

“An Experimental Study Using Fly Ash and Steel Fiber to Partially Replace Cement for the Production of Green Concrete”

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Abstract

The primary objective of the study is to reduce the use of cement and to find a substitute for cement in concrete in the form of fly ash (FA) without compromising the compressive strength of the concrete. Silica Fume (SF) is utilized in the study to enhance the strength of concrete, making it a greener concrete by utilizing waste materials. In this study, cement is partially replaced with FA at proportions of 20%, 25%, and 30%, and SF is added at 1%, 1.5%, and 2% for each mix. The investigation is carried out for M 25 and M 30 grade concrete, evaluating properties such as workability, compressive strength, flexural strength, and split tensile strength. For both M 25 and M 30 concrete grades, the compressive strength is maximum effective when cement is partially replaced with FA at 20%, 25%, and 30%, combined with 1% SF. However, for M 25 grade, the optimal compressive strength is achieved with 20% FA and 1.5% SF. The highest split tensile strength 2.75 N/mm² for M 25 and 3.60 N/mm² for M 30 is obtained with 20% FA and 1% SF. Maximum flexural strength is observed at 30% FA replacement with 2% SF. Furthermore, workability improves with 30% FA replacement in both grades.

Keywords: Compressive Strength; Workability; Flexural Strength; Split Tensile Strength; Fly Ash; Silica Fume

1. Introduction

Concrete is broadly used in construction but has high costs and environmental impacts. Producing 100 kg of Portland cement emits 100 kg of CO₂, contributing about 7% of global greenhouse gas emissions. India's cement demand is growing by 9–10%, driven by infrastructure and housing. Thermal power plants supply 65% of India's electricity, using coal with 25–45% ash content. Fly ash (FA), a byproduct, is partly replacing cement, reducing pollution and costs. India produces 195 million tons of FA annually, projected to reach 300 million tons by 2020, though only 15% is used effectively (Amran, 2021).

Construction and demolition (C&D) waste, mainly concrete debris, can replace natural aggregates in concrete, cutting costs and reducing landfill use. Using FA, recycled aggregates, and other industrial wastes promotes green concrete (Chandru, 2019), which is energy-

efficient, sustainable, and despite the benefits of using "green" materials in concrete, several barriers limit their adoption:

- **Cost-effectiveness:** Recycling and processing waste like plastics, glass, and RCA require extra energy and costs, which project managers must weigh against natural aggregates.
- **Concrete properties:** Some wastes may reduce workability or strength, and data on long-term performance is often limited.
- **Industry perception:** The construction sector is conservative, concerned about product failure, and hesitant to adopt materials perceived as less durable, like fly ash concrete.

Green Concrete Rating (Green Building System)

- **Water Efficiency:** Uses less water than standard concrete but requires proper water balance to maintain foam quality.
- **Atmosphere & Energy:** Provides better insulation, soundproofing, and fire resistance, reducing energy use.
- **Materials & Resources:** Utilizes industrial waste like fly ash, reducing raw material consumption.
- **Indoor Environmental Quality:** Improves air quality and sound absorption in buildings.
- **Design & Innovation:** Encourages use of fly ash, surfactants, and other eco-friendly materials for sustainable construction.

Objective

The following list includes the thesis' primary goals: -

- Utilizing steel fibres to develop the concrete/fly ash mix ratio.
- Figuring out the water-to-cement ratio as it is important for the strength and workability of design mixtures.
- To investigate how the utilisation of steel fibres and FA affects flexural strength, compressive and tensile strength of the concrete.
- Evaluating and analyzing the impact of different proportions of FA and steel fibres in concrete.

Scope of the Study

Green concrete is a highly novel research area in the old days of the civil industry. This type of concrete is appropriate for using waste materials, which reduces environmental impact and

expenses. In India, municipal enterprises are frequently unable to control garbage. The final product will aid in eliminating waste and the incorporation of FA in regular concrete.

2. Review in Literature

General

In the concrete-based constructions firm FA and fibers of steel were first used in concrete in the later 18th century. A number of the initial investigation projects involved replacing cement with various pozzolanic elements to create high performance concrete. Along with pozzolanas, there has also been advancement in the field of fibre-reinforced concrete. The several studies that have been mentioned in this chapter are listed below.

(Amran, 2021) studied green concrete using recycled concrete aggregates (RCA) for structural applications. Tests showed durability factors above 88%, exceeding ASTM C 666-97 standards, with minimal length change ($<0.032\%$) and high resistance to freeze-thaw, chloride penetration, and carbonation. RCA's residual mortar significantly influenced concrete properties, confirming RCA as a viable alternative to virgin aggregates.

(Chandru, 2019) examined using recyclable materials like fly ash, coal dust, marble powder, waste plastic, and recycled aggregates in green concrete. Fly ash reduces CO₂ emissions from cement production, promoting cost-effective, eco-friendly construction and encouraging material reuse while minimizing environmental contamination.

(Chu, 2021) compared Portland cement concrete with mixes using waste materials, analyzing benefits and challenges of green concrete. Their survey showed limited use of green materials but highlighted more advantages than drawbacks in adopting supplementary cementitious materials (SCMs).

(Chun, 2019) studied replacing fine aggregate in concrete with 0–50% coal bottom ash. Tests for compressive, flexural, and tensile strength showed that concrete with up to 50% bottom ash achieved sufficient strength for most construction applications, proving its practical feasibility.

(Herath, 2020) demonstrated that replacing 0–40% cement with fly ash and using locally available crushed aggregates can produce affordable high-performance concrete (HPC) reaching 60 MPa at 28 days and 65 MPa at 56 days. Tests confirmed workability, strength, and durability improvements, making sustainable, low-cost HPC feasible with varying binder contents.

(Nayak, 2021) studied how fly ash (FA) fineness affects mortar properties. Using 20–40% FA with varying fineness, results showed higher compressive strength, pozzolanic activity, and

sulphate resistance with finer FA. Mortars with finely ground FA outperformed coarse FA and, after 90 days, exceeded control mix strength.

(Prakash, 2020) studied the production of recycled coarse aggregate (RCA) and the influence of original concrete on its properties. RCA was obtained from six concrete sources, including sidewalks, masonry blocks, and airport pavements. Findings showed source type minimally affected RCA quality, highlighting the importance of understanding residual mortar effects and accurately characterizing RCA properties.

(Promsawat, 2020) found hydrochloric acid ineffective for RCA, especially acid-sensitive OVA like limestone, which disintegrates. Microscopic analysis revealed cracks and voids in OVA and less stable sandstone aggregates. Double crushing reduced defects, but further grinding caused new cracks. RCA in SSD form showed 3–15% lower specific gravity and 3–6 times higher water absorption than natural aggregates.

To assess the flexural strength, compressive strength, and tensile strength of a material, investigators employ a number of methods and tests. Several investigators have examined standard concrete produced using fly ash, yet in the present research an evaluation of concrete classes produced with fiber steel and fly ash is conducted. Compressive, flexural and tensile strength evaluations are also carried out.

3. Material Properties

The fine, gray-colored powdered is cement. It covers up voids that exists in the fine aggregate. As the concrete reinforces following being mixed with water, it assists in binding the sand, gravel, and crushed stone together. It takes up 20% of the overall volume of the concrete mix yet it has the least influence on the compressive property of the concrete. Every requirement ought to be met by cement of excellent quality that complies with I.S. norms. The most significant kind of cement is OPC, that is made by processing the clinker of Portland cement into a fine powder (Chu, 2021). Based on the 28-day strength, OPC is separated under 3 grades: 33 Grade, 43 Grade, and 53 Grade. The several IS codes define guidelines regarding cement of any grade. In the present investigation, standard Portland Cement with Grade 43 (Shree Cement) in compliance per Indian Standard IS 8112: 2013 is being used. It was lump-free and completely fresh (Chun, 2019). Different chemical properties of cement are listed in Tables 3.1 and physical properties of cement are listed in Tables 3.2.

