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AN INVESTIGATION INTO THE USE OF POLYMERIC WASTE MATERIALS IN THE CONSTRUCTION OF LONG-LASTING ROAD PAVEMENTS

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ABSTRACT

Concrete has a high compressive strength but is weak in tension and brittle. Cracks begin to form as soon as the concrete is poured. These three disadvantages prevent the use of standard concrete in pavements because they cause ductility, fracture, and failure. Concrete's shortcomings can be reduced by employing fibres as reinforcement in the concrete mix. Waste products such as polyethylene and tyres pollute the environment, resulting in a variety of health issues. Polyethylene and scrap tyres can be recycled and utilised efficiently as fibre reinforcement in concrete. Polyethylene is a synthetic hydrocarbon polymer that can increase ductility, strength, shrinkage, and other properties. This research investigates the effects of polyethylene fibre addition on the characteristics of concrete. Polyethylene and tyre fibres were chopped into 30mm x 6mm pieces and used at 1.5% by volume each. M30, M35, and M40 concrete grades were used. For the design of the concrete mix, IRC 44:2008 was used. The results of the Strength characteristics of Polyethylene fibre reinforced concrete have been provided in this study. Flexure and shear strength were determined in the laboratory using a four-point bending test and a double shear test. The 28-day compressive strength increased by 18%, while flexure and shear strength increased by 39% and 32%, respectively. The trials revealed a 22% decrease in deflection in the 4 point bending test and a 36% decrease in the double shear test. Theoretical study of deflection was performed using energy methods. Within the acceptable limits, practical values were validated against theoretical values. Finally, it is possible to conclude that polyethylene and tyre can be efficiently used in reinforced cement concrete.

Keywords: *concrete, fiber reinforcement, polyethylene, waste tires, pavement, ductility, fracture, failure, environmental pollution, health problems, strength properties, 4-point bending test, double shear test, compressive strength, flexure, shear strength, deflection, energy methods, sustainable construction*

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 [25]. 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” [1]. The fibers used are of various types such as steel fibers, polymer or natural fibers etc. [5 and 6]. 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 [3, 4, 13, 14, 15, 16 and 25].

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. Recently, other forms of recycled fibers like plastic, disposed tires, carpet waste and wastes from textile industry are also being adopted for the same purpose. Basic function of these fibers is to act as crack arresters. Fibers help in resisting the minor cracks and would not let them grow into macro cracks. Hence, the material transforms into a material with improved ductility and toughness to failure

[4, 13, 14 and 16].

Fig 1.1 Steel Fiber (Source: Google Images)

Fig 1.2: Polypropylene Fiber (Source: Google Images)

Fig 1.3: Polyethylene Fiber (Source: Google Images)

1.2 Use of Waste Polyethylene and Tires

Plastics are very strong and non-biodegradable in nature. The chemical bonds in plastics make it extremely sturdy and impervious to ordinary common techniques of degradation. The daily use of plastics has increased very rapidly and it has become a common habit of people to just throw out the plastic and causing environmental pollution. Over 1 billion tons of plastic have been produced since 1950s, and the same is likely to remain as such for many years [28]. These wastes get mixed with MSW or they are simply thrown causing nuisance to the society. There is a big need of recycling of the plastics as well waste tires because we don't have any other option of disposing them without securing environment from pollution. For example, there are two processes for the disposal of wastes: land filling and incineration. If the wastes are simply dumped, they cause soil and water pollution and if they are incinerated, they cause air pollution. Hence, there is a need to recycle the wastes into something useful which will not hamper the environment and the process in which it is used [28].

1.3 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%.

The main goal of the study is to utilize waste materials polyethylene and tire to achieve greater concrete strength properties in order to recycle them into something very useful and helping in reducing the environmental impact that the both of them have.

2. Base Materials

2.1 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 fiberare chosen. The fibers to be used in the concrete mix are:

1. Polyethylene fiber
2. Tire (Nylon) fiber

Both fibers to be used in concrete matrix will be made from the waste materials. The wasted pouches of OMFED milk will be used for making the polyethylene fiber whereas wasted tire willbe used to prepare nylon fiber.

2.1.1 Water

Water is the most important material in concrete. It performs the following roles in concrete matrix:

1. It gives cement the adhering property. The quality, quantity, stability and rate of formation of the adhesive material that binds the aggregates depend on the quality and quantity of water added.
2. It also controls the workability of concrete. The more the water content (up to certain limit) the more is the workability.
3. The mechanical properties of hardened concrete as compressive, flexural strength and toughness also depend on hydration products of cement and there by depend on water content.
4. The plasticity of concrete depends on the water content.

