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Performance of Steel Fiber Concrete as Rigid Pavement

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ABSTRACT:

Steel Fiber-Reinforced Concrete (SFRC), which offers better mechanical and durability properties than traditional plain cement concrete, is quickly becoming a game-changer in the building of rigid pavements. With an emphasis on its improved flexural strength, impact durability, crack resistance, and fatigue behavior under repeated loading, this study investigates the performance of SFRC in rigid pavement applications. Increased joint spacing and possible slab thickness reductions are made possible by the substantial improvement in post-cracking toughness and load transmission efficiency provided by the use of steel fibers. These enhancements result in increased structural dependability, reduced maintenance costs, and extended service life—particularly for pavements that are subjected to dynamic loading conditions and high traffic volumes. Despite early expenses and handling difficulties, SFRC is a durable and financially feasible substitute for contemporary pavement infrastructure due to its long-term advantages. With a focus on real-world applications, structural benefits, and lifecycle value, this article provides a thorough assessment of SFRC's contribution to redefining stiff pavement performance. The purpose of this study is to examine how well cylindrical composite beams composed of M20 grade concrete mix, measuring 100 cm2 in cross section and 50 cm in length, with varying percentages of fiber content, perform in the combined states of flexure, torsion, and shear. Straight fibers of 28 mm in length and 0.28 mm in diameter were used, and their aspect ratio was 100. Twelve cylindrical beams were developed, each with a fiber percentage of 0, 0.5.0.75, and 1% by weight. Consequently, a total of 48 cylindrical composite beams were created. Additionally, 12 standard-sized cubes and 12 cylinders with varying fiber content percentages were cast.

Keywords: SFRC, Rigid Pavement, Compressive Strength, Tensile Strength

Introduction:

A combination of hydraulic cement, steel fibers, and fine and coarse aggregates makes up SFRC. Small enough to be randomly distributed in an unhardened concrete mixture using standard mixing techniques, the steel fibers are short, discrete lengths of steel with an aspect ratio (length to diameter) ranging from roughly 20 to 100 and any of a number of cross-sections. Under tensile stress and impact loads, unreinforced concrete readily cracks due to its low tensile strength. Steel reinforcing bars are inserted into the concrete to overcome this weakness. It is possible to scatter fibers throughout the concrete matrix and cast them in place. By filling in the gaps, they increase the structure's serviceability. Numerous variables affect the degree of improvement, including fiber type, aspect ratio, strength, modulus, content, orientation, and surface bonding properties. Steel fibers have been the subject of extensive research to improve the concrete members' ability to support loads.

Fig 1 Steel Fiber Concrete Pavement

Steel Fiber Concrete Pavement in India:

India's rapidly expanding road network and increasing traffic loads necessitate more durable and long-lasting pavement materials. Traditional rigid pavements, while effective, often suffer from cracking and require frequent maintenance. Steel Fiber-Reinforced Concrete (SFRC) offers a promising alternative, with superior mechanical properties and enhanced crack resistance, making it particularly suitable for Indian conditions where roads are subjected to heavy loads, climatic variations, and limited maintenance cycles.

SFRC pavements in India are gradually gaining acceptance in several infrastructure projects, particularly in the following areas:

- Industrial and Container Yards: Ports like Jawaharlal Nehru Port Trust (JNPT) and Chennai Port have used SFRC pavements due to their high load-bearing and impact resistance capabilities.
- Urban Roads and Bus Terminals: Municipal corporations in cities like Mumbai, Bengaluru, and Pune have piloted SFRC in bus depots, parking areas, and urban roads.
- Airport Pavements: SFRC has been considered in certain taxiways and apron areas where resistance to rutting and impact is critical.
- Toll Plazas and Weighbridges: These high-impact zones benefit from the toughness and fatigue resistance of SFRC.
- Overlays and Repairs: SFRC is used as a material for pavement overlays and patch repairs due to its quick-setting and durable nature.

Objectives of the Study

The primary objective of this study is to evaluate the performance of Steel Fiber-Reinforced Concrete (SFRC) as a rigid pavement material under various loading and environmental conditions. This research seeks to analyze the effects of steel fiber inclusion on the mechanical properties of concrete, such as compressive strength, flexural strength, and fatigue resistance, with the goal of improving pavement durability and service life. The study also aims to investigate the influence of fiber dosage and distribution on crack control, load transfer efficiency, and structural performance. Additionally, the research intends to assess the practical implications of using SFRC in terms of mix design, workability, construction practices, and cost-effectiveness. By combining experimental investigations with comparative analysis, the study strives to establish performance benchmarks for SFRC pavements and propose guidelines for its effective implementation in real-world road infrastructure.

