Effect of Steel Fibers in Compressive Strength of Concrete Cube and Cylinder Specimens

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Abstract: Research has shown that incorporating steel fibers into concrete effectively reduces its brittleness. When added in specific proportions, steel fibers enhance the compressive strength of concrete and help control cracking. This study aimed to assess and compare the variations in compressive strength between conventional concrete and steel fiber-reinforced concrete (SFRC) by introducing different percentages of steel fibers. Experimental investigations were conducted on concrete cylinders and cubes to evaluate the improvement in compression capacity and observe the load-deflection behavior of SFRC. To achieve this, SFRC specimens with fibers of an aspect ratio of 55 were prepared for both concentric and eccentric loading, alongside control specimens made of plain concrete. Their relative compression capacities were tested. Stone chips (20 mm) were used in the concrete mix, as the inclusion of steel fibers significantly enhances its compressive strength. The study specifically aimed to test the compressive strength of concrete cylinders and cubes with varying steel fiber content (0%, 0.3%, 0.5%, 1%, 1.5%, and 2% of the total concrete weight). The compressive strength of the specimens was measured at 3, 7, and 28 days. Additionally, various material tests were performed to assess material properties, and a slump test was conducted to evaluate concrete workability. The findings indicate that the compressive strength of SFRC cylinders and cubes increases with higher steel fiber content, and plain concrete exhibits lower strength compared to SFRC.

Keywords: *SFRS, Compression Test, Slump, Concrete, Workability, Steel Fiber.*

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I. INTRODUCTION

Concrete is a widely used construction material made from cement, along with other cementitious substances like fly ash and slag, combined with aggregates (typically coarse aggregates such as gravel, limestone, or granite, and fine aggregates like river sand), water, and chemical admixtures. Despite its many advantageous properties, concrete has relatively poor performance under tensile stress. A more recent innovation in this field is steel fiber-reinforced concrete (SFRC). However, the idea of using fibers for reinforcement is not new, as fibers have been employed for strengthening materials since ancient times. [1]. Concrete is prone to brittle failure, meaning that once a crack initiates, it leads to a nearly complete loss of load-bearing capacity. This limitation can be mitigated by incorporating small amounts of short, randomly distributed fibers—such as steel, glass, synthetic, or natural fibers—which help address concrete's weaknesses, including low tensile strength, high shrinkage cracking, and limited durability.

Fiber-reinforced concrete (FRC) is a composite material composed of cement, mortar, or concrete combined with discrete, discontinuous fibers that are uniformly dispersed throughout the mix. While various types of fibers have been tested in cement and concrete, not all are equally effective or economically viable. Each fiber type has distinct properties and limitations. Commonly used fibers include steel, polypropylene, nylon, asbestos, coir, glass, and carbon, with steel fibers being the most widely utilized [2], [3]. Uniaxial compression tests indicate that the failure behavior of fiber-reinforced concrete shifts significantly from brittle to ductile. Due to the fiber bridging effect, the fibrous specimens largely remain intact, experiencing only minor spalling on the sides until the test is completed. [4]

The main reasons for adding fibers to concrete matrix is to improve the post-cracking response of the concrete, i.e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. Also, it helps to maintain structural integrity and cohesiveness in the material.

II. MATERIALS AND METHODS

Steel fiber is a relatively recent addition to concrete-based construction. Incorporating varying proportions of steel fibers in concrete is not only cost-effective but also environmentally beneficial. However, public awareness of its advantages remains limited. This study was undertaken to highlight the benefits of Steel Fiber Reinforced Concrete (SFRC) and assess its effectiveness.

The materials used in this research include Portland composite cement, stone chips, coarse sand, steel fibers, and water. While steel fibers and cement were sourced from commercial suppliers, the stone chips, coarse sand, and water were obtained from the Material Lab at Stamford University Bangladesh. To produce concrete cylinders and cubes, an M-20 mix ratio (1:1.5:3) was utilized, with steel fiber percentages varying at 0%, 0.3%, 0.5%, 1%, 1.5%, and 2%. When mixed with water, cement, sand, and aggregate form a paste that binds the components together as the mixture hardens.