Table 3.1 Chemical Breakdown of Standard Portland Cement

Chemical Structure	SiO ₂	CaO	SO ₃	Na ₂ O ₃	Al ₂ O ₃	MgO	Fe ₂ O ₃	LOI
%	18.45	64.52	2.84	1.38	4.8	2.18	4.01	1.15

Table 3.2 Typical traits for Portland Cement

S. No.	Traits	Result	Specified Values in accordance with Indian Standard Code
1.	Normal Consistency	31.5%	25% - 35%
2.	F.S. T	238 minutes	Not more than 600 minutes
3.	I.S. T	86 minutes	Should not be less than 30 minutes
4.	Specific Gravity	3.12	3.10 – 3.16

Table 3.3: Fly ash's chemical composition

Chemical Composition	CaO	SiO ₂	MgO	SO ₃	Al ₂ O ₃	LOI	Fe ₂ O ₃
%	2.87	55.43	5.21	0.75	26.91	3.55	5.28

Fine aggregates

Fine aggregates are defined as material that can pass through a sieve with a 4.75 mm opening. As a fine aggregate, natural sand is often used. Sand from nature is employed for experimental work. Fine aggregates which were free of silt and clay were obtained from a nearby supplier for this experiment (Herath, 2020). The usage of various-sized sieves set up on a sieve shaker for sieve analysis are presented in Figure 3.1 and the physical features of the fine aggregates are presented in Table 3.4.

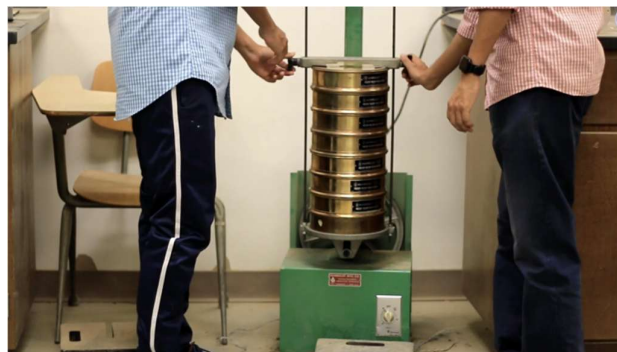


Figure 3.1: Sieve Analyses of Fine Aggregates

Coarse aggregate

The term "coarse aggregate" relates to the aggregates that are passed through an IS sieve with a 4.75 mm opening. Several different forms of coarse aggregate are possible: In addition to completely crushed gravel or rock generated by mixing the two aforementioned forms, crushed gravel or stone is produced by breaking gravel or hard stone. According to the physical properties of the various types of aggregates, crushed aggregates prefer to improve strength because of the interaction of angularity particles, at the same time rounded aggregates because of the less internal frictional force enhance the workability (Oktaviani, 2020). Coarse aggregate usually varies in size from 10 mm to 20 mm. Broken stones with a maximum size of 20 mm that were readily available nearby were employed as the coarse aggregate for the present study. Physical properties of coarse aggregate are tabulated in table 3.4 and 3.5.

Table 3.4: Characteristics of Fine Aggregate

Properties	Water absorption	Fineness Modulus	Specific gravity	Type	Grading Zone
Value	1.03%	2.55	2.6	Natural Sand	II

Table 3.5: Coarse aggregate's Physical Characteristics

Properties	Value
Shape	Angular
Specific Gravity	2.63
Colour	Grey
Max Size	20 mm

Steel Fibre

Concrete, mortars, as well as other cementitious compositions can be strengthened with Novocon URW1050 Steel Fibres. Cold drawn wires fibre named Novocon URW1050 is periodically deformed to deliver performance in a concrete mix (Prakash, 2020). Novocon URW1050 steel fibres have been developed specifically to meet the requirements for performance of European Standard EN 14889:2006.

• Benefits and Features

- Improves fracture resistance, ductility, energy absorption, or toughness of concrete through the addition of homogeneous multidirectional reinforcement.
- Develops the concrete's shear strength, fatigue resistance, and impact resistance.
- Improved ultimate load-carrying capability that could enable concrete section decrease.

- Incorporate into concrete more easily than traditional reinforcing.
- High tensile strength fibres which span joints and fissures to produce tighter aggregate interlock, increasing the ability to carry more weight.
- Provide more advanced tools for project management together with affordable reinforced concrete solutions.
- Suitable for use with manual or vibrating screeds, small screeds, and all common finishing tools.

Table 3.6: Characteristics properties of S.F.

Properties	Value
Diameter of the fibre	1.0mm
Deformation	Deformed Continuously
Length of the fibre	50mm
Aspect ratio of fibre	5
Fibre Appearance	Clean and Bright
Tensile strength of fibre	1100 MPa

4. Experimental Setup

The research study included casting and testing specimens of cubes (150 mm x 150 mm x 150 mm) with different mixes of concrete with varied proportion of fly ash while employing steel fibre quantity, in addition to beam samples (100 mm x 100 mm x 500 mm) for flexural strength as well as cylindrical specimens (150 mm x 300 mm) for tensile testing with two different types of concrete grades. Concrete specimens were tested subjected through to assess their tensile, flexural, and compressive strengths (Promsawat, 2020). The main purpose of this study is to examine the compressive, flexural, and tensile strength tests performed on two common concrete grades spanning a number of days.

Mix Proportions

Mix design is a technique that incorporates selecting suitable concrete ingredients and figuring out the proportions that need to be used in a concrete mix. The design mix utilized for this field experiment is based on the Indian Standard approach. The quantity of materials required for producing fly ash fibre reinforced concrete needs to be calculated, together with other linked parameters based on the materials' qualities. The ratios that followed were realized to produce concrete of grade M 25 and M 30 are 1:1.86:2.8:0.50 and 1:1.56:2.65:0.45 respectively. Cement, fine aggregate, coarse aggregate, water, and these ratios are used to formulate the design mix for concrete as per IS 10262.

Table 4.1: Mix Design of M 25 Grade

Material	0% FA	20% FA	25% FA	30% FA
Cement	370 kg/m ³	296 kg/m ³	277.5 kg/m ³	259 kg/m ³
Fine Aggregate	688.2 kg/m ³	688.2 kg/m ³	688.2 kg/m ³	688.2 kg/m ³
Coarse Aggregate	1036 kg/m ³	1036 kg/m ³	1036 kg/m ³	1036 kg/m ³
Water	185 kg/m ³	185 kg/m ³	185 kg/m ³	185 kg/m ³
Fly ash	-	74 kg/m ³	92.5 kg/m ³	111 kg/m ³
W/C	0.50	0.50		0.50

Table 4.2: Mix Design of M30 Grade

Material	0% FA	20% FA	25% FA	30% FA
Cement	445 kg/m ³	356 kg/m ³	333.75 kg/m ³	311.5 kg/m ³
Fine Aggregate	694.2 kg/m ³	694.2 kg/m ³	694.2 kg/m ³	694.2 kg/m ³
Coarse Aggregate	1179.25 kg/m ³	1179.25 kg/m ³	1179.25 kg/m ³	1179.25 kg/m ³
Water	200 kg/m ³	200 kg/m ³	200 kg/m ³	200 kg/m ³
Fly ash	-	89 kg/m ³	111.25 kg/m ³	133.5 kg/m ³
W/C	0.45	0.45	0.45	0.45

Fresh Concrete

To make use of a weighing devices to exactly determine each material's weight in line with the mix design. The concrete mixer has been filled with all the materials. To ensure enough mixing, cement, sand, and coarse aggregates are set in a concrete mixer and rotated dry for two minutes (Song, 2021). Water is subsequently added to the concrete mixer. Water is added after three minutes of mixing.



Figure 4.1: Concrete Mixer

Workability

In order to determine if fresh control concrete is workable, a slump cone test is used. Freshly mixed concrete is put in a slump cone and smashed with a rod in a total of three stages involving 25 blows each per each batch of concrete utilized throughout the study. The vertical distance measured from top to bottom surfaces of the original and relocated blocks of cement after removing the mould is known as the slump value.



