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Mechanical Properties of Fiber Reinforced Self Curing Concrete Incorporating Polyethylene Glycol-600

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Abstract: As described by the American Concrete Institute (2010), self-curing concrete functions by dispersing water throughout a freshly poured cementitious mixture. This is achieved through reservoirs that readily release water to support hydration or replace moisture lost through evaporation or self-desiccation. Because self-curing concrete has an innate weakness in withstanding tensile pressures, it is prone to breaking under modest amounts of tension. Concrete's overall mechanical performance can be improved by combining fibers in the right way, creating performance synergy. The key elements influencing the mechanical properties of fiber-reinforced concrete are the fibers' geometric size and modulus. This study investigates how adding polyethylene glycol-600 (PEG-600) as a self-curing agent enhances the characteristics of fiber-reinforced self-curing concrete. The strength properties of concrete reinforced with steel fibers and having a self-curing agent were examined in this experimental investigation and contrasted with those of a typical nominal mix. The mix design was done using the IS approach. Compressive strength, split tensile strength, flexural strength, and modulus of elasticity were among the characteristics evaluated in the study. The ideal percentage of fiber addition was determined by the results.

Keywords: Fiber Reinforced Self Curing Concrete, Poly Ethylene Glycol, Compressive strength, Split tensile strength, Flexural strength, Modulus of elasticity

1. INTRODUCTION

Concrete can be molded into a wide variety of forms and sizes, which is why it is used so frequently in construction. Reaching the appropriate strength is essential for its efficient application, which mostly depends on the cement mortar hydrating. Sustained strength development is ensured by constant hydration, which is made possible by curing [1]. External and internal curing are the most often utilized curing techniques. Internal curing, also known as self-curing, adds moisture to the concrete, improving cement hydration and decreasing self-desiccation.

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"Internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water," said the ACI 308 committee [2]. An important development in concrete building has been the discovery that water-soluble polymers are efficient self-curing agents in concrete. When concrete with polyethylene glycol (PEG) added as a self-curing agent was compared to other curing agents, research by M.I. Mousa et al. (2014) showed that the concrete had better mechanical qualities [3].

PEG usually improves the concrete's ability to retain water by lowering the surface tension of the mixing water and evaporation [4]. Improved hydration, stronger development, decreased autogenous shrinkage, higher durability, and decreased cracking and permeability are some advantages of internal curing. These advantages start to show up two or three days after the cement first hydrates [1]. Concrete's intrinsic weakness in resisting tensile forces makes it prone to breaking under modest tensile stress, despite its many positive qualities. Fibers aid to prevent cracks caused by drying shrinkage and plastic, and they also increase tensile strength, impact resistance, durability, and fracture toughness when added to the concrete mix [5].

1.1 Self-Curing Concrete

Curing is a process that controls temperature and moisture to aid in cement hydration and manage moisture movement within and outside the concrete. The two main types of curing methods are water-retaining and water-adding techniques [6]. However, the concept of self-curing was developed and is now applied to address various challenges encountered with traditional curing methods.

1.1.1 Self-Curing Principle and Mechanism

Due to the differential in chemical potentials between the vapor and liquid phases, moisture evaporation from an exposed surface occurs continuously. In a blended cement system, the full reaction of the mineral admixtures might result in a substantially higher need for external or internal curing water compared to regular standard Portland cement concrete [8]. There may be considerable autogenous deformation and early-age cracking if this water is not easily accessible. The cement paste develops empty holes as a result of the chemical shrinkage that takes place during cement hydration. This shrinkage may result in early-age cracking as well as a decrease in the paste's internal relative humidity. Concrete voids that develop within the material affect the cement hydration process' kinetics and ultimately restrict the amount of hydration that occurs [1]. The rate at which continuous chemical shrinkage must be satisfied cannot be met by externally supplying water from the top surface for curing. A decrease in the vapor pressure is caused by the polymers added to the mixture, which primarily form hydrogen bonds with water molecules and lower their chemical potential [9]. Water is retained in the concrete because the use of polyethylene-glycol decreases water evaporation from the surface.

1.1.2 Polyethylene-Glycol

Polyethylene glycol (PEG) is known by different names depending on its molecular weight, including polyethylene oxide (PEO) and Polyoxyethylene (POE). Its general structure follows the formula $H(OCH_2CH_2)nOH$, where "n" represents the average number of repeating Oxyethylene groups, typically ranging from 4 to approximately 180. The abbreviation "PEG" is followed by a numeric suffix indicating the average molecular weight. Low molecular weight forms, with n=2 to n=4, correspond to specific molecules such as diethylene glycol, Triethylene glycol, and Tetraethylene glycol. Polyethylene glycols typically range in molecular weight from 200 to 8000 g/mol. Higher molecular weight PEGs, above 1000, are waxy solids with melting points reaching 67°C, while lower molecular weight versions, up to 700 g/mol, are colorless, odorless, viscous liquids with freezing points as low as -10°C (as in diethylene glycol). A common characteristic of PEG is its solubility in water, as well as its ability to dissolve in many organic solvents, particularly aromatic hydrocarbons. It is widely used in pharmaceutical and medical products as a solvent, dispersing agent, ointment, suppository base, vehicle, and tablet excipient. PEG is non-toxic, odorless, neutral, lubricating, non-volatile, and non-irritating. In this study, PEG-600 was used as the self-curing agent, with its properties summarized in Table 1.