The specimens were cast in cylindrical molds of 150mm × 300mm and cubic molds of 150mm. Concrete was poured in three layers, with each layer receiving 25 tamping blows to ensure proper compaction. After 24 hours, the molds were removed, and the specimens were transferred to a curing tank, where they were submerged for 3, 7, and 28 days at a water temperature of 20–28°C. Following the curing periods, the cubes and cylinders were tested using a Universal Testing Machine (UTM) to determine their compressive strength. The failure load was recorded, and for each category, one cube and two cylinders were tested, with the average value documented.

Table 1: Properties of Steel Fiber [5]

Properties	Description
Cross Section	Straight , hook- end, deformed
Diameter	0.7mm
Length	25.4 – 38.1mm
Density	7900 kg/m3
Young‘s Modulus	2.1 x 105 N/mm2
Resistance to Alkalis	Good
Resistance to Acids	Poor
Heat resistivity	Good
Tensile Strength	500-2000 N/mm2
Specific Gravity	7.80
Aspect Ratio	55
General Use	10 kg/m3
Elongation	5-35 %

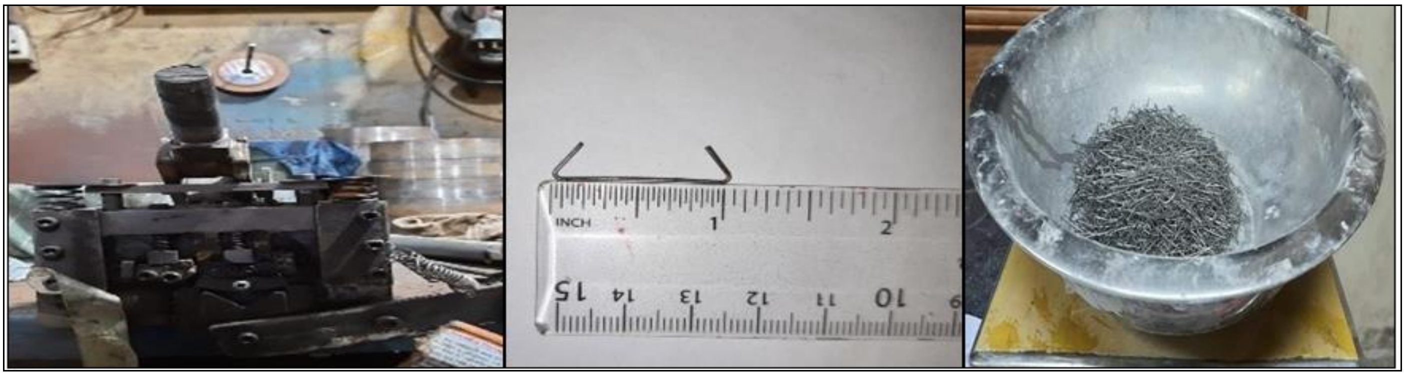


Fig 1: Preparation of Steel Fiber

III. RESULTS AND DISCUSSIONS

The test results were categorized into two main sections: the compressive strength assessment of concrete cylinders and cubes at 3, 7, and 28 days. A compression testing machine was employed to apply force to the specimens. In this study, the compressive strength of the concrete was determined by measuring the load per unit surface area at the moment of fracture in the cylindrical specimens. The average strength was evaluated under consistent conditions, including the same water-cement ratio, mix proportion, maximum coarse aggregate size, and compaction method. The specific parameters used were a water-cement ratio of 0.48, a mixing ratio of 1:1.5:3, and a curing duration of 28 days.