Figure 4.2: Slump Cone Testing for assessing Workability

Curing and Casting of specimens

Three cubes of (150 mm X 150 mm X 150 mm) size are cast for every batch of concrete, based on a specific number of trial days. Fresh concrete is utilized to fill each cube, while a vibrating table is employed to eliminate voids. The test for compressive strength is carried out for seven, fourteen, and twenty-eight days. Once the specimens are allowed to dried in the normal atmospheric conditions for 24 hours, these are taken out from the moulds. These samples are subsequently promptly cured in a water tank till they reach the required ages.



Figure 4.3: Cubes & beam casting.

TESTING METHOD

Multiple cube, beam, and cylinder specimens were castes, cured and tested at young ages of 7, 14, and 28 days with the objective to examine the concrete's respective compressive, flexural, and tensile strengths. In the present research effort, the concrete is subjected to the following tests.



Figure 4.4: Testing of Cubes for Compressive Strength using UTM



Figure 4.5: Flexural Testing of specimens using UTM



Figure 4.6: Cylinders undergoing split tensile test and curing

5. RESULTS AND DISCUSSION

Workability

A slump test in line with IS 1199: 1959 is performed to check whether the concrete is workable or not with fibre reinforcement. Table 5.1 includes an overview of both the mixture's composition of materials and the outcomes of the slump test for grade M 25 concrete having 20%, 25%, and 30% of fly ash and 1%, 1.5%, and 2% steel fibres, correspondingly. As the quantity of steel fibres grows, the slump value decreases with the highest value at 1% SF.

Table 5.1: Workability of M 25 FA concrete reinforced with SF

Mix Type M-25 (FA% & S.F.%)	Cement (kg/m ³)	FA (kg/m ³)	Coarse Aggregates (kg/m ³)	Fine Aggregates (kg/m ³)	W/C Ratio	Slump Value, mm
20% & 1%	296	74	1036	688.2	0.5	39
20% & 1.5%	296	74	1036	688.2	0.5	34
20% & 2 %	296	74	1036	688.2	0.5	32
25% & 1%	277.5	92.5	1036	688.2	0.5	41
25% & 1.5%	277.5	92.5	1036	688.2	0.5	39
25% & 2 %	277.5	92.5	1036	688.2	0.5	37
30% & 1%	259	111	1036	688.2	0.5	48
30% & 1.5%	259	111	1036	688.2	0.5	45
30% & 2 %	259	111	1036	688.2	0.5	42

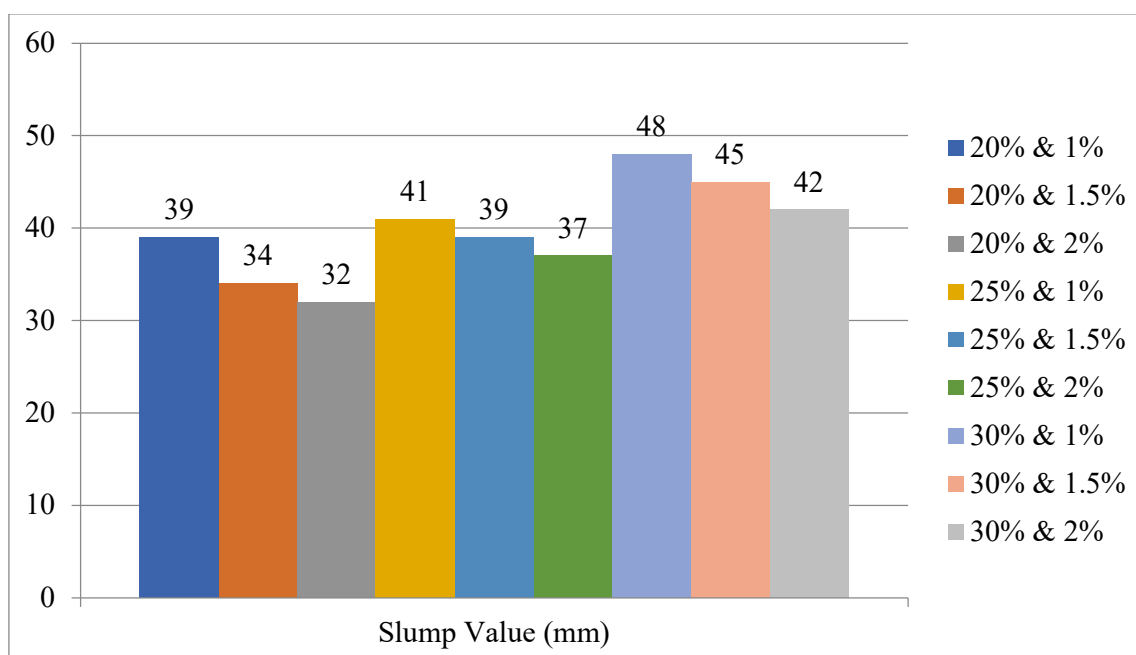


Figure 5.1: Workability of M 25 Steel Fibre Reinforced Fly Ash Concrete

Table 5.2 presents an overview of both the mixture's composition of materials and the outcomes of the slump analysis for grade M 30 concrete that included 20%, 25%, and 30% fly ash and 1%, 1.5%, and 2% steel fibres, accordingly. As the quantity of steel fibres grows, the slump value decreases with the highest value at 1% SF.

Table 5.2: Workability of M 30 FA concrete reinforced with SF

Mix Type M-30 (FA % & S.F.%)	Cement (kg/m ³)	FA (kg/m ³)	Coarse Aggregates (kg/m ³)	Fine Aggregates (kg/m ³)	W/C Ratio	Slump Value, mm
20% & 1%	356	89	1179.25	694.2	0.45	44.5
20% & 1.5%	356	89	1179.25	694.2	0.45	41
20% & 2 %	356	89	1179.25	694.2	0.45	38.5
25% & 1%	333.75	111.25	1179.25	694.2	0.45	47
25% & 1.5%	333.75	111.25	1179.25	694.2	0.45	43
25% & 2 %	333.75	111.25	1179.25	694.2	0.45	40.5
30% & 1%	311.5	133.5	1179.25	694.2	0.45	49
30% & 1.5%	311.5	133.5	1179.25	694.2	0.45	45.5
30% & 2 %	311.5	133.5	1179.25	694.2	0.45	43

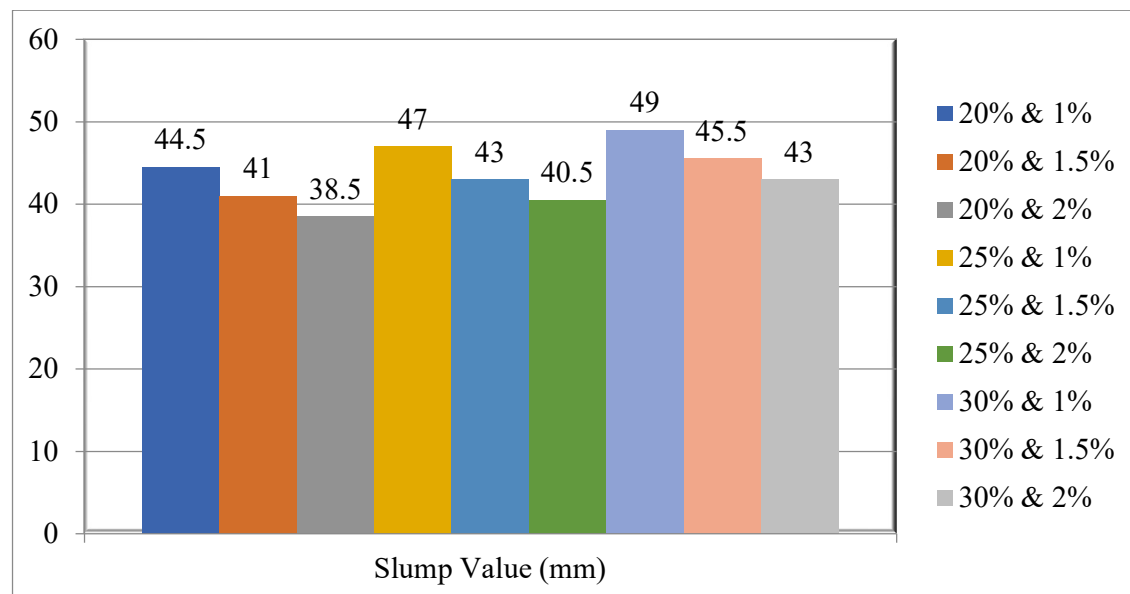


Figure 5.2: Workability of M 30 Steel Fibre Reinforced Fly Ash Concrete

5.1 COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength of various FA compositions incorporated into concrete and FA fibre reinforced concrete has been estimated by conducting a compressive testing that complies with IS 516: 1959. Tables 5.3 list the compressive strengths of concrete produced with plain concrete, FA, and concrete reinforced with steel fibres. Figures 5.3 to 5.4 show line diagrams relating the FA and steel fibre percentage vs. strength at compression. The compressive strength

test's results are shown in Figure 5.3, and stronger results are achieved when 1% of steel fibres are mixed with 20% FA.

