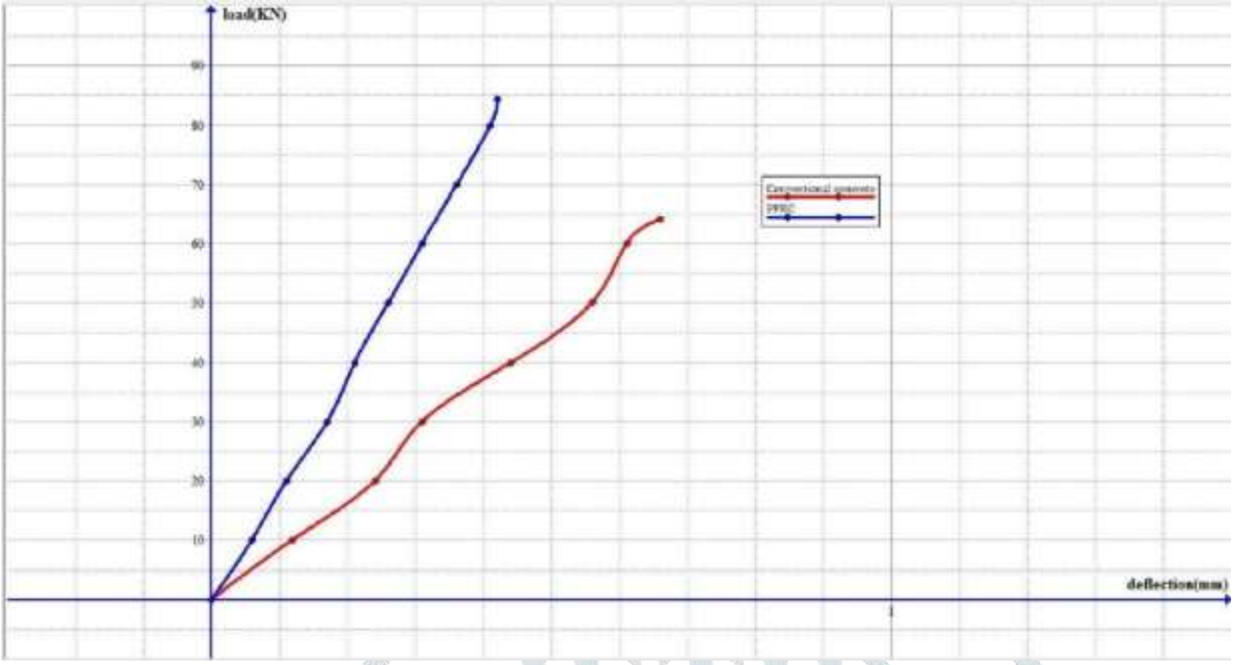


Fig-4.3(b): Double shear test Load vs Deflection for M30 concrete

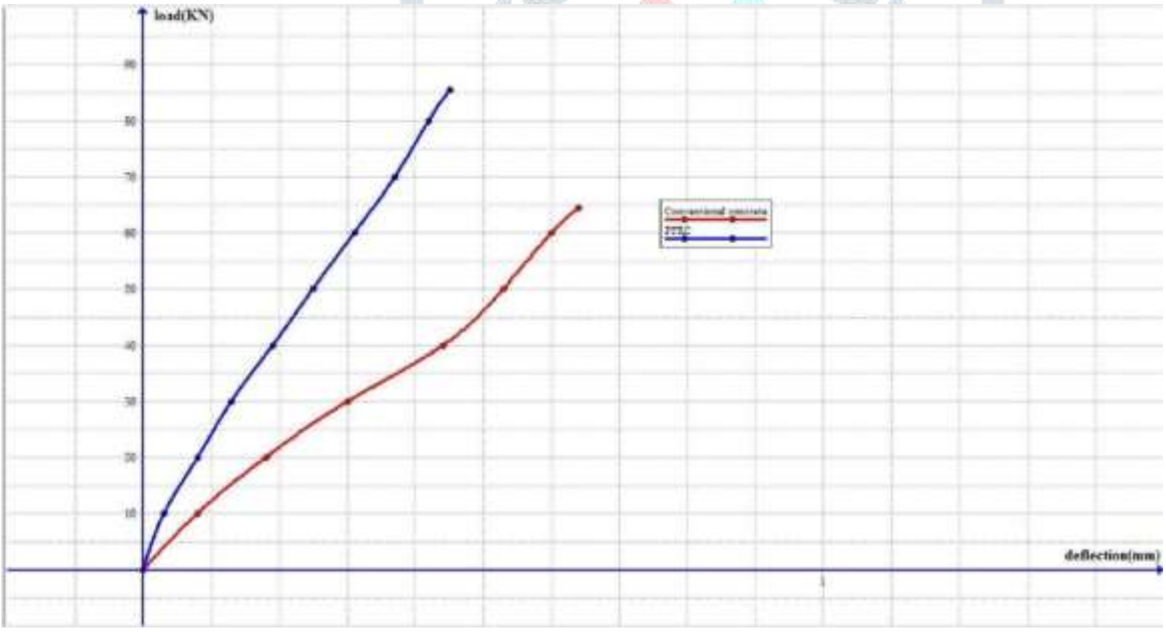


Fig-4.3(c): Double shear test Load vs Deflection for M35 concrete

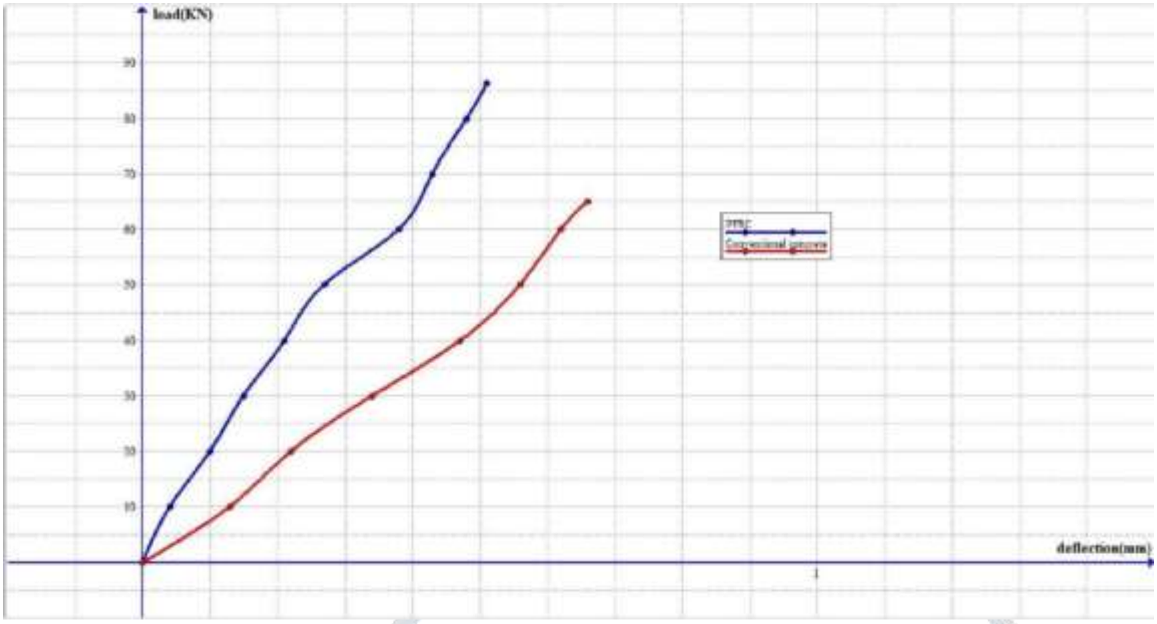


Fig-4.3(d): Double shear test Load vs Deflection for M40 concrete

RESULT ANALYSIS

5 Methodology

The values of deflection are calculated theoretically and the obtained values are compared with the values obtained in the respective experiments.

Some standard values are taken into consideration:

- Poisson's ratio (μ) = 0.2
- Modulus of elasticity (E) = 5000 $\sqrt{f_{ck}}$

Where f_{ck} = characteristic strength of concrete
So for M30, E =27386.13 MPa
M35, E = 29580.40 MPa
M40, E = 31622.77 MPa
As in case of fiber introduced concrete the mean of the cube strengths are taken into consideration, same will be done for conventional concrete. 3. Moment of inertia (I) = $bd^3/12$

$= 100x75^3/12$

$= 3515624\ mm^4$

The effective length is taken as the length of the specimen So $L = L_{eff}$ = 400 mm

5.1 Point bend test

Deflection at center of the span = $\delta = (23PL^3/1296EI) \times [1+ \{216d^2(1+ \mu)/115L^2\}$