- *Compression Testing of Cylinders (Following ASTM C39):*

Conventional concrete cylinders failed upon reaching their estimated crushing strength. However, wrapping the cylinders with layers of Steel Fiber Reinforced Concrete (SFRC) significantly enhanced their load-bearing capacity. Initially, an 800kN capacity machine was used for testing SFRC-wrapped cylinders, but as additional layers of SFRC increased the crushing strength beyond the machine's capacity, testing was shifted to a 2000kN capacity machine. The application of a single SFRC layer induced substantial confining stress, greatly improving resistance to compression, while the addition of three layers altered the concrete's behavior from brittle to highly ductile. The reinforced cylinders were able to withstand exceptionally high loads before ultimately failing with an intense splitting sound. The corresponding capacities of different cylinders are stated below:

Table 2: Average Compressive Strengths Sustained by Cylinder Sets in Accordance with Presence of SFRC Layers (3 days)

Cylinder labels	Sample Number	Ultimate Capacity (MPa)	Average Compressive Strength (MPa)
0%	1	10.72	10.56
	2	10.40	
0.3%	1	10.84	12
	2	13.13	
0.5%	1	11.83	12.48
	2	13.14	
1%	1	13.18	12.76
	2	12.34	
1.5%	1	12.27	13.15
	2	14.03	
2%	1	13.56	13.90
	2	14.24	

Table 3: Average Compressive Strengths Sustained by Cylinder Sets in Accordance with Presence of SFRC Layers (7 days)

Cylinder labels	Sample number	Ultimate Capacity (MPa)	Average Compressive Strength (MPa)
0%	1	11.60	13.84
	2	16.08	
0.3%	1	13.35	14.12
	2	14.89	
0.5%	1	16.48	14.98
	2	13.48	
1%	1	14.76	15.39
	2	16.02	
1.5%	1	15.94	16.26
	2	16.59	
2%	1	17.60	17.52
	2	17.42	

Table 4: Average Compressive Strengths Sustained by Cylinder Sets in Accordance with Presence of SFRC Layers (28 Days)

Cylinder labels	Sample number	Ultimate Capacity (MPa)	Average Compressive Strength (MPa)
0%	1	20.44	19.19
	2	17.95	
0.3%	1	20.46	21.10
	2	21.74	
0.5%	1	19.61	21.34
	2	23.07	
1%	1	21.94	22.55
	2	23.15	
1.5%	1	25.42	24.73
	2	24.04	
2%	1	26.15	25.90
	2	25.66	

