Effect of Mechanical Properties of Steel Fibers as A Replacement for Granite in A Composite Concrete

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ABSTRACT: The rising need for innovative and sustainable construction materials has spurred the exploration of steel fibers as a partial replacement for coarse aggregates in composite concrete. This study investigates the mechanical behavior of concrete when varying percentages (10%, 20%, and 30%) of coarse aggregates are replaced with steel fibers. Slump and compressive strength tests were conducted on concrete cubes cured for 7, 14, and 28 days to assess workability, strength development, and overall performance. The project aims to determine the optimal steel fiber content that balances early strength, workability, and structural integrity. Results revealed that moderate inclusion of steel fibers, particularly at 20%, enhanced early compressive strength and improved crack resistance due to better internal bonding and energy absorption. At 7 days, the 20% replacement exhibited higher strength (17.4 N/mm²) than the control and 10% mixes. However, the 14-day compressive strength of the 10% mix was slightly lower than that of the control, suggesting that while early strength improves with steel fiber, long-term curing behavior can be affected by mix uniformity and hydration efficiency. The 30% fiber mix showed inconsistencies, indicating possible challenges with workability and compaction. The study concludes that partial replacement of coarse aggregates with steel fibers can be beneficial if optimized properly. A 20% replacement ratio appears to offer the best balance of workability, strength, and durability in early curing stages. This research contributes to sustainable construction practices by promoting the reuse of steel waste and enhancing concrete performance in structural applications. Future studies are recommended to evaluate tensile and flexural properties, long-term durability, and cost-effectiveness in real-world conditions.

Keyword: *Steel-Fibers, Composite-Concrete, Replacement, Granite.*

I. INTRODUCTION

In Nigeria, the integration of steel fibers into concrete has garnered attention for its potential to enhance the mechanical properties and durability of construction materials, particularly in the context of low-cost housing and infrastructure development (Ige et al., 2022). Concrete is one of the most widely used construction materials due to its high compressive strength and durability. However, it is brittle and exhibits poor tensile strength and crack resistance. To improve its mechanical properties, various reinforcing materials, such as steel fibers, are incorporated into concrete to create composite concrete with enhanced performance. Steel fibers are short, discrete lengths of steel that are added to concrete to enhance its properties. The inclusion of steel fibers helps bridge cracks, improve ductility, and increase impact resistance. The effectiveness of steel fibers depends on their type, shape, aspect ratio (length/diameter), and volume fraction used in the concrete mix (Ogungbire et al. 2018)

The growing interest in steel fiber-reinforced concrete is driven by the need for more resilient and long-lasting structures, particularly in environments exposed to heavy loads, dynamic forces, or harsh weather conditions (Alabi and Arum 2020)

A study by (Baba et al. 2024) utilized response surface methodology to optimize the properties of concrete containing these recycled steel fibers. The findings indicated that specific combinations of fiber aspect ratio and volume fraction could significantly improve the compressive strength of the concrete, highlighting the potential of recycled materials in enhancing concrete performance. Additionally, research by (Mustapha 2023) focused on the mechanical properties of concrete reinforced with Dramix hooked-end steel fibers. The study assessed various fiber proportions and observed improvements in compressive, tensile, and flexural strengths, with a 2% volume fraction identified as the optimal content for practical applications (Mustapha et al. 2015) These findings underscore the effectiveness of steel fiber reinforcement in enhancing the structural performance of concrete. Collectively, these studies contribute to a growing body of evidence supporting the use of steel fibers in composite concrete within the Nigerian construction industry. By optimizing fiber content and exploring sustainable sources, such as recycled materials, SFRC can offer a cost-effective and durable alternative to conventional reinforcement methods. This approach not only improves the mechanical properties of concrete but also aligns with sustainable construction practices, addressing both economic and environmental considerations (Ogunjiofor et al. 2023)

II. LITERATURE REVIEW

Fibers have been used to reinforce brittle materials since ancient times; straw was used to reinforce sunbaked bricks in many Middle Eastern countries. Vegetable origin fibers such as Jute and Sisal as well as naturally occurring fiber (asbestos) were also utilized by ancient architects. Gypsum plasters, utilizing horse hair was used widely in Europe during the renaissance. Asbestos cement construction products are widely used throughout the world today. Large-scale commercial use of asbestos fibers in a cement paste matrix began with the invention of the Hatschek process in 1900. However, due to the health hazards associated with asbestos fibers, different types of fibers have been developed in the last twenty to thirty years (Shah, 1983).

