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A Study on Use of Polymeric Waste Materials in Concrete for Road Pavements

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Abstract - Concrete, while strong in compression, is weak in tension and prone to brittleness, leading to early crack formation and limiting its use in pavements due to the lack of ductility and susceptibility to fracture and failure. These drawbacks can be addressed by incorporating fibers as reinforcement in the concrete mix. Waste materials like polyethylene and tires, which contribute to environmental pollution, can be recycled and used as fiber reinforcement in concrete, enhancing its mechanical properties. Polyethylene, a synthetic hydrocarbon polymer, is known to improve ductility, strength, and shrinkage characteristics in concrete. This study investigates the effects of adding polyethylene and tire fibers on the properties of concrete. Polyethylene and tire fibers, cut to 30mm x 6mm, were used at 1.5% each by volume. The concrete mixes were designed for M30, M35, and M40 grades following IRC 44:2017 guidelines. Strength properties were evaluated through a series of tests, including a 4-point bending test and double shear test for determining flexure and shear strength. The results showed an 18% increase in 28-day compressive strength, a 39% increase in flexural strength, and a 32% increase in shear strength. Additionally, there was a 22% reduction in deflection in the 4-point bending test and a 36% reduction in the double shear test. Theoretical deflection values were analyzed using energy methods and aligned with practical values within permissible limits. In conclusion, recycled polyethylene and tire fibers can be effectively utilized in reinforced cement concrete, offering significant improvements in mechanical performance.

Keywords: Polyethylene Fiber, Tire Fiber, Reinforced Concrete, Compressive Strength, Flexural Strength, Shear Strength, Deflection, Pavements.

1.Introduction

In developing countries like India, road networks are essential for ensuring durable and comfortable surfaces for vehicles. Traditionally, bitumen is the primary material used for pavements, but in some cases, concrete pavers are preferred. Recent research suggests that fiber-reinforced concrete (FRC) can be effectively used in pavement construction due to its high strength and durability (Balaguru & Shah, 1992). FRC, as defined by ACI Committee 544, is a form of concrete consisting of cement, fine and coarse aggregates, water, and discontinuous fibers. These fibers, such as steel, polymeric, and natural fibers, are mixed to enhance the mechanical properties of concrete (ACI Committee 544, 1996; Nataraja, Dhang, & Gupta, 1999). Research shows that FRC not only strengthens localized stress regions but also improves compression and tension resistance, reduces deflection and shrinkage, and increases overall durability (Johnston, 2001). The use of polymer fibers, such as ecron 3s, polyester, and polypropylene, as well as recycled fibers from plastic, tires, carpet, and textile waste, has been explored. These fibers act as crack inhibitors, preventing the growth of small cracks into macrocracks and enhancing the material's resistance to fractures (Shah & Rangan, 1994).

Incorporating fibers into concrete has also been shown to improve resistance to plastic shrinkage, reduce water absorption, increase impact resistance, and improve flexural and tensile strength (Ramkrishnan, 1987). Guidelines such as IS: 456:2000 and IRC: SP: 76:2008 recommend the use of fiber-reinforced concrete in pavements, with agencies like CPWD, ISRO, and the Airports Authority of India adopting this practice (Kumar & Sanjeevan, 2009).

Additionally, the recycling of waste materials like polyethylene and tires in concrete has gained attention due to their non-biodegradable nature. Recycling these materials into construction products helps mitigate environmental pollution while enhancing the eco-friendliness of construction practices (Al-Manaseer & Dalal, 1997).

2. Objectives

The aim of this work is to use two polymeric waste materials such as polyethylene and tire fibers to strengthen the concrete coating. The main objective of this work is to evaluate the benefits of using such waste materials, such as the increase in compressive, flexural and shear strength of the resulting concrete and the reduction of flexural properties, and to determine the deflection in a laboratory test and compare this with the theoretical deflection and check that the errors are within the 20% tolerances.

The main goal of the research is to use waste materials such as polyethylene and tires to achieve better durability properties of concrete so that they can be recycled into something very useful and help reduce the environmental impact of both.

Fig 1. Steel fiber

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Fig .2: Polypropylene fiber

2.1 SCOPE OF THE PRESENT STUDY:

This project focuses on investigating the use of polypropylene and polyethylene fibers in fiber-reinforced concrete (FRC) for pavement construction. It aims to analyze the mechanical properties of FRC enhanced with these fibers, assessing improvements in compressive, tensile, and flexural strength, as well as resistance to cracking and shrinkage. The project will also evaluate the environmental benefits of incorporating recycled polyethylene fibers, emphasizing sustainability. Compliance with relevant standards and guidelines will be ensured, while a cost-benefit analysis will explore the economic viability of using these fiber types in real-world pavement applications, promoting durable and eco-friendly infrastructure solutions.