For $\delta < L/900$, $\delta = 1.5\ \delta$ For $\delta > L/900$, $\delta = 8\ \delta$

Using the formula given above theoretical values of deflection are calculated. The theoretical and experimental values of deflection for conventional concrete and fiber introduced concrete are tabulated in table 5.1 and 5.2. The comparison between theoretical data and experimental data is shown in table 5.3.

Table 5.1: Theoretical and experimental deflection of conventional concrete

GRADE OF CONCRETE	SPECIMEN NO.	FAILURE LOAD (KN)	THEORETICAL DEFLECTION (mm)	EXPERIMENTAL DEFLECTION (mm)
M30	1	5.41	0.093	0.088
	2	5.5	0.0945	0.091
	3	5.6	0.096	0.091
M35	1	5.66	0.0915	0.086
	2	5.57	0.090	0.086
	3	5.76	0.0915	0.083
M40	1	5.77	0.090	0.079
	2	5.65	0.0855	0.077
	3	5.91	0.090	0.076

Table 5.2: Theoretical and experimental deflection of fiber introduced concrete

GRADE OF CONCRETE	SPECIMEN NO.	FAILURE LOAD (KN)	THEORETICAL DEFLECTION (mm)	EXPERIMENTAL DEFLECTION (mm)
	4	7.53	0.079	0.071
M30	5	7.57	0.08	0.071
	6	7.58	0.08	0.068
M35	4	7.92	0.079	0.065
	5	7.93	0.079	0.064
	6	7.92	0.078	0.066
M40	4	8.07	0.076	0.061
	5	8.08	0.075	0.063
	6	8.12	0.076	0.06