2.1 Mechanical Properties

Tensile Strength: According to a study by (Song et al. 2019), steel fiber reinforcement can improve the tensile strength of concrete by up to 50%. Flexural Strength: Research by (Banthia et al. 2014) found that steel fiber can enhance the flexural strength of concrete, making it more resistant to bending and deformation. Impact Resistance: A study by (Mastali et al. 2018) showed that steel fiber reinforced concrete exhibits higher impact energy absorption capacity, reducing the risk of damage from external loads.

(a) Durability Properties

Crack Resistance: Steel fiber has been found to reduce the width and propagation of cracks in concrete, improving its durability and service life (Soutsos et al., 2016). Freeze-Thaw Resistance: Research by (Richardson et al. 2012) showed that steel fiber reinforcement can improve the freeze-thaw resistance of concrete, reducing the risk of damage from repeated freezing and thawing cycles.

(b) Applications of Mechanical Properties

Industrial Floors: Steel fiber reinforced concrete is commonly used in industrial floors, where it provides improved durability and resistance to heavy loads and impacts (Concrete Society, 2014). Highway Pavements: Steel fiber reinforced concrete has been used in highway pavements, where it provides improved durability and resistance to traffic loads and environmental stresses (ACI Committee 544, 2018).

(c) Challenges and Limitations of Mechanical Properties

Cost: Steel fiber reinforcement can be more expensive than traditional reinforcement methods, which can limit its adoption (Mindess, 2019). Mix Design: The mix design of steel fiber reinforced concrete can be complex, requiring careful consideration of fiber content, concrete strength, and workability (Mehta & Monteiro, 2014).

2.2 Types of Fiber

(i) Steel Fibers

A review of the U.S Patent Office during the 19208 by Ramachandran and Feldman (1981) revealed several applications for steel fibers to be used as reinforcing agent for concrete.

The only bonding process between concrete and steel is a mechanical type. As a result manufacturers of steel fibers have attempted to improve this mechanical bonding by mechanically deforming the steel fibers. The diagram of some commercial steel fibers are shown in Figure 2.1

Figure 2.1: Commercial Steel Fiber

In designing Steel Fiber Reinforced Concrete (SFRO).Three important factors should be considered. The first is the aspect ratio in relation to the aggregate size. Mannant (1978) stated that as the aggregate size increases, uniform fiber dispersion decreases; this is shown in Figure 2.2.

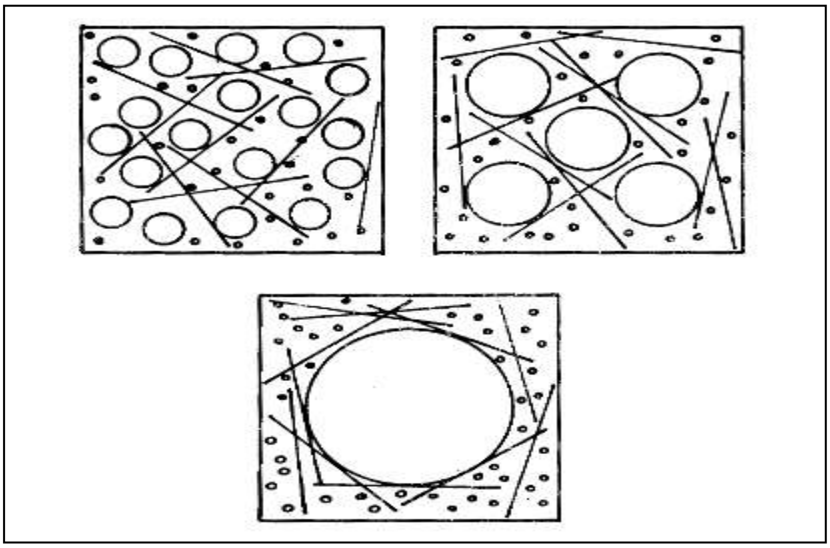

Figure 2.2: Effect of aggregate size on fiber distribution

Empirical evidence has indicated that steel fiber reinforced concrete (SFRC) should contain 30 percent coarse aggregate between 0.2 inch and 0.5 inch and 70 percent mortar by volume. The aspect ratio is defined as the mensch of the steel fiber divided by its diameter lid. The American Concrete Institute recommends an aspect ratio of between 30 to 150. The second consideration is the need to increase the cement content of the concrete design mix as the percentage of steel fiber increases. The reason for this is to coat the steel fiber surface area. The third factor to be considered is the fiber volume. This volume can be calculated by the following equation:

$$\frac{M_F}{V_M} \times \frac{D_D}{D_M} \qquad \text{(I)}$$

where:
M_F= Weight of fiber
V_F= Volume of fiber
D_F and D_M = Density of fiber and matrix
In terms of volume percentage for the normal weight concrete, the American Concrete Institute's (ACI) recommendation is between 0.38% which is equal to 50 pounds per cubic yard up to 2.5% which is equal to 256 pounds per cubic yard. However the high range limit is usually between (1.2% to 2.0%), which is 160 to 200 pounds per cubic yard.