3. **Materials and Methodology**

3.1 Material Used:

The main materials of concrete are:

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

In the case of polymer fibers, reinforced concrete fibers are added. 2 fiber types are selected for this experiment. The fibers used in the concrete mix are:

1. Polyethylene fibers
2. Tire fibers (nylon)

Both fibers used in the concrete matrix are made from waste materials. Waste OMFED milk bags are used to make polyethylene fiber, while waste tires are used to make nylon fiber.

Properties of Material

The following tests were conducted on the soil. The index and engineering properties of soil were determined.

Cement is a key ingredient in concrete, known for its binding and adhesive properties, which are activated when mixed with water through an exothermic hydration process. The project focuses on utilizing Ordinary Portland Cement (OPC), specifically the 53-grade type, due to its high compressive strength. Fine aggregates, such as Zone III sand, and coarse aggregates of 10mm and 20mm sizes will be used to enhance the concrete matrix. The project incorporates innovative admixtures, like Sikament-170, to optimize the mix's properties. Additionally, polyethylene and tire fibers will be used as reinforcements, providing improved tensile strength and resistance to impact and abrasion. The preparation process for the fibers involves cleaning and shredding used polyethylene packaging and tires, ensuring uniform distribution within the concrete mix. Specific gravities of the materials are recorded, with cement at 3.04, fine aggregate at 2.6, coarse aggregate at 2.7, polyethylene fibers at 0.94, and tire fibers at 1.14.

4.1 Methodology

This project aims to study various parameters of polymer-reinforced concrete, focusing on its durability and service life with minimal maintenance. The methodology includes a series of tests on aggregates and concrete to evaluate their properties.

Testing of Aggregates:The tests conducted on aggregates will include abrasion resistance, impact resistance, and compressive strength. The Los Angeles abrasion test will determine the abrasion resistance of coarse aggregates, following a standardized procedure that involves drying the aggregates, rotating them with steel balls, and measuring the weight of fines produced. The impact resistance of aggregates will be assessed using the impact value test according to IS 2386 Part IV, where aggregates are subjected to free-fall impacts to gauge their resistance to loading.

Concrete Tests: Various tests on concrete will include physical inspection, 28-day compressive strength test, flexural strength test, and shear strength tests using both two-point load and double shear tests.

4.2 Mix Design

For the concrete mix design, proportions will be established to ensure the desired workability and strength while enhancing toughness and durability. The design mixes will conform to IRC 44:2008 specifications for M30, M35, and M40 grades. The materials used will comprise Ordinary Portland Cement (OPC) 43 grade, Zone 3 fine aggregates, and crushed rock coarse aggregates of 10mm and 20mm sizes. A plasticizer will be incorporated as an admixture to enhance the mix.

The water-cement ratio will be maintained between 0.4 to 0.45 to achieve optimal consistency. In the case of fiber-reinforced concrete, polyethylene fibers and tire fibers will each be added at a rate of 1.5% by volume of concrete mass. This methodology will provide a comprehensive assessment of the performance and durability of polymer-reinforced concrete.

Concrete Mix Design Specifications

1. M30 Grade Concrete:
   Water: 0.45
   Cement: 1 part
   Fine Aggregate: 2.1 parts
   Coarse Aggregate (10mm): 3.06 parts
   Coarse Aggregate (20mm): 0.34 parts
   Admixture: 0.019 parts
2. M35 Grade Concrete:
   Water: 0.43
   Cement: 1 part
   Fine Aggregate: 1.6 parts
   Coarse Aggregate (10mm): 2.7 parts
   Coarse Aggregate (20mm): 0.3 parts
   Admixture: 0.022 parts
3. M40 Grade Concrete:
   Water: 0.4
   Cement: 1 part
   Fine Aggregate: 1.8 parts
   Coarse Aggregate (10mm): 2.7 parts
   Coarse Aggregate (20mm): 0.3 parts
   Admixture : 0.023 parts

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Standard-sized cubes measuring 150mm x 150mm x 150mm are cast for the compression test, while beams are cast in dimensions of 500mm x 100mm x 75mm. The samples include 3 cubes each of M30, M35, and M40 conventional concrete, along with fiber-reinforced equivalents. Additionally, 6 beams of each type are cast, totaling 18 cubes and 36 beams. After remaining in the molds for 24 hours, the samples are immersed in water for curing. After 28 days, the cubes and beams are removed, dried, and prepared for testing.

