RESEARCH ARTICLE

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# Enhancing M30 Grade Concrete: A Comparative Study of Hooked vs. Crimped Steel Fibers in Fly Ash Mixes

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**Abstract:** The realm of concrete offers vast opportunities for inventive applications, design, and construction methodologies, given its adaptability and cost-effectiveness. Its versatility in meeting diverse requirements has established it as a highly competitive building material. To address escalating structural demands and harsh environmental factors, new cementitious materials and concrete composites are continually being developed, followed by the need for enhanced durability and performance, as well as pressure to utilize industrial waste materials. The research explores the impact of incorporating fly ash and steel fiber into M30-grade concrete, alongside cement, coarse, and fine aggregate, through experimental methods, with the primary aim of determining optimal ingredient proportions for achieving desired strength. The study evaluates compressive strength variations with fly ash ranging from [10%] to [30%] while hooked and crimped steel fibers [ranging from 0% to 1.5%] in concrete, alongside cement, fine and coarse aggregate. Environmental considerations and the imperative to utilize industrial waste have significantly contributed to advancements in concrete technology and sustainability. Through meticulous analysis of results, meaningful inferences are made in relation to the strength attributes of fly ash fiber-reinforced concrete. Two sets of experiments were conducted, one altering fly ash content while maintaining fixed steel fiber content, and the other varying steel fiber content while keeping other parameters constant. The study aims to provide practical insights for engineers seeking cost-effective and sustainable building construction methods, adhering to specified norms (IS Code: 456-2000).

**Keywords:** Compressive Strength, Concrete, Durability, Fly Ash, Steel Fiber

## 1. Introduction

Concrete constitutes a composite substance blending fine aggregate and coarse aggregate, water, and hydraulic cement, which undergoes a chemical reaction with water, resulting in a stone-like substance. Although concrete boasts robust compression properties, its tensile strength is limited due to inherent brittleness [1]. While concrete exhibits significant compressive strength, it lacks tension, leading to the expansion of micro cracks under tensile stress, consequently diminishing its tensile strength. Incorporating steel fiber into concrete is often recommended to enhance both flexural and tensile strength. The disposal of fly ash, a byproduct of thermal power plants, poses environmental challenges [2, 3]. Rather than discarding fly ash, it can be economically and environmentally beneficially utilized in concrete production, offering significant commercial and environmental advantages [4]. Fly ash proves especially advantageous in mass concrete applications, aiding in managing thermal expansion resulting from cement paste hydration [5]. Concrete ranks as the world's second most consumed substance, following only water. Given the adverse environmental impacts of steel and cement production, prioritizing waste reduction and reuse is crucial for sustainable development [6].

Concrete reinforced with steel fibers and fly ash (SFFAC) amalgamates cement-based concrete that has randomly oriented and evenly distributed fiber material to bolster structural integrity. This blend, functions as crack arrestors within the cement fly ash-based matrix, curbing the formation and expansion of microcracks under load. The integration of SFFAC, including fiber-reinforced concrete, has found applications in various scenarios such as thin bridge deck overlays, marine structures, and tunnel linings [7].The substitution of fly ash for cement in concrete promotes energy conservation. Incorporating steel fiber into concrete aims to impede crack propagation, particularly in regions prone to light loads at the tensile end of the member.

## 2. Materials and Methods

### 2.1 Portland Cement

The cement utilized in the exploratory research is of (43) Grade Standard Portland cement. All characteristics of portland cement are tried by alluding IS 12269: [1987] detail for (43) Review Conventional Portland cement is mentioned below.

**Table 1** Experimental tests of cement

| Specifics | Normal Range |
|---|---|
| Factor of lime saturation (LSF) | 0.87 - 0.91 |
| The ratio of alumina to iron oxide | 1.45 - 1.60 |
| Remainder insoluble [% mass] | 1.25 - 1.70 |
| MgO [% mass] | 2.40 - 3.30 |
| $SO_3$ [% mass] | 1.50 - 1.85 |
| Net loss of ignition [% mass] | 1.10 - 1.50 |
| Cl [% mass] | 0.020 - 0.015 |
| Characteristics | Value |
| Specific Gravity (G) | 3.15 |

| | |
|---|---|
| Initial Setting Time (min) | 38 - 40 |
| Final Setting Time (min) | 180-185 |

## 2.2 Coarse Aggregate

The study utilized locally available coarse aggregate of 20mm and 10mm size, with specific gravity values of 2.958 and 7.136, and a fineness modulus of 5.829. {IS Code-383:1970}.