(ii) Asbestos Fibers

Asbestos is a general name for several varieties of naturally available mineral fibers, which have been used in combination with Portland cement paste to form a material called asbestos cement. This naturally occurring mineral possesses a unique range of chemical and physical properties. According to (Hannant 1978) the strongest type of asbestos fibers is Crocidolite or blue asbestos (Na,O. FezOz.3Fe0.8510,•1,°). This type of asbestos is considered to be the most dangerous form of asbestos regarding the hazard to health. Only few countries are considered the major producers of asbestos, of which the largest concentrations of asbestos production are located in Canada, USS, and South Africa. Asbestos cements were used widely for making building products such as shingles, sheets, corrugated roofing elements, and pipes.
The desirable mechanical, thermal, and chemical resistance of this fiber as well as being relatively inexpensive were the major reasons for its wide application. Asbestos fibers have been used in concrete by up to three percent by weight of cement. Hannant 1978 pointed out that the compressive strength and the modules of elasticity of asbestos reinforced cement are not increased as a result of the addition of asbestos fibers; however asbestos cement is known to be very durable under natural weathering conditions. Due to asbestosis (depletion and lung cancer) which is associated with asbestos, a great demand exists now for a suitable fiber substitute.

(iii) Glass Fibers

The credit for the initial development of dispersed glass fibers utilized as a reinforcement for cement is given to a Russian scientist Biryukovich. He was involved in the construction of a factory roof in (Kiev in 1963). His work stimulated the work of Majumdar and Nurse at the Building Research Establishment in England. This directly led toward the development of glass fiber. The commercial methods of producing the flat sheet material from glass fibers and cement paste are those which were used by Biryukovich. The common glass fibers, E-glass are believed to be chemically attacked by the alkaline environment of cement paste which over a time period contributes to the loss of strength in the glass fiber reinforced concretes. This strength reduction can be eliminated by using alkali-resistant glass fibers, organic coating of the glass fibers, and reducing the exposure of glass fiber reinforced concrete to high humidity environment. As a result, conclusions regarding the durability of the glass fibers in Portland cement matrix should be treated with caution. An investigation by Marsh and Clark (1985) on the effect of alkali resistance glass fiber on the physical properties of Portland cement concrete has shown that the addition of glass fibers has improved the flexural strength of (GFRC) by 4.9 times over the strength of plain concrete also a 20 to 25 percent increase in compressive strength over the non-reinforced concrete. They have concluded that the addition of glass fibers can improve the flexural strength and crack resistance of the concrete.

(iv) Organic Fibers

Organic fibers include natural fibers such as sisal, straw, bamboo, and synthetic fibers such as polypropylene, and polyethylene. The high cost of man-made fibers (steel, glass, polypropylene, and polyethylene), in combination with the reduced usage of asbestos fibers due to its health hazard properties, has directed many scientists to devote their efforts to find substitutes, especially natural organic fibers which exist in large quantities in many countries around the world. Based on a study by (Castro and Naaman 1985), natural fibers of the agave family were found to have significant mechanical properties which made this fiber suitable as a potential reinforcement for cementations material. The agave family fibers (Lechuguilla and Mayueyatroviens) which are widely available in Mexico were found to have tensile strength of 80,000 pounds per square inch (PSI) and an elastic modulus of up to three million PSI, making these fibers suitable for low-cost housing applications, especially where the cost of reinforcement constitutes a major portion of the total cost. Variety of fiber lengths and volume fractions were used in Portland cement mortar matrix, up to three inches in fiber's length and volume fraction of up to 11 percent. Study indicated that the cementations matrix reinforced with natural fibers can achieve good resistance to environmental exposures.