Figure 5.3 shows the outcomes of the compressive strength test, indicating improved strength when employing 1% steel fibres and 30% FA and in case of 25% replacement with FA the maximum value is achieved at 2% S.F as shown in figure 5.4. The comparative analysis between various variations of steel fibres and FA for concrete of the M-25 grade is shown in Figures 5.3–5.8.

Table 5.3: Compressive Strength Results of M 25 Grade

Duration n (Days)	Compressive Strength in N/mm ²									
	Design Mix	20% FA			25% FA			30% FA		
		1% SF	1.5% SF	2% SF	1% SF	1.5% SF	2% SF	1% SF	1.5% SF	2% SF
7	16.25	15.5	15	14.25	15.85	15.20	14.82	18.75	17.25	15.75
14	22.0	21.68	20.75	20.10	22.75	22.25	21.25	23.05	22.30	21.50
28	33.75	32.80	31.56	32.05	32.85	33.15	33.50	34.70	33.64	33.82

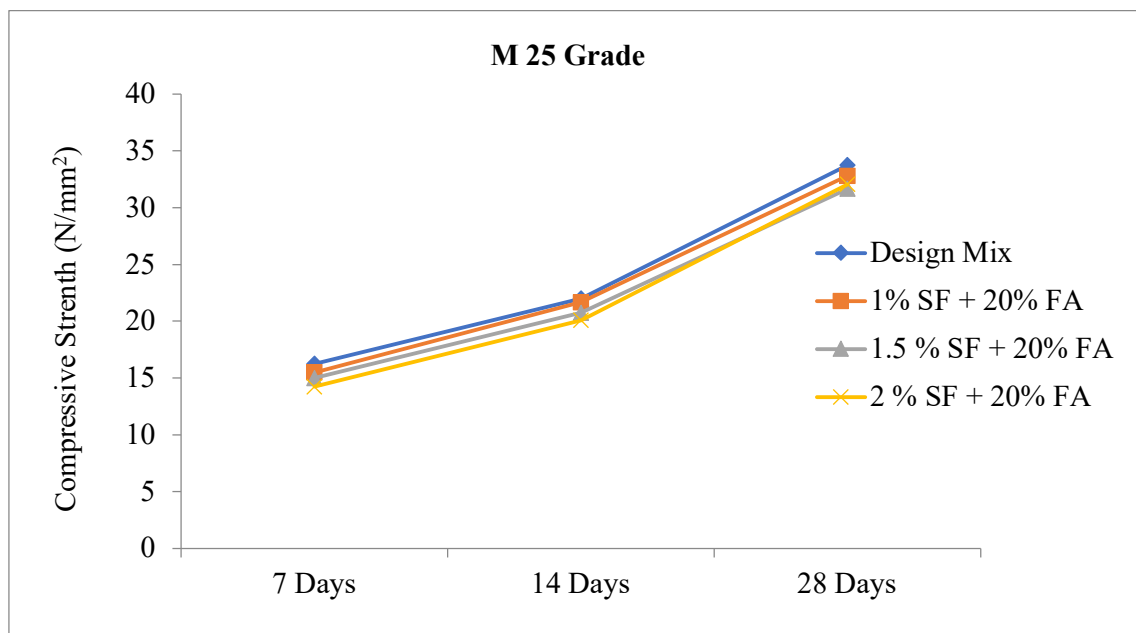


Figure 5.3: Concrete Compressive test results utilizing 20% FA and various percentages of SF

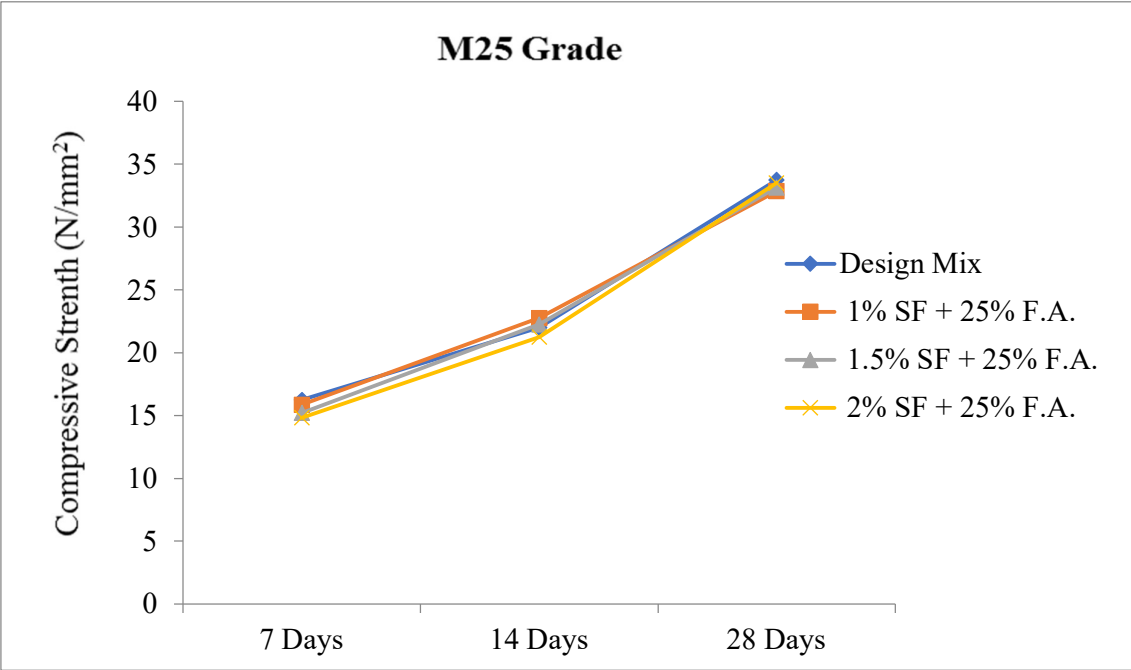


Figure 5.4: Concrete Compressive strength results utilizing 25% FA and numerous percentages of SF