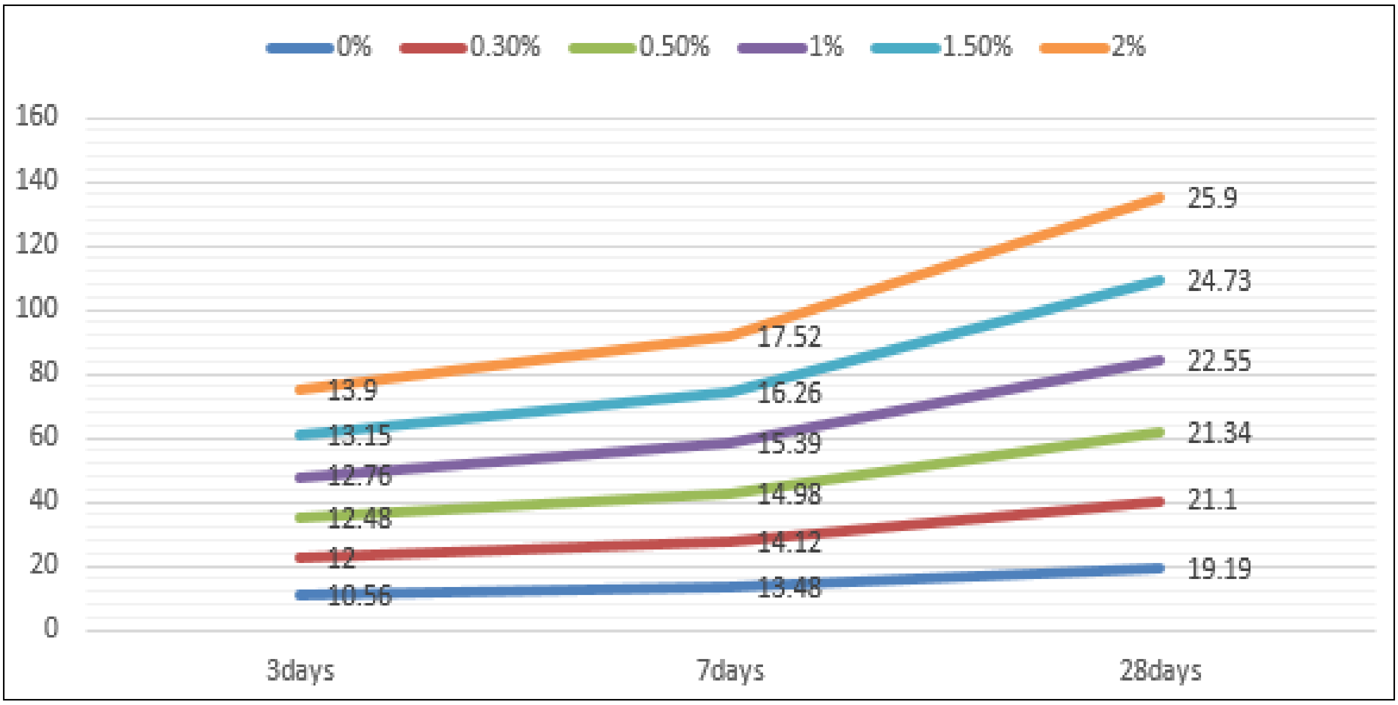


Fig 2: Compressive Strength of Cylinders

Analyzing the compressive strength variations with different steel fiber contents, it is evident that incorporating steel fibers into the concrete mix led to a noticeable improvement in the average compressive strength of the cylinders. The strength values increased progressively from 19.19 MPa to 21.10 MPa, 21.34 MPa, 22.55 MPa, 24.73 MPa, and finally 25.90 MPa. This enhancement became even more prominent when the steel fiber-reinforced cylinders were wrapped with SFRC. From the trend observed in the graph, it is clear that increasing the percentage of SFRC significantly boosts concrete strength. For practical applications, SFRC can be effectively utilized to retrofit concrete members subjected to compressive stress or to reinforce existing concrete structures under service loads. The application of SFRC, combined with surface priming and an additional hardener, is highly recommended for structural strengthening.