(v) Polypropylene Fibers

Polypropylene fibers were first suggested as an admixture to concrete by (Goldfein 1965), for the construction of blast-resistance buildings for the U.S Corp of Engineers. Goldfein incorporated various natural and man-made fibers in mortar and cement. According to (Zonsveld, 1976), its mode of polymerization, its highly molecular weight, and the way it is processed into fibers combine to give polypropylene many useful properties. These properties include: a high melting point, resistance to most chemicals, and zero water demand due to having a hydrophobic surface which helps to prevent chopped fiber from balling up during mixing, high crystallinity and regular atomic arrangement in the polymer molecule. The parallel orientation of the polymer chain molecules that characterize these fibers helps the fiber to have high tensile strength. A study by (Naaman, Shah, and Throne, 1985) on the performance of polypropylene fibers in cementations composites has revealed that the best bonding properties polypropylene fibers with concrete can be obtained by improving the mechanical bonding of the fibers and concrete, namely by twisting them or adding end buttons to the fibers. A study by (Lovata 1985) on the interfacial bond between polypropylene fiber and cement matrices has revealed an increase in the interfacial bond between fiber and matrix due to crystalline growth as a result of the fiber surface treatment utilizing oleic acid.

2.3 Compaction and Fiber Orientation

The theories that explain the behavior of fiber reinforced concrete have been developed for a uniform fiber distribution and random orientation of fibers in space. Based on the study by (Edgington and Hannant 1972), this is not necessarily the case as fibers tend to become aligned due L the external vibration during compaction. According to (Hannant 1978) fibers may be oriented randomly in three dimensions in the mixer, however, hardened concrete can exhibit anisotropic behavior with strength up to 50 percent higher in one direction than another. This phenomenon may depend on the direction of vibration, aggregate size, and specimen shape. From the practical point of view of manufacturing components, the anisotropic properties could be put to good use by arranging the compaction procedure so that fibers are aligned in the most beneficial direction relative to the field of stress.

An experimental study by (Cook and Uher 1974) indicated that vibration had produced some fiber orientation. Herring et al. (1974) verified the effect of vibration from results of cube tests. Potrzebowski 1983 reported that vibration of fiber concrete destroys the randomness of the fiber distribution and produces anisotropy with regard to strength characteristics. Steel fiber concrete may be compacted by table vibration, by poker vibrators, or by surface vibration. The type and direction of vibration however can create critical effects on the orientation of the fibers. The orientations of fibers in steel fiber reinforced concrete were found to be directly related to the direction of the applied stress. This fiber alignment can be achieved accidentally or intentionally in many ways, such as surface vibration which causes the fibers to align at right. Angles to the direction of vibration as shown in Figure 2.3

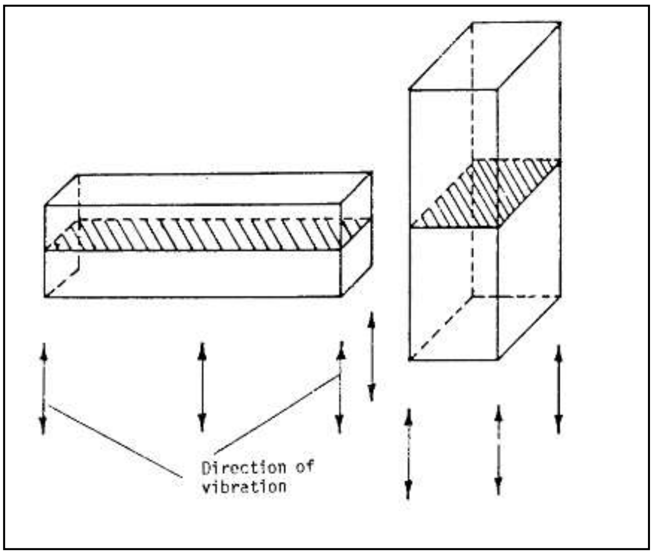

Figure 2.3: The effect of vibration on fiber alignment

Magnetic fields in combination with vibration have been used by (Bergstrom 1975) to assist fiber orientation in the desired direction. Classification of fiber arrangements is shown in Figure 5. Specimen ID represent fiber alignment in a single planes parallel to each other; specimen 2D. Represent fiber alignment in a random and mating pattern. Specimen 3D which is three dimensional indicates how steel fiber should be aligned in the matrix, preferably randomized and in three dimensions.