Methodology:

Steel Fiber-Reinforced Concrete (SFRC) is evaluated for its appropriateness for stiff pavement applications using a mix of experimental inquiry, comparative analysis, and performance assessment. In order to comprehend current research, establish performance characteristics, and choose the right fiber kinds and dose levels, the study starts with a thorough literature analysis. Concrete mix designs with different percentages of steel fibers (usually between 0.5% and 2.0% by volume) are created based on this review. Key mechanical characteristics, such as compressive strength, flexural strength, splitting tensile strength, impact resistance, and fatigue performance, are then assessed using standard laboratory tests. To investigate how well the fiber controls microcracks, crack diameter and spacing are also examined. Standard laboratory tests are then conducted to evaluate key mechanical properties, including compressive strength, flexural strength, splitting tensile strength, impact resistance, and fatigue performance. Crack width and spacing are also monitored to study the fiber's effectiveness in controlling micro-cracks. Workability and durability aspects such as abrasion resistance and permeability are assessed to understand long-term pavement behavior. The test results of SFRC mixes are compared with those of conventional concrete to highlight performance enhancements. Additionally, structural analysis is carried out to estimate the influence of SFRC on pavement slab thickness and joint spacing. Where possible, case studies and field applications are reviewed to validate laboratory findings. The overall methodology aims to provide a comprehensive, data-driven assessment of SFRC as a viable material for rigid pavement design.

Mix Design Procedure:

As per the guidelines of IS-10262: (1982), the normal strength concrete mix M20 was designed. To obtain normal strength fibrous concrete, plain steel fibers were added at the ratio of 0.0, 0.5, 0.75 and 1.0 % by weight to the normal strength mixes. The detailed constitution of the mixes is given in the Table 1.

Table 1 Constitution of mixes

Mix designation	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water Cement ratio	Fibre % By weight
M 20	372	579.6	1159.85	0.5	0.00
	372	579.6	1159.85	0.5	0.50
	372	579.6	1159.85	0.5	0.75
	372	579.6	1159.85	0.5	1.00

Table 2 Details of specimens

Type and size of Specimens	Type of test	Avg. no of Specimens tested	No. of specimens used for each % of fibers	Total no. of specimens
Cylindrical beams (Diameter = 11.28 cm, Length = 50 cm)	Combined effect of flexure Torsion and shear,	3	12	48
Cubes (150 cm x 150 cm Cm x 150 cm)	Compressive test	3	3	12
Standard cylinder (diameter = 150 mm Length = 300 mm)	Split tensile test	3	3	12

Results

In the present investigation 3D squares of size 150 mm x 150 mm x 150 mm were tried under uniaxial pressure with the assistance of Compression testing machine. M20 evaluation cement was tried with changing level of steel fiber substance differing from 0 to 1 %. by weight. Table 3 gives the mean compressive pressure and mean compressive strain esteems for all changing fiber substance tried. Fig 1 demonstrates the mean pressure versus mean strain bend under uniaxial pressure for all the four-fiber substance tried for M20 evaluation of cement.

Table 2: Mean Stress Strain data of M20 mixed with varying percentage of Fibers

F=0 %		F=0.5 %		F=0.75 %		F=1%	
Mean Stress	**Mean Strain**	**Mean Stress**	**Mean Strain**	**Mean Stress**	**Mean Strain**	**Mean Stress**	**Mean Strain**
0	0	0	0	0	0	0	0
1.07	0.13	1.07	0.13	1.07	0.2	1.07	0.13
2.15	0.27	2.15	0.33	2.15	0.4	2.15	0.27
12.9	2.27	12.9	1.87	12.9	1.93	12.9	2.17
13.97	2.47	13.97	2.01	13.97	2.13	13.97	2.43
15.05	2.6	15.05	2.13	15.05	2.33	15.05	2.7
16.12	2.73	16.12	2.27	16.12	2.53	16.12	2.97
17.2	2.93	17.2	2.47	17.2	2.73	17.2	3.23
19.35	3.33	19.35	2.87	19.35	3.2	19.35	3.77
21.51	3.81	21.51	3.34	21.51	3.67	21.51	4.31
23.65	4.21	23.65	3.82	23.65	4.22	23.65	4.83
25.81	4.62	25.81	4.33	25.81	4.73	25.81	5.43
27.95	5.21	27.95	4.86	27.95	5.27	27.95	6.03
30.12	5.8	30.12	5.53	30.12	5.81	30.12	6.63
32.25	6.63	32.25	6.26	32.25	6.41	32.25	7.37