## 2.3 Water

Drinkable water is utilized in concrete preparation as a lubricant, chemically binding with cement to form paste for reinforcing and coarse aggregate and facilitating concrete mix flows into the formwork.

## 2.4 Steel fiber

The study utilized high-quality low-carbon steel wire for concrete strengthening, with varying hooked and crimped steel fiber composition coming from 0.5% to 1.5%. The fibers were 50mm long and 1.0mm diameter. The experimental analysis revealed their advantages in tensile strength and toughness.

Table 2 Properties of Hooked and Crimped Steel fiber

| | |
|---|---|
| Length [mm] | 50 |
| Diameter [mm] | 1 |
| Aspect Ratio [L/D] | 50 |
| Tensile Strength [N/mm2] Hooked | 1225 |
| Tensile Strength [N/mm2] Crimped | 1300 |

## 2.5 Fly ash [Class F]

Fly ash, also called flue gas residue, is a byproduct generated during coal combustion, composed of fine particles that ascend with the flue gas. It is typically captured by electrostatic precipitators or particulate filtration systems prior to exiting coal-fired power plant stacks.

Table 3. Chemical composition of Fly Ash

| Constituents | Fly Ash [Class F] |
|---|---|
| [SiO2 +Al2O3 +Fe2O3], min, % | 70.0 |
| [SO3], max, % | 5.0 |

| | |
|---|---|
| Content of Moisture, max, % | 3.0 |
| Loss upon ignition., max% | 6.0 |

## 2.6 Mix Proportion

Mix design involves choosing the components and ratios for a concrete mix. In this study, the IS Code [456]-2000 guidelines were adhered to, determining quantities of cement, fine aggregate, and coarse aggregate. The mixture was then cast into molds, with fly ash added at varying percentages ([10%], [20%], [30%]). Three samples were cast for each percentage, while considering parameters such as cement, aggregates (coarse and fine), and steel fiber.

M30 general mix (1:1.7:2.6) was developed as per guidelines of IS Code: [456-(2000)] standards.

**Table 4.** Mix design proportion of M30

| Grade | Cement | Fine aggregates (FA) | Coarse aggregates (CA) | w/c ratio |
|---|---|---|---|---|
| M30 | 379 Kg | 619 Kg | 1238 Kg | 0.40 |

## 2.7 Test Specimen

A study prepared 150x150x150 mm$^3$ cubes using standard modulus and cast them using different fly ash percentages. Steel fiber content was varied in the second set, and samples were dismantled 24 hours after casting. The cubes were stored in water-filled tanks for 7 and 28 days, with 150 specimens tested for compressive strength. Details and indications are provided below.

**Table 5.** Total No. of cubes

| S. No. | Representation | Number of Cubes |
|---|---|---|
| 1 | C1 (Control mix) | 6 |
| 2 | C2 [(0%) ash] | 18 |
| 3 | C3 [(10%) ash] | 18 |
| 4 | C4 [(20%) ash] | 18 |
| 5 | C5 [(30%) ash] | 18 |

## 2.8 Mixing and casting of specimens mix.

Concrete mixing was done by hand to achieve a homogeneous mixture of all ingredients. The process involved weighing coarse aggregate, adding fine aggregate, adding fly ash and cement, and thoroughly drying the mixture. Steel fibers were added according to the study's recommended proportion. Superplasticizer was blended with water after being introduced thoroughly until a uniform color was obtained.

- Hand mixing of ingredients for homogeneous mixture.
- Weight-based batching of concrete.
- Weighing coarse aggregate, adding fine aggregate, adding fly ash and cement, and thoroughly mixing.
- Steel fibers are added according to study proportion or quality.
- Superplasticizer and water mixtures mixed until uniform color.
- Fly ash addition required more mixing time.
- Mixing continued until completion of all tests.