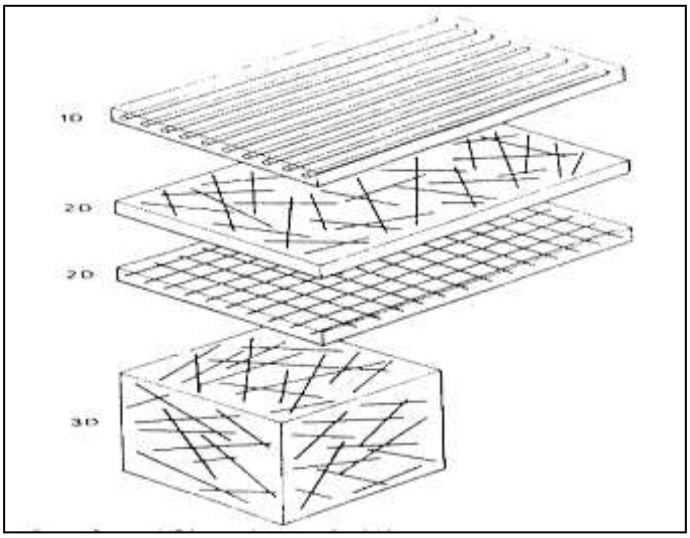

Figure 2.4: Classification of Fiber arrangement

2.4 Cracking Arresting Properties

One of the major benefits of steel fiber reinforced concrete is it crack arresting properties. Figure 2.5 is a representation of the crack arresting effects of steel fibers.

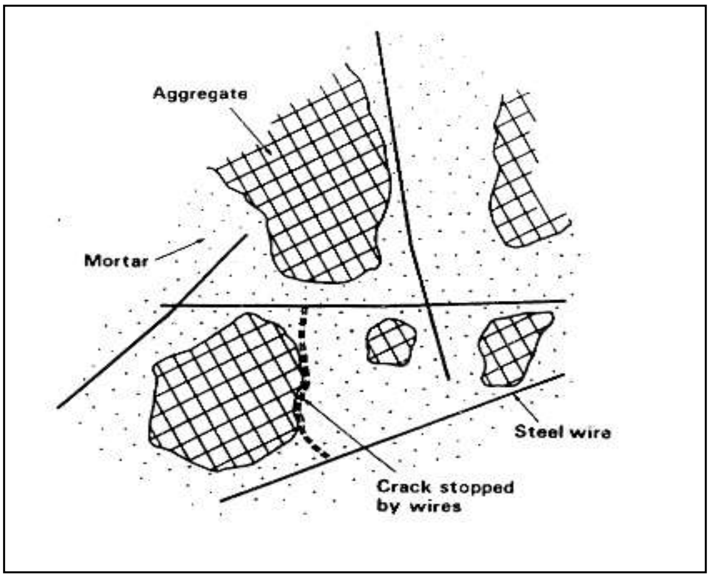

Figure 2.5: Crack arresting of steel fibers in concrete

2.5 Fiber Strength

It is generally accepted that higher strength steel fibers tend to give higher strength composites. However, in the case of steel fiber reinforced concrete this is not the cage because fiber pullout will accrue first. The strength of this type of composite depends on the bond strength between the see! Fiber and the matrix (Hannant, 1978).

III. MATERIAL AND METHODS

3.1 Materials selection and Equipment Required

The materials needed for this research includes:
(i) Steel Fibers (ii) Cement (Ordinary Portland Cement) (OPC) (iii) Fine aggregate
(iv) Coarse Aggregate and (v) Water Solution
The list of equipment needed are;
(i) Head Pan (ii) Bucket (iii) Shovel (iv) Framework (Steel) (v) Compaction Rod.

3.2 Experimental Test for the Steel Fibre

Slump test and compressive test, was carried to achieve our desire objectives of this research.

(a) Slump Test

Concrete Slump Test determines the workability of concrete, the test is carried out using a metal mould in the shape of a conical frustum known as a slump cone that is open at both ends and has attached handles. The tool typically has an internal diameter of 100mm at the top and of 200 mm at the bottom with a height of 300 mm. The cone is placed on a hard non-absorbent surface. This cone is filled with fresh concrete in three stages. Each time, each layer is tamped 25 times with a long bullet-nosed metal, at the end of the third stage, the concrete is struck off flush with the top of the mould. The mould is carefully lifted vertically upwards, so as not to disturb the concrete cone. The concrete then slumps (subsides). The slump of the concrete is measured by measuring the distance from the top of the slumped concrete to the level of the top of the slump cone.