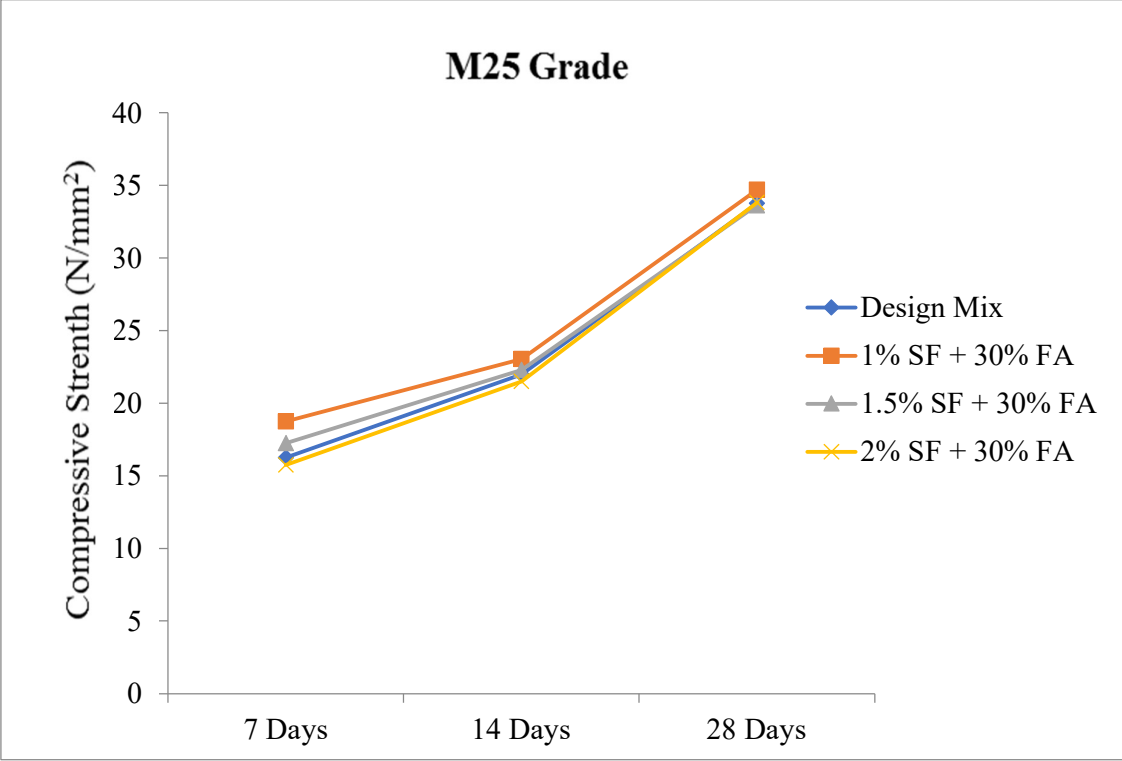


Figure 5.5: Concrete Compressive strength results utilizing 30% FA and various percentages of SF

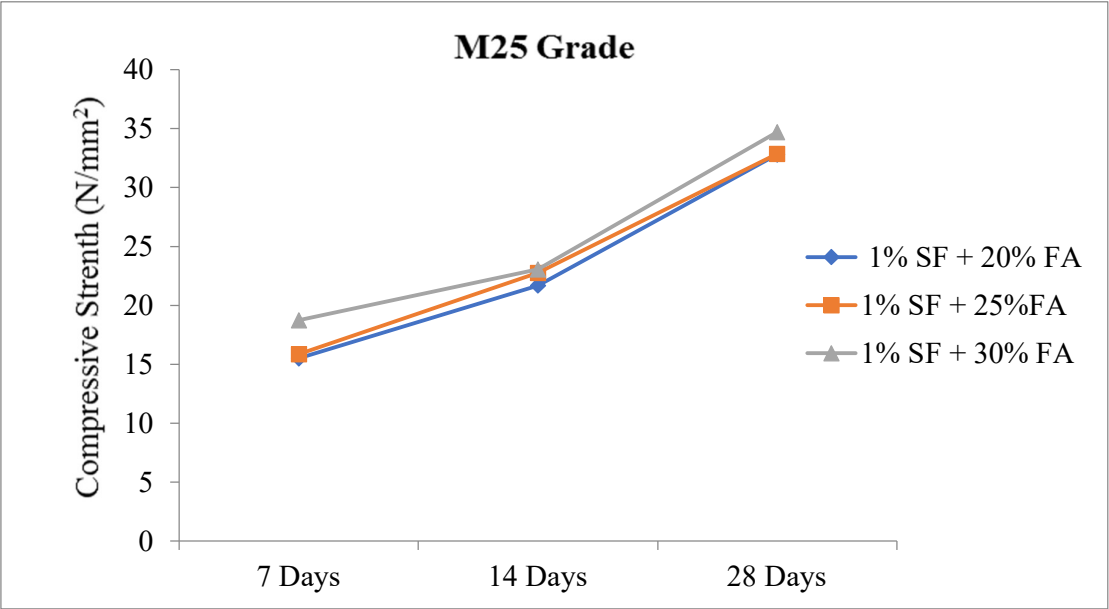


Figure 5.6: Comparative study of compressive strength of concrete with 1 % SF and different dosages of FA

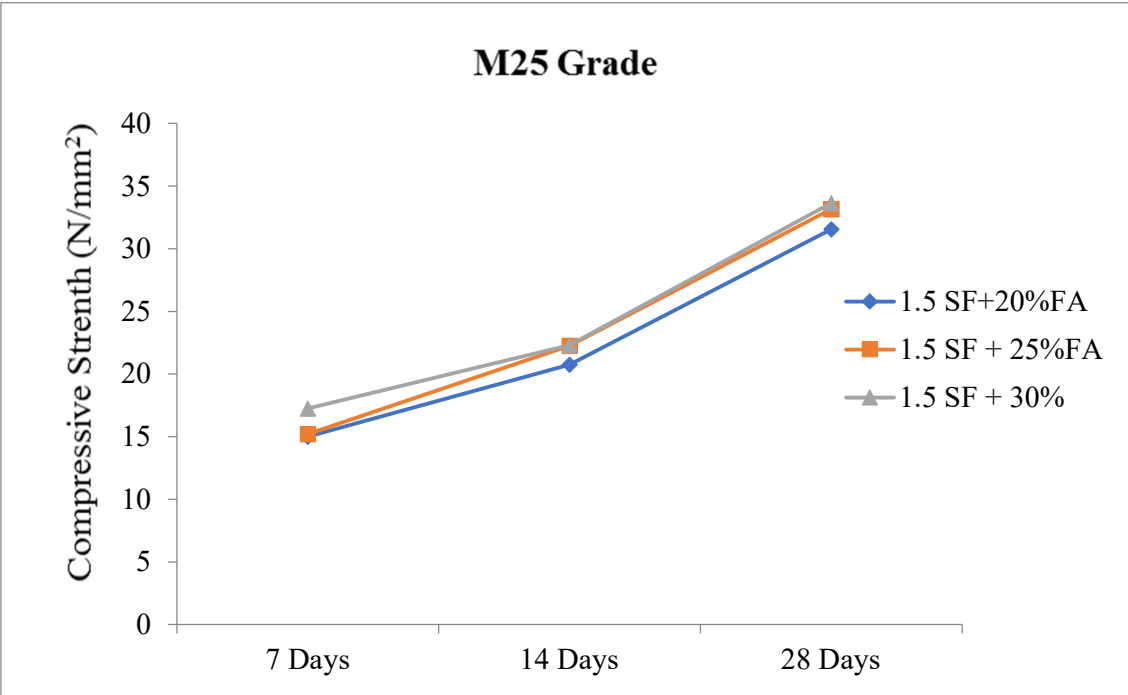


Figure 5.7: Comparative study of compressive strength of concrete with 1.5 % SF and different dosages of FA