## 2.9 Compressive strength test

Compressive strength tests are crucial in concrete testing, as they are designed to withstand compressive stresses. These tests were conducted on 150mm x 150mm x 150mm cubes using compression testing equipment with a capacity of 3000 KN. The compressive strength was calculated using the formula: breaking load / cross-sectional area. The target mean strength of 38.25 Mpa was achieved by replacing varying amounts of cement with fly ash, adding [30%] fly ash, and 1% steel fiber. However, an economic approach suggests using a mixture with 1% steel fiber and [30%] cement and [30%] fly ash to achieve the target medium strength.

M30 Grade Concrete Mixture Creation

- Uses fly ash as partial replacement of cement in [10%], [20%], [30%] cement mixture.
- Addition of steel fiber in 0.5%, 1%, 1.5%, and 2% increments for strength increase.
- Creates a mold size of 150 x 150 x 150 x 150 mm3.
- 7 days and 28 days after curing, the cube is ready.
- Tested on Compression Testing Machine (CTM).
- Calculated cube strength for different days.
- Achieved effective target mean strength when added 1% hooked and crimped fiber and partially replacing the cement with [10%], [20%], and [30%] of fly ash as partial replacement as two different sets.

## 2.10 Flexural tensile test

Flexural tests do not directly measure the concrete's tensile strength. It evaluates the ability of a weak concrete or slab to resist flexural failure. The results of concrete cracking tests are presented as a fracture standard expressed in MPa or psi (MR). Concrete tests can be performed using the three-point load test which includes the following steps.

- Replace cement with fly ash in [10%] and add steel fiber in 1%.
- Creates a mold size of 700 x 100 x 100 mm3.
- Calculated Beam strength for different days.

### 2.11 Split tensile test

Concrete's tensile strength is an essential factor and important characteristic that affects the size and size of cracks. Additionally, due to the brittleness of the stone, its tensile capacity is quite weak. Therefore, when the tensile strength exceeds the tensile strength, cracks will appear in the concrete. Therefore, to determine the load that reinforced concrete elements can break, it is necessary to ascertain the concrete's tensile strength. In addition, the cylinder splitting tensile strength test is a technique for figuring out concrete's tensile strength.

- Replace cement with fly ash in [10%] and add steel fiber in 1%.
- Creates a mold size of 150 x 300 mm3.
- Calculated Beam strength for different days

## 3. Results and Discussion

### 3.1 Analysis of Compressive strengths

The experimental analysis reveals that increasing the fiber content up to 1% leads to increased compressive strength, while further increases decrease it. However, partial replacement of cement with fly ash over [20%] is not a significant choice for concrete effectiveness, as it does not significantly affect the strength. Flexural Tensile test and Split Tensile test was done on [10%] fly ash, and up to 1% of Steel Fiber (Hooked and Crimped) leads to increase in 29.7% and 18.3% of Tensile strength, respectively.

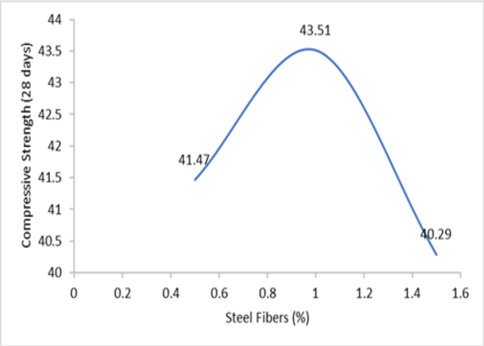
**Table 6.** Experimental Data of Testing