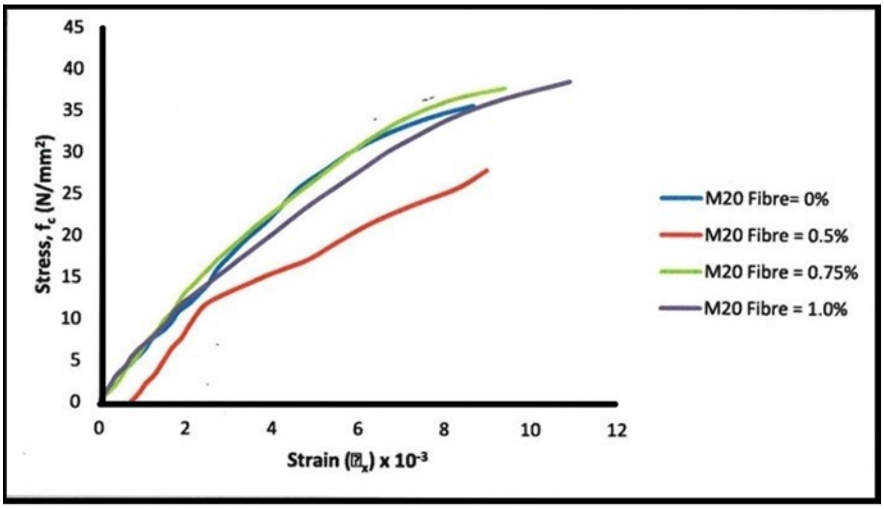

Fig 2 Combined Stress strain curve for M20 cylinders

Behavior of SFRC Cylinders in Splitting Tensile Strength Test

In the present experiment, splitting tensile strength tests were performed on Cylinders 150 mm diameter and 300 mm height. The study involves the testing of M20 grade of concrete with varying percentage of Fiber content varying from 0 to 1.0 % (0,0.5,0.75 and 1.0 %). Table 3 gives the mean split tensile stress and mean tensile strain values for all the varying fiber content tested. Fig 3 shows the comparative stress strain curves for all the four fiber contents tested for M20 grade of concrete.

Table 3: Mean Stress Strain data of M20 mixed with varying percentage of Fibers

F= 0 %		F=0.5%		F=0.75%		F=1%	
Mean Stress	Mean Strain	Mean Stress	Mean Strain	Mean Stress	Mean Strain	Mean Stress	Mean Strain
0	0	0	0	0	0	0	0
0.35	0.13	0.35	0.13	0.35	0.33	0.35	0.27
0.72	0.28	0.72	0.33	0.72	0.6	0.72	0.41
1.05	0.41	1.05	0.6	1.05	0.87	1.05	0.6
1.4	0.61	1.4	0.93	1.4	1.13	1.4	0.93
1.75	0.82	1.75	1.33	1.75	1.53	1.75	1.4
2.12	1.08	2.12	1.8	2.12	1.93	2.12	2.01
2.45	1.33	2.45	2.33	2.45	2.33	2.45	2.8
2.8	1.87	2.8	2.93	2.8	2.8	2.8	3.6
3.15	2.41	3.15	3.6	3.15	3.27	3.15	4.4
3.51	3.54	3.51	4.68	3.51	3.93	3.52	5.4

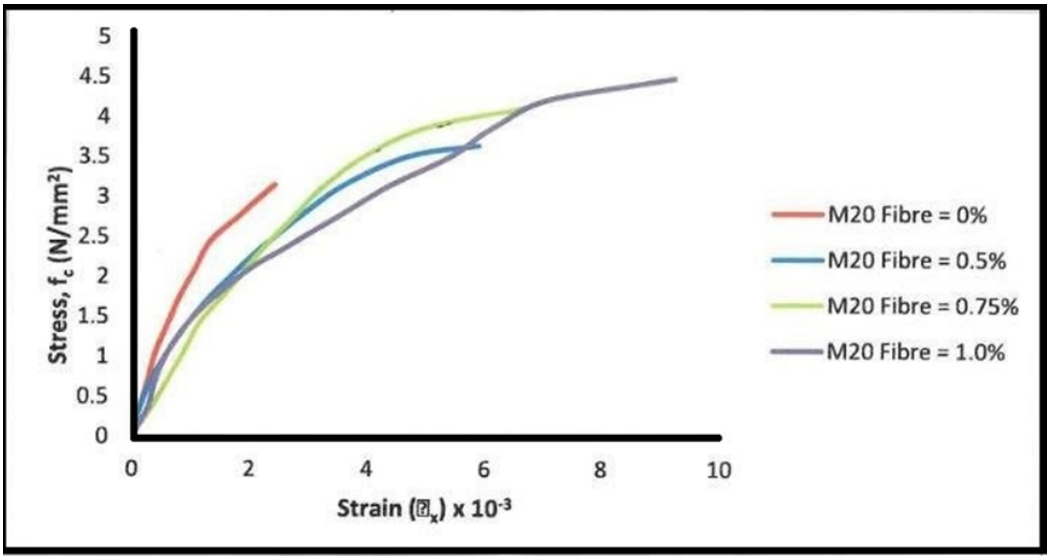

Fig 3 Combined Stress strain curve for M20 cylinders

Table 4 Ultimate Bending stress of beams with varying percentage of fibers at a particular torsion