Table 5.3: Comparison of theoretical and experimental deflection

TYPE OF CONCRETE	GRADE OF CONCRETE	MEAN THEORETICAL DEFLECTION (mm)	MEAN EXPERIMENTAL DEFLECTION (mm)	PERCENTAGE OF VARIATION
Conventional concrete	M30	0.0945	0.09	4.76
	M35	0.091	0.085	6.59
	M40	0.088	0.077	12.5
fiber introduced concrete	M30	0.0796	0.07	13.7
	M35	0.0786	0.065	17.3
	M40	0.0756	0.061	19.31

5.2 Double shear test

Deflection at center of the span = δ = $(97PL^3/5078EI)$

For δ < L/900, δ = δ/1.7 For δ > L/900, δ = δ/2.1

Using the formula given above theoretical values of deflection are calculated. The theoretical and experimental values of deflection for conventional concrete and fiber introduced concrete are tabulated in table 5.4 and 5.5. The comparison between theoretical data and experimental data is shown in table 5.6.

Table 5.4: Theoretical and experimental deflection of conventional concrete

GRADE OF CONCRETE	SPECIMEN NO.	FAILURE LOAD (KN)	THEORETICAL DEFLECTION (mm)	EXPERIMENTAL DEFLECTION (mm)
M30	1	64.2	0.81	0.66
	2	64.29	0.82	0.72
	3	64.36	0.82	0.84
M35	1	64.52	0.82	0.64
	2	64.61	0.84	0.69
	3	64.71	0.86	0.76
M40	1	65.03	0.80	0.66
	2	65.10	0.82	0.66
	3	65.16	0.84	0.66

Table 5.5: Theoretical and experimental deflection of fiber introduced concrete

GRADE OF CONCRETE	SPECIMEN NO.	FAILURE LOAD (KN)	THEORETICAL DEFLECTION (mm)	EXPERIMENTAL DEFLECTION (mm)
M30	4	84.32	0.52	0.42
	5	84.44	0.53	0.45
	6	84.56	0.54	0.46
M35	4	85.38	0.50	0.45
	5	85.68	0.51	0.44
	6	85.96	0.52	0.44
M40	4	86.32	0.47	0.51
	5	86.40	0.48	0.53
	6	86.49	0.79	0.56

Table 5.6: Comparison of theoretical and experimental deflection

TYPE OF CONCRETE	GRADE OF CONCRETE	MEAN THEORETICAL DEFLECTION (mm)	MEAN EXPERIMENTAL DEFLECTION (mm)	PERCENTAGE OF VARIATION
Conventional concrete	M30	0.82	0.72	12.19
	M35	0.84	0.69	17.86
	M40	0.82	0.66	19.5
fiber introduced concrete	M30	0.53	0.44	16.98
	M35	0.51	0.44	13.72
	M40	0.48	0.43	10.41

The theoretical values for deflection under given load are calculated for both 4-point bend test and double shear test for conventional concrete and polymer fiber reinforced concrete beams for each grade and compared with the values of deflection obtained from respective experimentations when similar beam is loaded under same physical conditions.

6.1 Conclusions

The following inferences have been drawn from the experiments done on concrete with polyethylene and tire fibers:

1. There is a gain of 17.93%, 15.98% and 16.1% in compressive strength of M30, M35 and M40 grade concrete respectively.
2. Gain in flexural strength were found to be 37.34%, 39.70% and 39.66% for M30, M35, and M40 respectively. And respective reduction in deflection were 22.22%, 23.53% and 20.78%.
3. There is a significant amount of gain found in shear strength. Gain in shear strength were found to be 31.33%, 32.56% and 32.72% for M30, M35, and M40 respectively. And respective reduction in deflection were 38.69%, 36.23% and 33.75%.
4. From the above observations it can be seen that the gain in flexural strength is more than gain in shear strength. However the center point deflection due to shear force is much more reduced than deflection due to flexure.
5. From theoretical analysis of results it is observed in case of 4-point bend test that the percentage of variation of deflection in fiber introduced concrete is much higher than that of conventional concrete and it goes on increasing with increase in characteristic strength for both conventional concrete and fiber introduced concrete.
6. The percentage of variation of deflection in conventional concrete is found to be 4.76%, 6.59% and 12.5% for M30, M35 and M40 respectively and for fiber introduced concrete it is found to be 13.7%, 17.3% and 19.31%.
7. However in case of double shear test that the percentage of variation of deflection in fiber introduced concrete is nearly equal to that of conventional concrete and it goes on increasing with increase in characteristic strength for conventional concrete and decreases for fiber introduced concrete beams.
8. The percentage of variation of deflection in conventional concrete is found to be 12.19%, 17.86% and 19.5% for M30, M35 and M40 respectively and for fiber introduced concrete it is found to be 16.98%, 13.72% and 10.41%.

From the above mentioned findings it can be concluded that the wasted polyethylene and tire fibers can be used effectively to positively influence the mechanical properties of the fiber reinforced concrete.

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