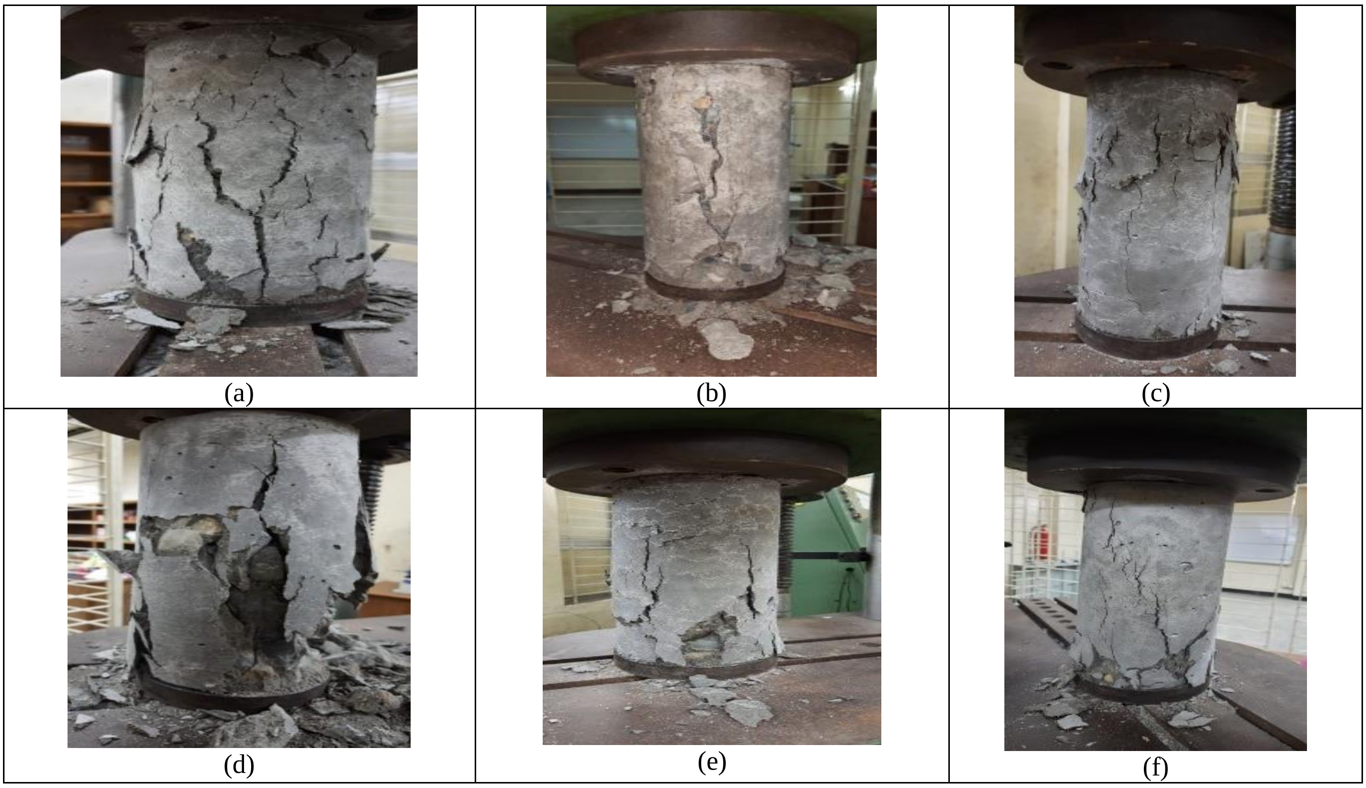

(a) (b) (c)
(d) (e) (f)

Fig 3: Failure Pattern of Concrete Cylinders with (a) 0%, (b) 0.3%, (c) 0.5%, (d)1.0%, (e) 1.5% & (f)2.0%

- *Compressive Strength for Cubes:*

Table 5: Compressive Strengths Sustained by Cubes Sets in Accordance with Presence of SFRC Layers (28 Days)

Cube labels	**Sample Number**	**Ultimate Capacity (MPa)**
0%	1	21.79
0.3%	1	23.57
0.5%	1	23.93
1%	1	25.50
1.5%	1	27.23
2%	1	28.09