Torsion in Nm	Reference value of ultimate bending stress Without fiber	Percentage variation in ultimate bending stress of beams at different percentage of fibers		
		0.5	**0.75**	**1.00**
0	5.439	13	17.4	30.4
219.89	4.730	20	30	40
270.17	4.257	18.18	44.44	56.8
320.44	4.730	10	10	10

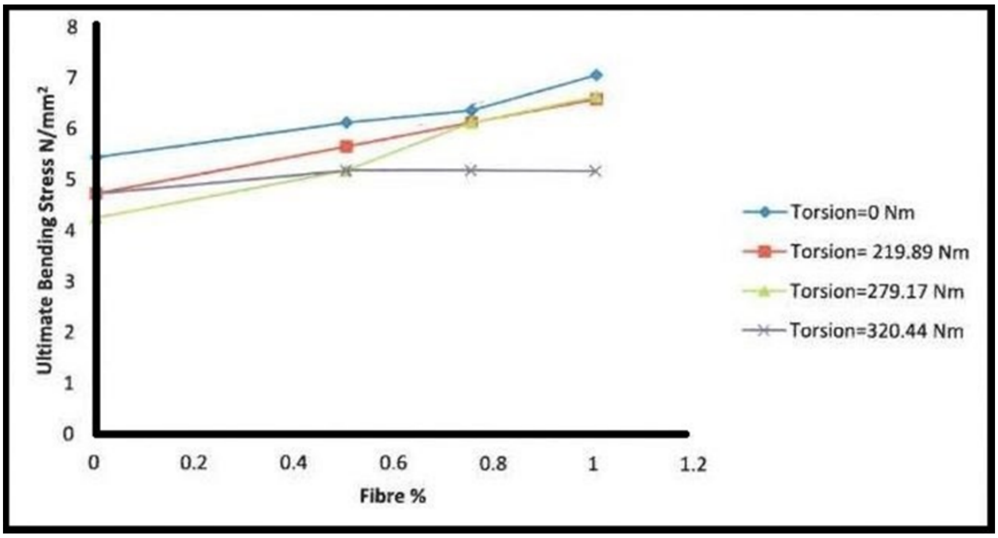

Fig 4 Ultimate bending stress vs percentage of fibers

Conclusion

This work investigates the performance of Steel Fiber Reinforced Concrete (SFRC) as a rigid pavement material, focusing on its structural behavior, economic feasibility, and environmental sustainability. Through a combination of literature review, experimental analysis, and comparative evaluation with conventional concrete pavements, the study assessed the viability of incorporating steel fibers in rigid pavement systems, particularly in the context of India.

The suggested study work has established a model for weather prediction that can be used to improve performance without incurring significant on the basis of experimental results, following conclusions are drawn

- In the beam tested for combined effect of Flexure, torsion and shear the ultimate bending stress and ultimate central deflection decreases as the torsion increases for a particular value of fiber.
- In the beam tested for combined effect of Flexure, torsion and shear the ultimate bending strength and ultimate central deflection increases as the torsion increases for a particular percentage of fibers.
- For a torsion of 270.17 Nm the value of bending stress increases from 4.273 N/mm2 to 6.676 N/mm2 by a maximum of 41.11 % as the fiber content is increased from 0 to 1.00 %.
- The value of central deflection at ultimate load increases with the increase in percentage of fibers for a particular value of torsion in the beams
- For the fiber content 1.00 %, the decrement to bending stress to maximum which is from 7.095 N/mm2 to 5.203 N/mm2 by a maximum of 26.66 %, as the torsion applied is increased from 0 Nm to 320.44 Nm.
- Steel Fiber Reinforced Concrete is a technically and economically viable material for use in rigid pavements, offering enhanced mechanical performance and durability.
- SFRC pavements outperform traditional concrete pavements in terms of fatigue resistance, load distribution, and crack control, making them suitable for a wide range of applications from highways to industrial floors and airport runways.
- Economic and environmental analyses support the adoption of SFRC, especially when considering life-cycle benefits and sustainability metrics.
- The performance benefits of SFRC should be leveraged by updating existing pavement design codes and incorporating performance-based design criteria.

the values of the parameters were recorded. In the Jupyter notebook environment, models were trained with pre-recorded parameter values and used to forecast weather parameters in a real-time setting. The model's output is compared to previous efforts in the literature, and the suggested system outperforms them somewhat in terms of accuracy. Furthermore, the system may be customized for commercial usage, and it has numerous uses in smart homes, buildings, sports, and hospitals, among others.

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