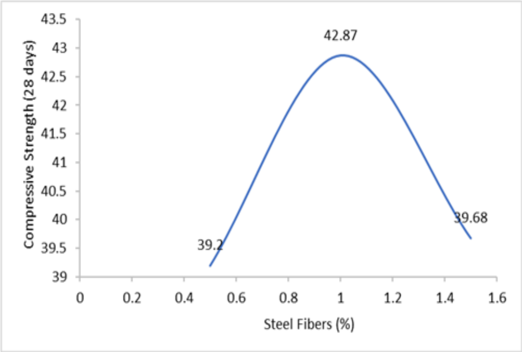
| S.no. | Fly ash [%] | Steel Fiber [%] | Hooked Fiber | | Crimped Fiber | |
|---|---|---|---|---|---|---|
| | | | Day 7th [MPa] | Day 28th [MPa] | Day 7th [MPa] | Day 28th [MPa] |
| 1 | 0 | 0.5 | 26.21 | 41.47 | 27.54 | 39.2 |
| | | 1 | 31.34 | 43.51 | 30.29 | 42.87 |
| | | 1.5 | 30.5 | 40.29 | 29.67 | 39.68 |
| 2 | 10 | 0.5 | 26.49 | 40.17 | 26.21 | 40.12 |
| | | 1 | 30.14 | 45.53 | 29.27 | 44.98 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 1.5 | 28.5 | 39.24 | 28.1 | 39.14 |
| 3 | 20 | 0.5 | 22.48 | 33.48 | 22.18 | 33.08 |
| | | 1 | 31.59 | 41.29 | 30.87 | 40.89 |
| | | 1.5 | 25.97 | 40.45 | 26.2 | 39.24 |
| 4 | 30 | 0.5 | 23.68 | 36.42 | 22.54 | 36.06 |
| | | 1 | 25.32 | 40.21 | 25.19 | 39.68 |
| | | 1.5 | 24.12 | 33.46 | 23.97 | 33.63 |