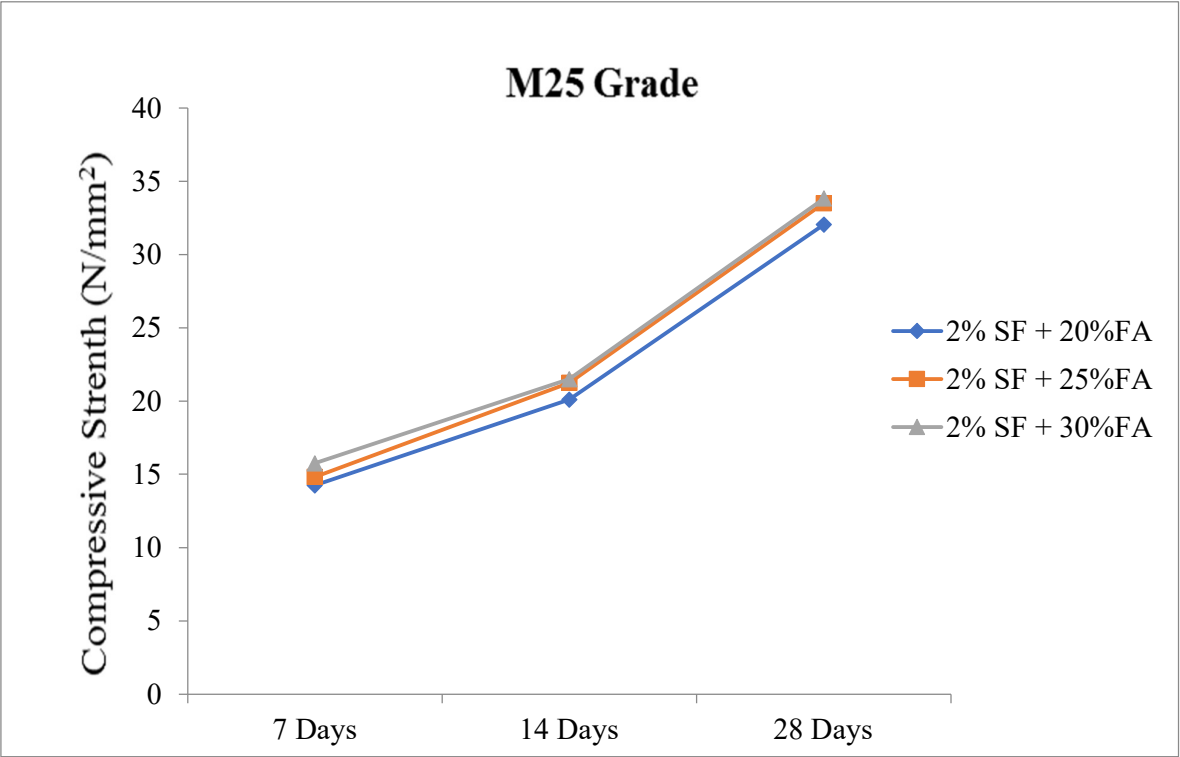


Figure 5.8: Comparative study of compressive strength of concrete with 2 % SF and different dosages of FA

Table 5.4: Compressive Test results of M 30 Grade

Duration (Days)	Compressive Strength in N/mm ²									
	Design Mix	20% FA			25% FA			30% FA		
		1% SF	1.5% SF	2% SF	1% SF	1.5% SF	2% SF	1% SF	1.5% SF	2% SF
7	25.41	24.72	24.05	22.10	26.10	24.91	23.05	27.80	25.50	26.30
14	32.72	31.85	31.10	30.62	32.83	32.0	31.25	34.05	32.25	31.62
28	36.96	35.71	34.16	33.0	37.25	35.35	32.50	39.25	37.62	35.10

The compressive strength test results are shown in Figure 5.9, and stronger results are obtained when 1% SF and 20% FA are added to the concrete mix.

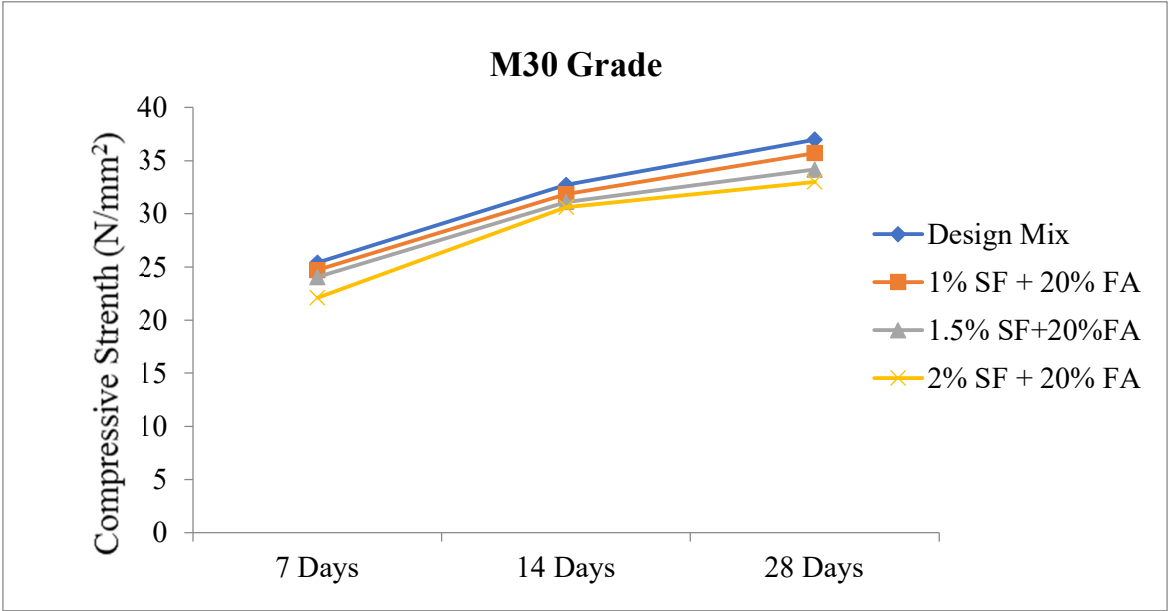


Figure 5.9: Concrete Compressive test results utilizing 20% FA and various percentages of SF

When 1% of steel fibres are used with 25% or 30% FA, respectively, the compressive strength test results shown in Figures 5.10 and 5.11 demonstrate stronger results. Only the comparative analysis between various variations of steel fibres and FA for concrete of the M 30 grade is shown in Figures 5.12–5.14.

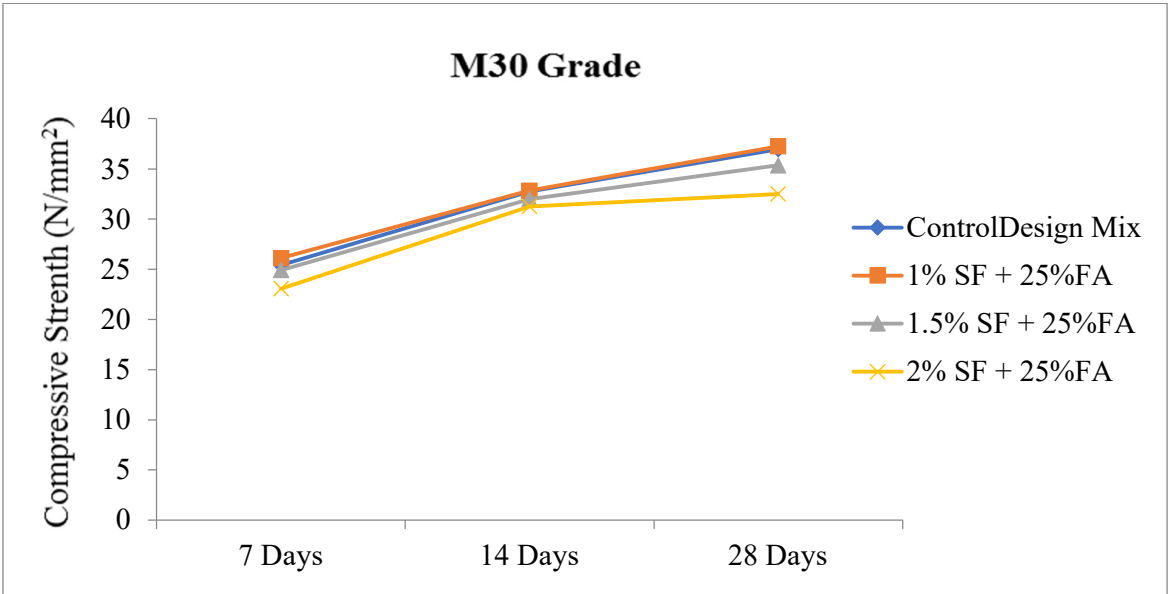


Figure 5.10: Concrete Compressive strength results utilizing 25% FA and various percentages of SF