5. Water is also needed for curing of hardened concrete to help concrete acquire its required strength.

2.1.2 Cement

Cement is a material which when combined with water exhibits cohesive and adhesive properties that helps in holding the aggregates together to form a concrete mass. It is also called as hydraulic cement as it gets its adhering property in an exothermic hydration process and forms a water resisting material.

2.2 Material Preparation

The materials used in the concrete mix are:

a. 53 grade OPC.

b. Zone – iii sand as fine aggregate.

c. 10mm and 20mm coarse aggregate.

d. Sikament – 170 admixture

e. Polyethylene fiber

f. Tire fiber

The aggregates of different grade to be used for preparing concrete mixes are sieved through different IS Sieves and they are kept in different containers with proper marking.

2.2.1 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.

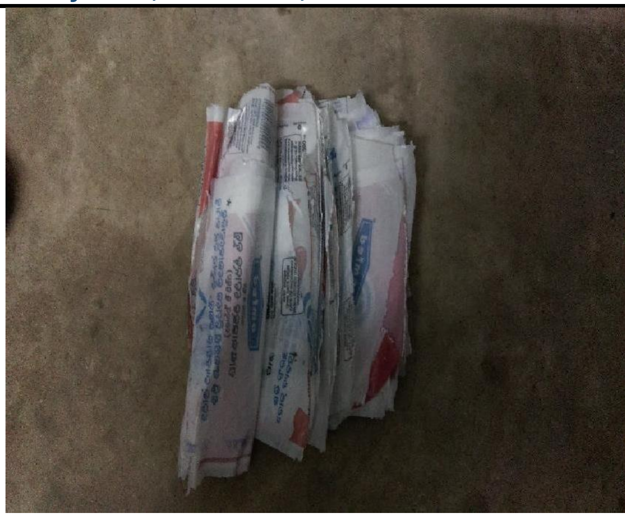

Figure 3.1(a): OMFED Polyethylene Used ***Figure 3.1(b): Shredded Polyethylene***

Figure 3.2: Steel Wires Taken Out (Left) And Tire Cut In 30mm X 6mm (Right)

Certain properties of materials used:

1. Specific gravity of cement = 3.04Grade of

   cement = OPC 53

2. Specific gravity of fine aggregate = 2.6Zone of

   sand = Zone – iii

3. Specific gravity of coarse aggregate = 2.7

4. Dimension of fibers = 30mm x 6mm Specific gravity of polyethylene = 0.94Specific

   gravity of tire = 1.14

The above data is used for mix design and batching of material to prepare concrete of required characteristic strength.

3.Experimental Work

3.1 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

The flexural strength test to be conducted is 2-point load test (4-point bend test) and the shearstrength test to be conducted is double shear test.

3.2 Tests on Aggregates

3.2.1 Abrasion Resistance of Aggregates

The Los Angeles abrasion test is conducted to calculate the abrasion resistance of coarse aggregate.

Procedure

I. Aggregates dried in oven at 105 - 110 °C to constant weight conforming to any one of the grading. E.g. 1250 gm of 40-25 mm, 1250 gm of 25-20 mm, 1250 gm of 20- 12.5 mm, 1250 gm of 12.5-10 mm with12 steel balls.

II. Aggregate weighing 5 kg is placed in cylinder of the machine (W_1).

III. Machine is rotated @ 30- 33 rpm for 500 revolutions.

IV. After 500 complete revolutions machine is stopped and complete material is taken out including dust.

V. Then the complete material is sieved through 1.7 mm sieve.

VI. Then the retained mass is washed thoroughly, oven dried for 24 hours and then weighed(W).

VII. So the weight of the mass passing = $W_1 - W = W_2$.

VIII. Then the abrasion resistance is calculated in terms of Los Angeles abrasion value (LAAV).

LAAV = (W_2 / W_1) x100

Where W_2 = Weight of fines passing 1.7 mm

W_1 = Weight of the sample

In this experiment

Weight of the sample = W_1 = 5000gms

Weight of fines passing 1.7 mm = W_2 = 1180gmsSo LAAV = W_2x100 / W_1

= 1180 x 100/5000

= 23.6%

3.2.2 Impact Resistance of Aggregates

The Impact value test is conducted to measure the resistance of the aggregate towards impact load. The impact test machine is used to determine the aggregate impact value of coarse aggregate as per IS 2386 Part IV - 1963 - Methods of test for aggregates.