(b) Compressive Test

Compressive strength is defined as the material's ability to resist forces that aim to decrease its volume or cause deformation. A force is applied to the top and bottom of the test sample until the sample deforms. Compressive strength tests various materials including concrete, rock, steel, etc where failure usually causes cracking. For ductile materials deformation is the major response to applied force. This ability to deform without immediate failure makes ductile materials useful in various structural applications.

(c) Procedure for Materials Preparation

(i) **Cement:** Fresh Ordinary Portland Cement (OPC) was used

(ii) **Fine Aggregate (sand):** Clean, well-graded river sand (free of clay/organic matter)

(iii) **Coarse Aggregate:** Clean, hard, angular stones, typically 20 mm down size

(iv) **Steel Fiber:** Diameter of 0.2 to 1.2mm, length 15 to 60mm

(v) **Water:** Clean, potable (drinkable) water, free from impurities.

The listed materials were mixed in correct ratio proportion.

(d) Procedures for compressive Test

(i) Prepare moisten cone and base plate.

(ii) Place cone vertically on the base plate.

(iii) Fill concrete in 3 equal layers.

(iv) Tamp each layer 25 times with tamping rod.

(v) Level the top surface and remove the cone vertically upward.

(vi) Measure the slump — vertical drop between the cone top and the highest point of slumped concrete.

(e) Procedures for Mould Making

Cleaning, Checking of Internal Dimension and application of release agent on the Mould**:** We ensure all dirt, hardened cement, or debris are removed by washing and drying the mould thoroughly, we used a tape rule to verify internal dimensions which are 150 mm × 150 mm × 150 mm and we applied a thin layer of oil or mold release agent on all internal surfaces, this helps in easy removal of the hardened concrete later, as shown in Plate 3.4.

IV. RESULT AND DISCUSSIONS

This chapter governs the results and discussion of test that were carried out on the cubes casted and cured for different day's i.e. 7, 14, and 28 days respectively and their graphical representations.

4.1 Experimental Results and Discussion

Cement, fine aggregates, coarse aggregates, steel fibers and water (2.56L) were uniformly mixed together thoroughly on a clean, non-absorbent surface. The slump test of the wet mix was determined by adding 2.56L of water, once the workability was determined, the wet mix was then poured into cube molds and kept for 24 hours. The samples were removed the next day (after 24 hours) and put into water tank for 7, 14, 28 days for water curing. Once the samples achieved specified curing of 7, 14, 28 days, the cube of dimension 150 mm x 150 mm was weighed using an electric scale. For control, 7 days = 8.32kg, 10% replacement of coarse aggregate with steel fiber = 8.38kg, 20% replacement of coarse aggregate with steel fiber = (i) 8.52kg (ii) 8.44kg. It was then tested in universal testing machine for compressive strength test as shown in Table 4.1.

Table 4.1: Weight of Materials

%	Fine Aggregate (kg)	Coarse Aggregate (kg)	Steel Fiber (kg)	OPC (kg)	Water (H_20) L
Control	12.4	24.8	-	6.4	2.56
10	14	25.2	2.8	7	4.2
20	15	24	6	7.5	4.5
30	15	23	9	7.5	4.5

Discussion 1:

Control Mix (0% Steel Fiber): This is the baseline mix without any steel fiber reinforcement. It contains 12.4 kg of fine aggregate and 24.8 kg of coarse aggregate, with 6.4 kg of Ordinary Portland Cement (OPC) and 2.56 L of water.

(i) **10% Steel Fiber Mix:**
   a. Steel fiber is introduced at 2.8 kg.
   b. There is a slight increase in both fine and coarse aggregates compared to the control.
   c. Cement content increases to 7 kg, and water to 4.2 L, indicating an adjustment for improved workability due to fiber inclusion.

(ii) **20% Steel Fiber Mix:**
   a. Steel fiber content rises to 6 kg.
   b. Fine aggregate continues to increase (15 kg), while coarse aggregate slightly decreases to 24 kg.
   c. Cement and water contents are further increased to ensure proper binding and hydration.

(iii) **30% Steel Fiber Mix:**
   a. The highest fiber content at 9 kg.
   b. Fine aggregate remains the same as in the 20% mix, but coarse aggregate decreases further to 23 kg.
   c. Cement and water remain constant (7.5 kg and 4.5 L), indicating a threshold point for acceptable mix workability and strength.

Table 4.2 show the compressive strength results development of control concrete cubes over different curing periods. At 7 days, the cube exhibited a compressive strength of 15.1 N/mm², indicating the initial gain in strength during early hydration.