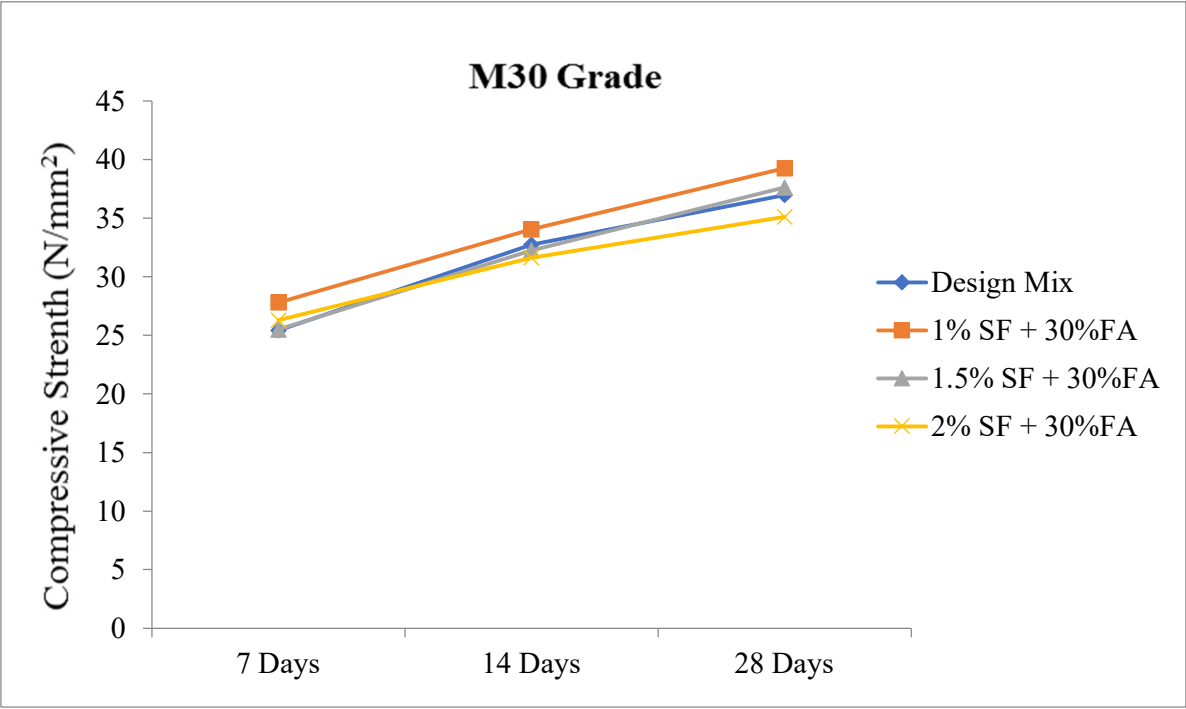


Figure 5.11: Concrete Compressive test results utilizing 30% FA and various percentages of SF

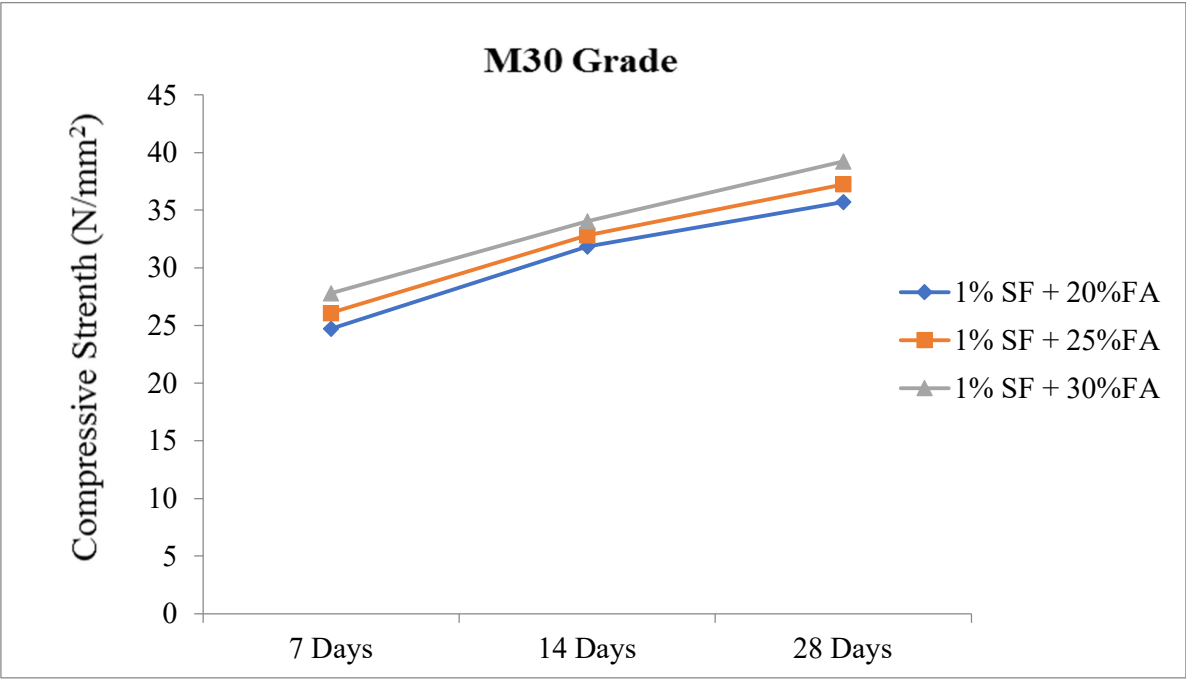


Figure 5.12: Comparative study of compressive strength of concrete with 1 % SF and different dosages of FA

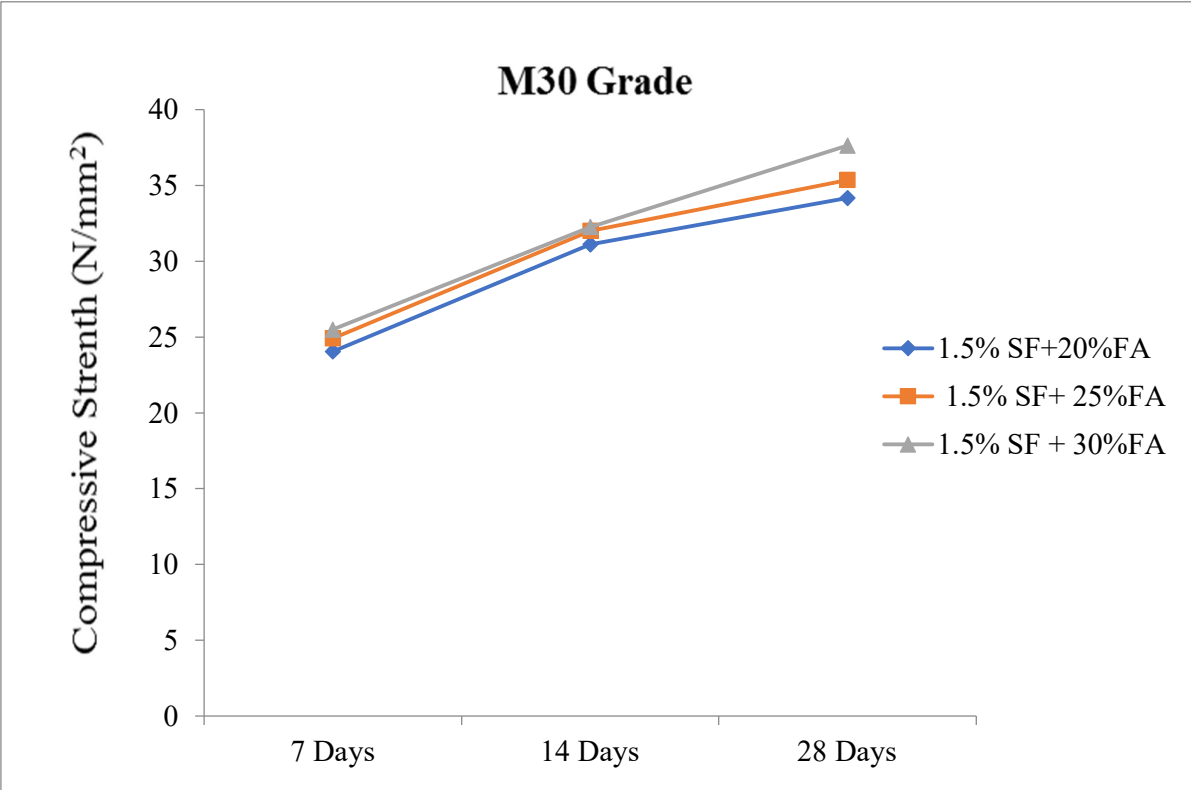


Figure 5.13: Comparative study of compressive strength of concrete with 1.5 % SF and different dosages of FA