4.5 Test of Concrete

The compressive strength test evaluates the concrete's resistance to crushing loads. The procedure includes cleaning the testing machine's bearing surface, positioning the specimen centrally, and applying load gradually at a rate of 140 kg/cm²/minute until failure occurs.

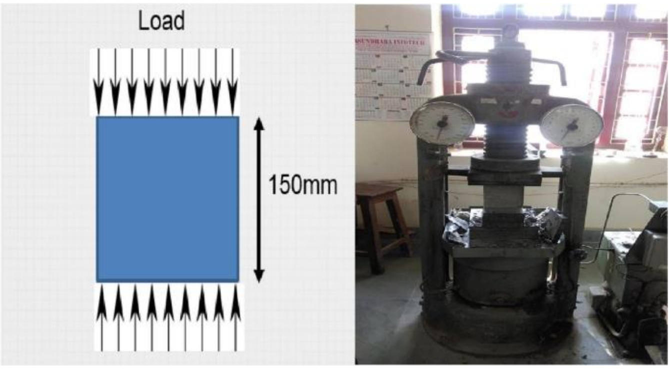

Fig.3Compressive strength test

5.Results and Discussion

RADE CONCRETE	SPECIMEN NO.	FAILURE LOAD (Tons)	COMPRESSIVE STRENGTH (N/mm²)	MEAN COMPREVE 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
		108	48	
		105	46.66	

Table. Compressive strength of without fiber introduced concrete cubes

The compressive strength of conventional concrete cubes is a crucial property that indicates the load-bearing capacity of concrete under compression. It is typically tested using cube specimens with dimensions of 150mm x 150mm x 150mm. The test is done 28 days after casting, which is the standard curing period that allows the concrete to reach its potential strength. The test is performed in a compression testing machine, where the cube is subjected to increasing

GRADE OF CONCETE	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
		122	4.22		
		122	4.22		

Table.2 Compressive strength of fiber introduced concrete cubes

Table.3Flexural strength of conventional concrete beams

Gradeof Concrete	Specimen no.	Failure load (KN)	Flexural streh (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	

Grade of concrete	Specimenno	Failure load (KN)	Flexural strength (N/mm²)	Mean Flexural strength (N/mm²)	Deflection (mm)	Mean defleton (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

Table 4.6: Flexural strength of fiber introduced concrete beams

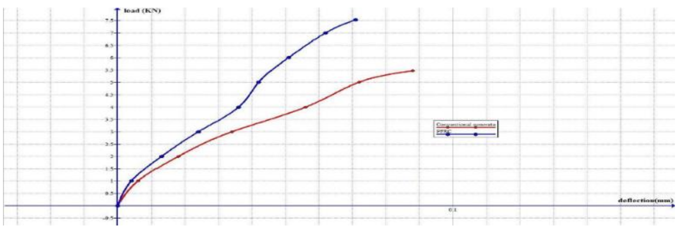

Fig-4. 4 Point bend test Load vs Deflection for M30 concrete

With the amounts of oil and its by-products decreasing every day, concrete pavements are a better alternative to bituminous pavements for road use. Locally available common OPC can be used to replace the coating with bitumen a product of petroleum distillation.

The use of non-biodegradable materials such as polyethylene waste is an economic and ecological approach in the transport sector. Unlike steel fibers, it is non-corrosive, light and cheaper.

Therefore, wasted tire fibers (striped steel wires) can be effectively used in concrete. These two materials together with concrete fulfill the two main requirements of road surface materials, cost efficiency and less pollution. It can be seen that FRC made from waste materials such as polyethylene and tire fibers significantly increase the strength of concrete. Fiber- reinforced concrete has shown good compressive strength, flexural strength and shear strength, which are the three most important properties of concrete. It also made the concrete harder and significantly reduced its deflection under external load.

6.Conclusions

The following conclusions were drawn from tests with polyethylene and concrete with tire fibers:

1.The compressive strength of M30, M35 and M40 grade concrete increases by 17.93%, 15.98% and 16.1% respectively.
2.The increase in flexural strength of M30, M35 and M40 was found to be 37.34%, 39.70% and 39.66% respectively. And the corresponding deflection reductions were 22.22%, 23.53% and 20.78%.
3.There is a significant amount of gain found in shear strength. Gain in shear strength found to be 31.33%, 32.56% and 32.72% for M30, M35, and M40 respectively. And respective reduction in deflection 38.69%, 36.23% and 33.75%.

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