Table 4.2: Compressive strength of Concrete Cube for control

Days	**Mass (kg)**	**Volume (mm^3)**	**Density kg/mm^3**	**Area of cube**	**Load, P (N)**	**Compressive Strength (N/mm^2)**	**Average compressive strength (N/mm^2)**
7	7.90	3375000	0.00000234	22500	350000	15.1	15.1
14	8.06	3375000	0.00000238	22500	400000	17.8	18.3
14	8.32	3375000	0.00000247	22500	420000	18.7	18.3
28	8.02	3375000	0.00000238	22500	370000	16.4	16.7
28	8.28	3375000	0.00000245	22500	380000	16.9	16.7

Discussion 2

At 7 days, the control concrete cube recorded a compressive strength of 15.1 N/mm², showing the initial strength gain at the early stage of curing. By 14 days, the strength improved noticeably to an average of 18.3 N/mm², indicating effective hydration and good development of the concrete's structural capacity.

At 28 days, the average compressive strength was 16.7 N/mm², slightly lower than the 14-day result. This drop suggests possible variations in curing or material properties, though the concrete still maintained adequate strength within the expected range.

Table 4.3 presents the compressive strength results for concrete cubes where 10% of the coarse aggregate was replaced with steel fibers. At 7 days, the concrete cube showed a compressive strength of 16.4 N/mm², which is slightly higher than the control specimen at the same age (15.1 N/mm²).

Table 4.3: Compressive strength of Concrete Cube for 10% replacement of coarse aggregate with steel fiber

DAYS	Mass (kg)	Volume (mm^3)	Density kg/mm^3	Area of cube	Load, P (N)	Compressive Strength (N/mm^2)	Average compressive strength (N/mm^2)
7	8.38	3375000	0.00000248	22500	370000	16.4	16.4
14	8.38	3375000	0.00000248	22500	350000	15.6	16.02
14	8.14	3375000	0.00000241	22500	370000	16.44	16.02
28	8.90	3375000	0.00000264	22500	390000	17.3	17.6
28	9.18	3375000	0.00000264	22500	400000	17.8	17.6

Discussion 3

At 7 days, the 10% steel fiber replacement cube achieved a compressive strength of 16.4 N/mm², which shows better early strength compared to the control mix. By 14 days, the strength values were 15.6 N/mm² and 16.44 N/mm², giving an average of 16.02 N/mm². This indicates that the mix maintained consistent strength development during the curing period.

At 28 days, the compressive strength further improved to 17.3 N/mm² and 17.8 N/mm², with an average of 17.6 N/mm². This increase reflects the positive contribution of steel fiber in enhancing long-term strength, showing that the modified mix sustained steady improvement up to 28 days. Table 4.4 shows the compressive strength of concrete cubes with 20% replacement of coarse aggregate by steel fibers. At 7 days, the two specimens recorded compressive strengths of 19.1 N/mm² and 15.6 N/mm², averaging 17.4 N/mm².

Table 4.4: Compressive strength of Concrete Cube at for 20% replacement of coarse aggregate with steel fiber

DAYS	Mass (kg)	Volume (mm^3)	Density kg/mm^3	Area of cube	Load, P (N)	Compressive Strength (N/mm^2)	Average compressive strength (N/mm^2)
7	8.52	3375000	0.00000252	22500	450000	19.1	17.4
7	8.44	3375000	0.00000250	22500	350000	15.6	17.4
14	7.50	3375000	0.00000222	22500	350000	15.6	15.8
14	8.12	3375000	0.00000241	22500	360000	16	15.8
28	8.66	3375000	0.00000257	22500	380000	16.9	16.5
28	8.38	3375000	0.00000248	22500	360000	16	16.5

Discussion 4

At 7 days, the 20% steel fiber replacement cubes showed compressive strengths of 19.1 N/mm² and 15.6 N/mm², with an average of 17.4 N/mm². This indicates strong early performance, suggesting that the inclusion of more steel fiber initially enhanced load-bearing capacity compared to the control.

At 14 days, the average strength was 15.8 N/mm², slightly lower than the 7-day result, pointing to limited strength gain during this period. By 28 days, the cubes reached an average compressive strength of 16.5 N/mm², showing moderate improvement but still not surpassing the early 7-day average. This suggests that higher fiber replacement may restrict later strength development despite boosting initial strength.

Table 4.5 is expected to show the Compressive strength of Concrete Cube at 7 days for 30% replacement of coarse aggregate with steel fiber (on the process).