Procedure

I. Aggregate passing through 12.5 mm IS sieve and retained on 10 mm sieve is taken.

II. The aggregates are filled in the cylindrical measure in 3 layers by tamping each layer by25blows.

III. Excess aggregates are stroke off using the tamping rod as a straight edge.

IV. The net weight of aggregate in the measure is (W_1).

V. The hammer is raised to height of 38 cm above the upper surface of the aggregates in thecup and is allowed to fall freely on the specimen.

VI. After subjecting the test specimen to 15 blows, the crushed aggregate is sieved through IS 2.36 mm sieve.

VII. The fraction passing through IS 2.36 mm sieve is weighed (W_2).

VIII. The impact resistances of the aggregates were expressed in terms of impact value.

Impact value = (W_2 / W_1) x100

Where W_2 = Weight of fines passing 2.36 mmW_1 =

Weight of the sample

In this experiment

Weight of the sample = W_1 = 327gms

Weight of fines passing 2.36 mm = W_2 = 71.3gmsSo Impact

value = W_2x100 / W_1

= 71.3 x 100/327

= 21.8%

3.2.3 Crushing Resistance of Aggregates

The Crushing value test is conducted to measure the resistance of the aggregate towards crushingload.

Procedure

I. Aggregates passing 12.5 mm and retained on 10 mm are selected for this test.

II. 3.25 kg of the sample is taken and filled in the cylindrical measure in 3 layers, tamping each layer 25 times.

III. After leveling the aggregates at the top surface the test sample is weighed (W_1).

IV. The cylinder is now placed on the base plate.

V. The cylinder with the test sample and plunger in position is placed on compression machine.

VI. Load is applied at a rate of 4 tons per minute up to 40 tons.

VII. The crushed aggregate is taken out and sieved through 2.36 mm IS sieve.

VIII. The materials passing through 2.36mm sieve is weighed (W_2).

IX. The crushing resistance of the aggregate is then expressed in terms of crushing value.

Crushing value = (W_2 / W_1) x100

Where W_2 = Weight of fines passing 2.36 mm

W_1 = Weight of the sample

In this experiment

Weight of the sample = W_1 = 353gms

Weight of fines passing 2.36 mm = W_2 = 75.2gmsSo Impact value = W_2x100 / W_1

= 75.2 x 100/353

= 21.3%

The experimental data is tabulated in table 4.1.

Table 4.1: Test on Aggregates

L.A. Abrasion Test	Impact Value Test	Crushing Value Test
Maximum value allowed in fiber introduced concrete= 30%	Maximum value allowed in fiber introduced concrete=45%	Maximum value allowed in fiber introduced concrete= 30%
Test Results on Average= 23.6 %	Test Results on Average= 21.8 %	Test Results on Average= 21.6 %

4.Result Analysis

4.1Methodology

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:

1. Poisson's ratio (μ) = 0.2
2. Modulus of elasticity (E) = 5000 $\sqrt{f_{ck}}$ Wheref_{ck} = characteristic strength of concrete

   So for M30, E =27386.13 MPa M35, E =

   29580.40 MPaM40, 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 specimenSo L = L_{eff}

= 400 mm

4.2 4-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 is 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 Conventional Concrete

Grade of Concrete	Specimen No.	Failure Load (KN)	Theoretical Deflection (mm)	Experimental Deflection (mm)
M30	4	7.53	0.079	0.088
	5	7.57	0.08	0.091
	6	7.58	0.08	0.091

M35	4	7.92	0.079	0.086
	5	7.93	0.079	0.086
	6	7.92	0.078	0.083
M40	4	8.07	0.076	0.079
	5	8.08	0.075	0.077
	6	8.12	0.076	0.076

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	0.88	0.077	12.5
Fiber Introduced Concrete	M30	0.0796	0.7	13.7
	M35	0.0786	0.065	17.3
	M40	0.0756	0.061	19.31

4.3 Double Shear Test

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

For $\delta < L/900$, $\delta = \delta/1.7$ For $\delta >$

$L/900$, $\delta = \delta/2.1$

Using the formula given above theoretical values of deflection is 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.

5. Conclusion

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%.

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