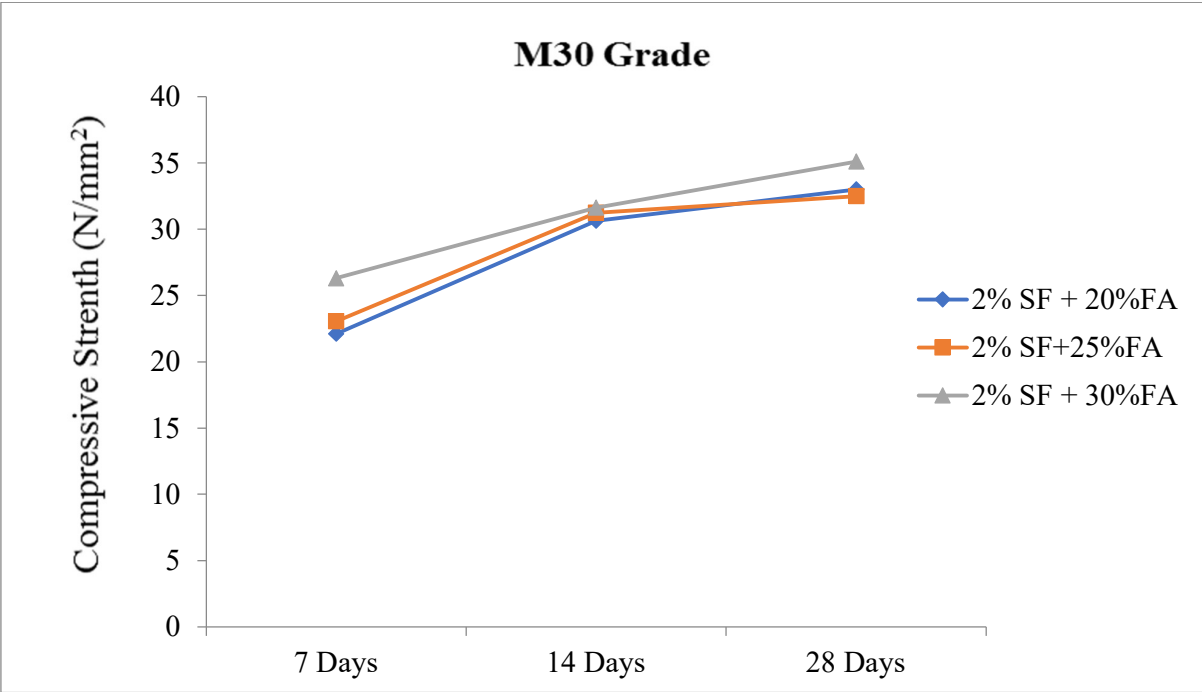


Figure 5.14: Comparative study of compressive strength of concrete with 2 % SF and different dosages of FA

Flexural Strength

Table 5.5: Results of flexural strength for M 25 Grade

Duration (Days)	Flexural Strength (N/mm ²)									
	Control Mix	20% FA			25 FA			30% FA		
		1% SF	1.5% SF	2% SF	1% SF	1.5% SF	2% SF	1% SF	1.5% SF	2% SF
7	15	14.5	13.25	13.375	14.85	14.70	14.40	15.35	14.25	15.05
14	15.50	15.275	14.875	14.50	15.25	15.05	15.25	16.05	16.25	15.95
28	15.875	17	16.50	15.30	17.25	16.85	16.0	17.35	17.10	16.85

Figure 5.15 shows the flexural strength evaluation results, that are stronger when 1% steel fibres are mixed with 25% and 30% FA respectively for M 25 grade.

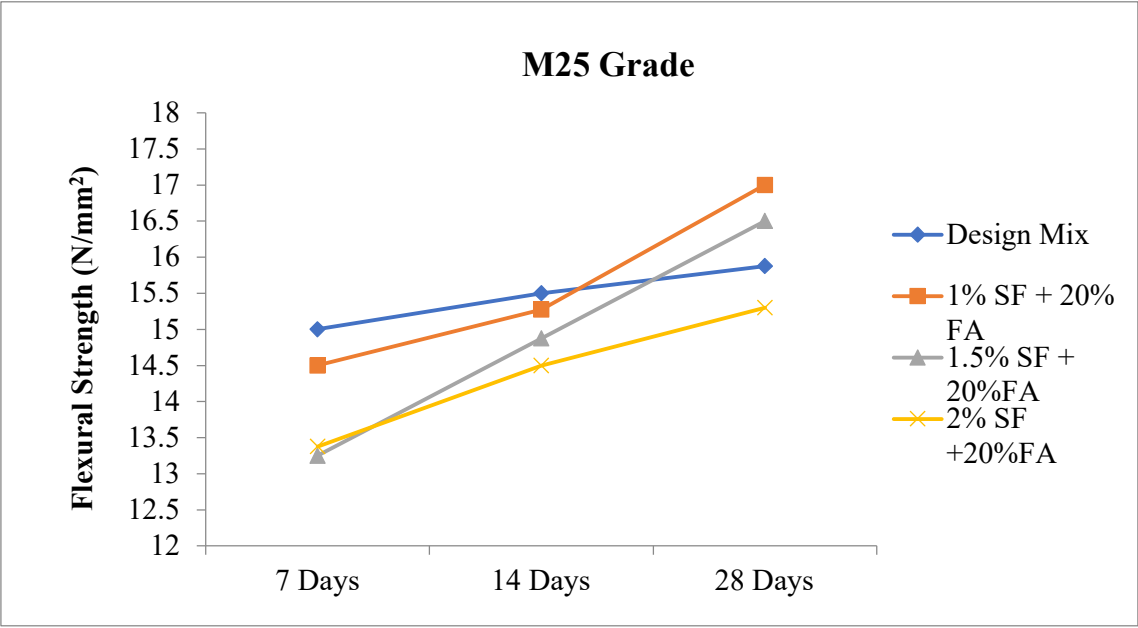


Figure 5.15: Test Result for Flexural strength with 20% FA and different dosages of SF

As long as concrete's brittleness remains a concern, exploring the effects of steel fibre combined with fly ash (FA) may continue to prove valuable. The key findings derived from the research study are as follows:

- The workability of concrete is enhanced on replacement of cement with 30% FA in both the Grades of Concrete.
- The compressive property of FA steel fibre concrete can be enhanced through the use of FA as a thirty percent substitute for cement.
- For M 25 grade concrete, the compressive strength of FA-SF concrete is most effective at 20%, 25%, and 30% cement replacement with FA combined with 1% steel fibre (SF) (Chu, 2021). However, at 20% cement replacement, the optimum strength is achieved with 1.5% steel fibre content.
- The compressive property of FS and SF concrete obtained at 20%, 25%, as well as 30% replacement of cement with FA with the inclusion of SF at 1% is maximum for the grade M30 of concrete amongst all substitutions of FA with SF (1%, 1.5%, and 2%).
- Concrete built with steel fibres and FA has a higher tensile strength when FA is used as a 30% replacement for cement. The FA steel fibre concrete's tensile strength was attained after replacing FA (20%, 25% and 30%) with SF (1%, 1.5%, and 2%).
- The replacement of FA (20%) with steel fibre (1%) results in an optimal tensile strength of 2.75 N/mm² and 3.60 N/mm² in the case of M25 and M30 grade of concrete respectively which is consistent with the compressive test results (Nayak, 2021).
- The maximum flexural strength was achieved at 30% cement replacement with fly ash (FA) and 2% steel fibre (SF) reinforcement, reaching approximately 17.35 N/mm² for M25 grade and 18.55 N/mm² for M 30 grade concrete.

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IS Codes

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2. IS 875 (part 1) “India standard code of practice for design loads (other than earthquake loads) for building and structures.
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4. IS 875 (part 3):2015 “India standard code of practice for design loads (other than earthquake loads) for building and structures.
5. IS 456:2000 “Indian standard plain and reinforced concrete-Code of practice” Bureau of Indian standard, New Delhi.