Table 4.5: Compressive strength of Concrete Cube at 7 days for 30% replacement of coarse aggregate with steel fiber

S/N	Mass (kg)	Volume (mm^3)	Density kg/mm^3	Area of cube	Load, P (N)	Compressive Strength (N/mm^2)	Average compressive strength (N/mm^2)
7	7.12	3375000	0.00000211	22500	270000	12	12.45
7	7.36	3375000	0.00000221	22500	290000	12.9	12.45
14	8.08	3375000	0.00000244	22500	300000	13.3	13.1
14	7.58	3375000	0.00000225	22500	290000	12.9	13.1
28	8.26	3375000	0.00000245	22500	310000	13.8	13.6
28	8.23	3375000	0.00000244	22500	30000	13.3	13.6

Discussion 5

At 7 days, the 30% steel fiber replacement cubes recorded compressive strengths of 12.0 N/mm² and 12.9 N/mm², giving an average of 12.45 N/mm². This shows that early strength was relatively low compared to lower replacement levels, indicating that higher steel fiber content may hinder early hydration and strength development. By 14 days, the average strength increased slightly to 13.1 N/mm², and at 28 days it further improved to 13.6 N/mm². Although there was progressive strength gain with curing age, the overall values remained lower than those of 10% and 20% replacements. This suggests that while 30% steel fiber addition contributes to some strength, it is less effective for long-term compressive strength compared to lower replacement levels.

At 30% by volume the mix becomes almost impossible to mix/compact — huge workability loss, severe voids/segregation, likely lower effective compressive strength because of poor consolidation.

So adding 30% fibers will not reliably produce the desired compressive strength and may reduce strength because of defects and lack of paste to bind aggregates.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the results of the compressive strength tests, it can be concluded that the inclusion of steel fiber as a partial replacement for coarse aggregate influenced the strength development of the concrete cubes across the curing ages. The 10% replacement level produced the most favorable long-term strength, with steady improvement up to 28 days, while the 20% replacement showed high early strength but limited later development. In contrast, the 30% replacement consistently recorded lower strength values compared to other mixes, indicating that excessive steel fiber content may reduce compressive performance. Overall, moderate replacement levels enhanced strength, but higher proportions proved less effective for long-term durability.

While steel fibers cannot entirely replace coarse aggregates, their strategic inclusion at controlled levels significantly improves concrete behavior under certain conditions. Future research could also explore hybrid mixes combining steel fibers with partial cement replacement materials to improve sustainability and reduce cost.

5.2 Recommendation

(i) Mix Design Adjustment: The inclusion of steel fibers requires adjustments in cement and water content to maintain mix workability and cohesion. It is recommended to incorporate super plasticizers or other admixtures to enhance flow without increasing water-cement ratio, which could otherwise weaken the concrete.

(ii) It is recommended that pilot-scale or field trials be conducted using the 10% and 20% steel fiber replacement mixes to evaluate performance under real-life environmental and loading conditions. This will help validate lab findings and assess practical viability.

(iii) Alternative Fiber Types and Blends: Future investigations could explore the combination of steel fibers with other fibers (e.g., polypropylene, basalt, or glass fibers) to study synergistic effects on both compressive and flexural properties.

(iv) Flexural and Tensile Strength Evaluation: Since steel fibers mainly contribute to crack control and post-crack performance, it is essential to include flexural and split tensile strength **tests** in subsequent research for a comprehensive structural evaluation.

5.3 Contribution to Knowledge

This project provides significant contributions to the field of Mechanical and civil structural engineering, particularly in the area of concrete technology and materials innovation. The study on the effect of steel fiber as a replacement material in composite concrete has yielded the following key contributions:

(i). Enhanced Understanding of Composite Behavior: The project deepens the understanding of how steel fibers influence the mechanical and durability properties of concrete, such as compressive strength, flexural strength, toughness, crack resistance, and ductility.

(ii). Alternative Reinforcement Method By incorporating steel fibers as a reinforcing component within the concrete matrix, this research proposes a viable alternative or supplement to traditional reinforcement techniques.

(iii). Improved Concrete Performance The study demonstrates how steel fiber addition can significantly reduce microcracking, improve post-cracking behavior, and enhance load-carrying capacity—leading to longer-lasting and more resilient concrete structures.

(v) This work provides practical data and recommendations for engineers, contractors, and builders who may consider integrating steel fibers into concrete mixes for specific applications, such as pavements, tunnel linings, precast elements, and industrial floors.

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