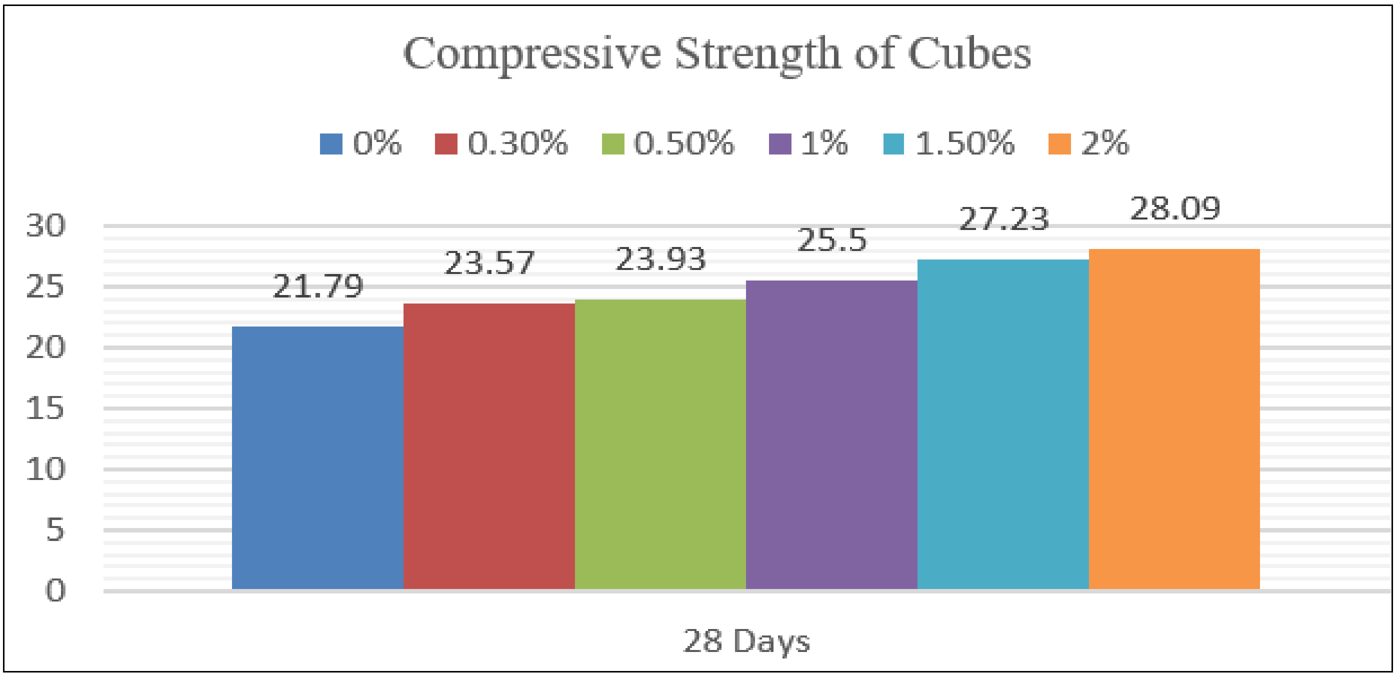


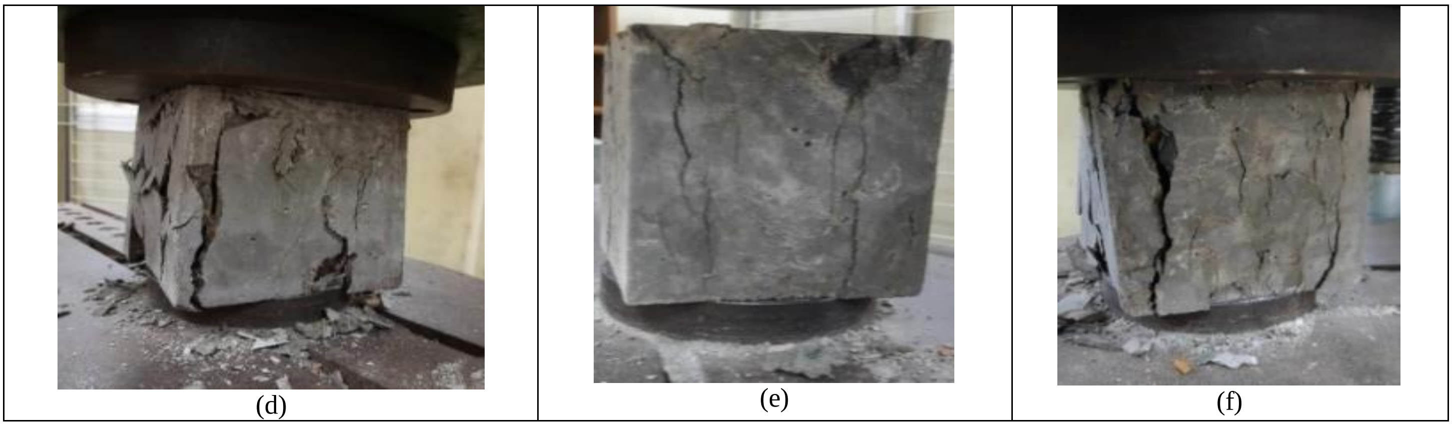
Fig 4: Compressive Strength of Cubes

Examining the compressive strength of both cylinders and cubes, it is evident that incorporating steel fibers into the concrete mix (1:1.5:3) resulted in a notable increase in strength. The average compressive strength of the cylinders improved from 19.19 MPa to 21.10 MPa at 0.3% fiber content, while for cubes, it increased from 21.79 MPa to 23.57 MPa at the same percentage. Similarly, for a concrete mix ratio of (1:2:4), the compressive strength of the cylinders rose to 22.55 MPa at 1% fiber content, whereas the cubes reached 25.50 MPa at the same proportion.


(a)


(b)


(c)



(d) (e) (f)