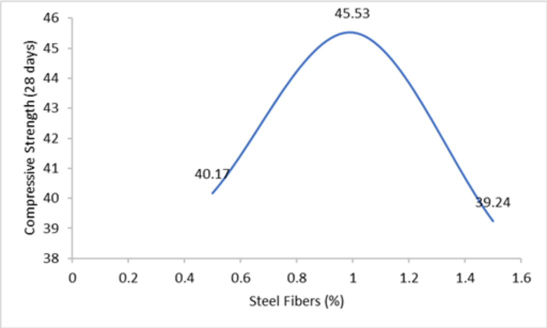
Hooked SF Crimped SF

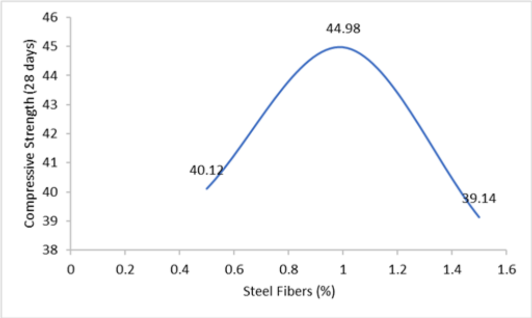
(a) 0% Fly Ash



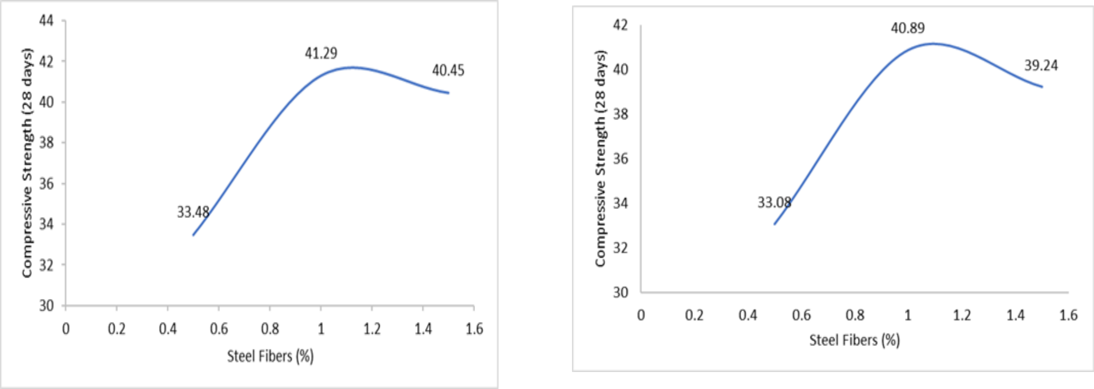




(b) 10% Fly Ash



(c) 20% Fly Ash




(d) 30% Fly Ash

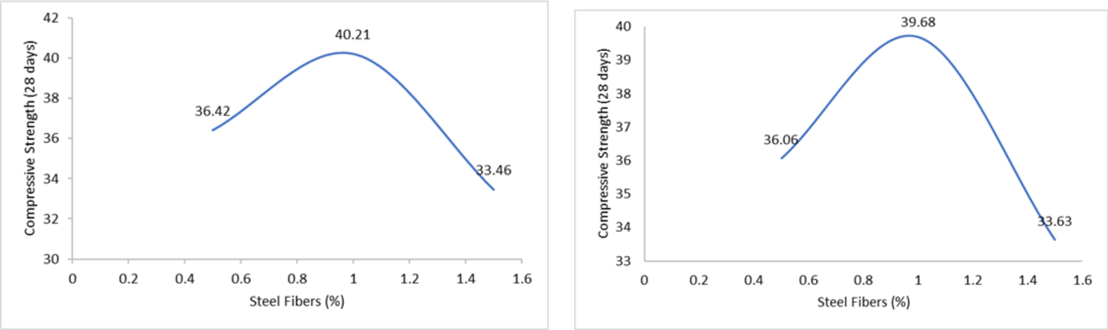



**Figure 1.** Compressive Strength Test Graphs

## 3.2 Flexural Tensile Test

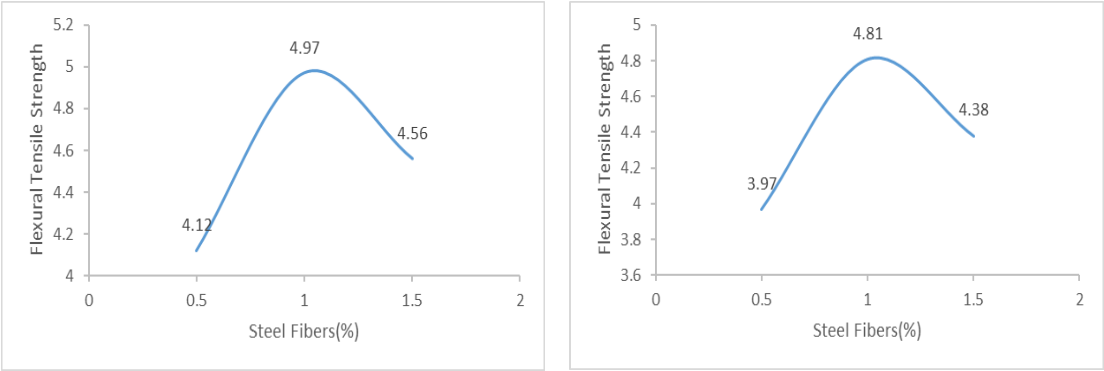



**Figure 2** Flexural Tensile Test Graphs

Table 7 Experimental Data of Flexural Tensile Test

| S.no. | Fly ash [%] | Steel Fiber [%] | Hooked Fiber | | Crimped Fiber | |
|---|---|---|---|---|---|---|
| | | | Day 7th [MPa] | Day 28th [MPa] | Day 7th [MPa] | Day 28th [MPa] |
| | | 0.5 | 2.74 | 4.12 | 2.64 | 3.97 |
| 1 | 10 | 1 | 3.31 | 4.97 | 3.24 | 4.81 |
| | | 1.5 | 3.04 | 4.56 | 2.92 | 4.38 |