Fig 5: Failure Pattern of Concrete Cubes with (a) 0%,, (b) 0.3%, (c) 0.5%, (d)1.0%, (e) 1.5% & (f)2.0%

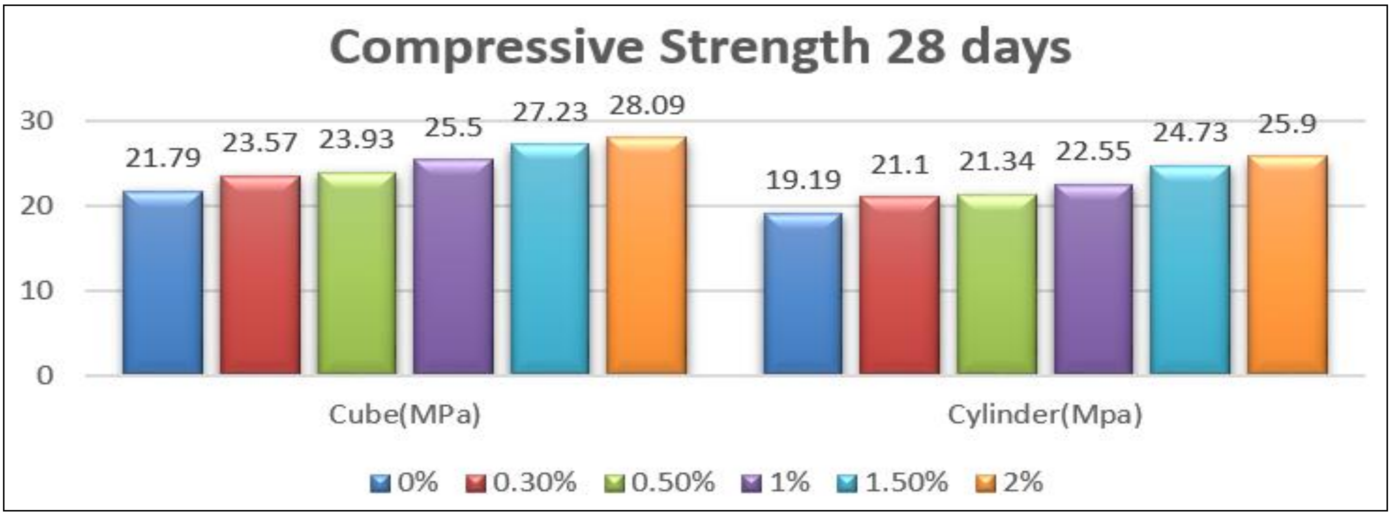


Fig 6: Comparison of Compressive Strength Cube and Cylinder on 28th Days

IV. CONCLUSION

The study indicates that as the steel fiber ratio in the concrete mix increases, the compressive strength of both concrete cylinders and cubes gradually improves, with the compressive strength of the cubes being higher than that of the cylinders. By testing the compressive strength of both the concrete cylinders and cubes, it was observed that the strength increased progressively with higher steel fiber content. It is suggested that further testing be conducted to evaluate the tensile strength of both cylinders and cubes.

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