## 3.3 Split Tensile Test

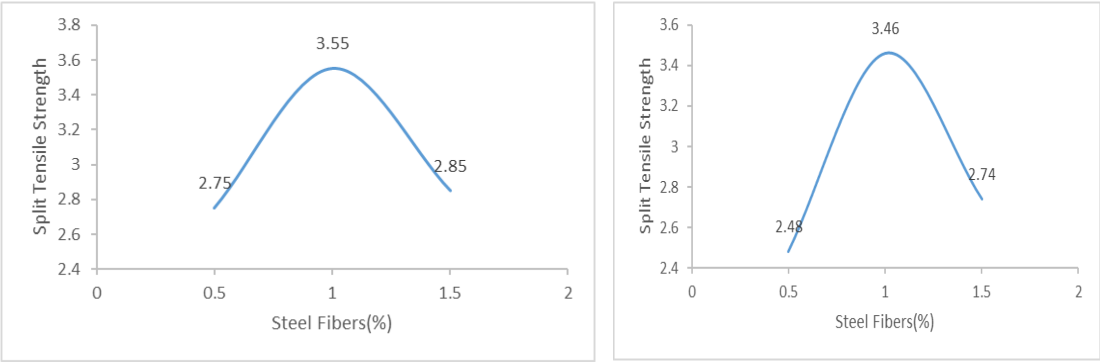



Figure 3. Split Tensile Test Graphs

Table 8 Experimental Data of Flexural Tensile Test

| S.no. | Fly ash [%] | Steel Fiber [%] | Hooked Fiber | | Crimped Fiber | |
|---|---|---|---|---|---|---|
| | | | Day 7th [MPa] | Day 28th [MPa] | Day 7th [MPa] | Day 28th [MPa] |
| | | 0.5 | 1.83 | 2.75 | 1.65 | 2.48 |
| 1 | 10 | 1 | 2.37 | 3.55 | 2.31 | 3.46 |
| | | 1.5 | 1.9 | 2.85 | 1.82 | 2.74 |

After conducting the aforementioned test, the target average strength of 38.28 MPa was achieved by replacing varying amounts of cement with fly ash: [10%], [20%], and [30%]. The results indicated that when replacing [10%] of fly ash with cement and adding 1% hooked steel fiber, economically feasible results were obtained by blending M30 grade concrete in this mixture.

Partial replacements of cement by [10%], [20%], and [30%], along with the addition of steel fiber at proportions of 0.5%, 1%, and 1.5%, were tested for their strength in a mixture comprising sand, aggregate ( fine and coarse), fly ash, cement and hooked steel fiber. The specimens, sized at 150 x 150 x 150 $mm^3$, were tested after 7 and 28 days using a Universal Testing Machine (UTM). It was observed that by adding 1% steel fiber and replacing [10%] of cement with fly ash, the target average strength was consistently achieved. The compressive strength variation after 7 and 28 days indicated that increasing the fiber content up to 1% led to enhanced strength, with further increments in fiber content resulting in diminishing strength.

## 4. Conclusion

The results were analyzed to draw useful conclusions about the strength of fly ash fiber reinforced concrete (FLY ASH-FRC). M30 concrete was used as composite material. While an optimum mix of hooked steel fibers and fly ash can significantly enhance compressive strength, exceeding the recommended fly ash content can lead to diminishing returns and potentially lower compressive strength due to reduced cementitious content and delayed hydration reactions. Increasing fly ash content beyond [10%] can decrease compressive strength due to reduced cementitious material, leading to weaker early-age strength development. Higher fly ash levels prolong concrete setting times, risking construction delays and cold joints. Additionally, excessive fly ash can limit pozzolanic activity, causing incomplete hydration reactions and diminishing strength gain over time. There was a 17.08% increase in compressive strength, a 29.63% increase in flexural tensile strength, and an 18.33% increase in split tensile strength observed with the addition of 1% hooked steel fibers and 10% fly ash.

As the percentage of fly ash and steel fiber increases, the compression coefficient decreases. Therefore, it can be concluded that the performance is lower when the fly ash and fiber content increases. According to the test results, the recommended percentage to obtain compressive strength, splitting tensile strength and bending strength is 1.0% hooked steel fiber volume with the addition of [10%] fly ash. Exceeding 1% steel fiber content in concrete can diminish compressive, tensile, and flexural strength due to factors like aggregate interference, fiber clustering, workability issues, and decreased cohesion. Higher fiber concentrations disrupt aggregate arrangement, lead to clustering, reduce workability, and weaken bonding between fibers and the concrete matrix, resulting in compromised mechanical properties and increased susceptibility to cracking and failure under load. Therefore, there was decrease in strength beyond 1% of hooked steel fiber.

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