Table 1. Properties of PEG-600

Sl.No	Description	Property
1	Molecular weight	600g/mol
2	Appearance	Clear fluid
3	Moisture	0.2%
4	pH	6
5	Specific gravity	1.13
6	Refractive index	n20/D 1.469
7	Vapor pressure	<0.01mmHg

1.2 Fiber Reinforced Concrete (FRC)

According to ACI 116R, Cement and Concrete Terminology, fiber-reinforced concrete (FRC) is described as concrete that has randomly oriented fibers divided throughout it [10]. Fibers are typically added to concrete to prevent shrinkage and plastic from occurring during drying. They also lessen water seepage and concrete permeability. Because of the intrinsic internal microcracks in the concrete, which eventually cause brittle fracture of the material, the concrete has a low tensile strength [3].

Tensile strength is increased by the usage of reinforcing bars. Furthermore, fibers can increase the homogeneity of the concrete and enhance its tensile response, especially its ductility. The characteristics of the fiber and the concrete affect the FRC's performance and character. Fiber is frequently defined by the useful metric known as aspect ratio. The fiber's length to diameter ratio is known as its aspect ratio. Aspect ratios often fall between 30 and 150. Increasing l/d ratios (where l is the fiber's length and d is its diameter) increases the likelihood of the fibers' heterogeneous dispersion and flocculation in the concrete mix. Comparably, concrete's workability is more significantly impacted by volume percent. According to ACI 544.3R-93, the ideal volume percentage for concrete mixes is between 0.25% and 2% by volume of concrete. More than 2% of fiber was shown to be inefficient and to cause the fibers to ball up, making the dosage unworkable [12]. The orientation of fibers per unit cross sectional area is somewhat more associated with the tensile strength ratio of fibrous to plain matrix.

2. METHODOLOGY

The following methodology was used for the current experimental investigation:

2.1 Selection of Materials

The materials used for the work include,

a) **Ordinary Portland Cement (53 grade):** A 53-grade Ordinary Portland Cement conforming to IS: 12269-2013 was used in this study [18]. Its properties, including initial setting time, standard consistency, specific gravity, and fineness modulus, were determined as per IS 4031:1988 [19, 20, 21, 22, 23].

b) **Coarse Aggregate:** Coarse aggregate with a size of 20 mm, compliant with IS: 383-1970, was employed. The characteristics of the coarse aggregate, such as specific gravity, fineness modulus, and water absorption, were measured according to IS 2386: 1963 [23,24], parts I and II.

c) **Fine Aggregate:** Manufactured sand was used as the fine aggregate in this investigation. Oversized particles were removed through screening, and zone II-compliant fine aggregate, as per IS: 383-1970, was used [25].

d) **Water:** Potable water was used for mixing. The strength of cement concrete primarily depends on the binding power of the hydrated cement gel. Only the amount of water required for the chemical reaction of unhydrated cement should be used; excess water creates unwanted voids in the hardened cement paste.

e) **Superplasticizer:** Ceraplast 300, a product from Cera Chem Pvt. Ltd., was used as a superplasticizer to enhance performance. After several trials and flow measurements, a dosage of 2.5% of the cement weight was determined to be optimal.

f) **Polyethylene Glycol (PEG-600):** PEG 600, a polymer with an average molecular weight of 600, was used in the experimental program. It is a transparent liquid with water-soluble properties.

g) **Hooked End Steel Fiber:** Hooked end steel fibers with a length of 50 mm, a diameter of 1 mm, and an aspect ratio of 50 were utilized. The properties of the selected materials are listed in Table 2.

Table 2. Material properties

Materials	Properties	Values
Cement	Specific gravity	3.125
	Standard consistency	30%
	Initial setting time	120min
	Fineness modulus	5%
Coarse Aggregate	Specific gravity	2.74
	Water absorption	0.8%
Fine Aggregate	Specific gravity	2.605
	Fineness modulus	2.8
PEG-600	Specific gravity	1.13
Super plasticizer	Specific gravity	1.2
Hooked end steel fiber	Tensile strength	1250 MPa
	Youngs modulus	210GPa
	Density	0.6 – 1.1 gm/cm^2
	Aspect ratio	50

2.2 Mix Proportioning

Trials were conducted in accordance with IS 10262:2009[26], IS 383:1970, and IS 456:2000[27] to determine the mix proportioning. The final mix was determined based on the specified requirements for M50 concrete, incorporating 1.5% PEG by weight of cement, ensuring a workability within a 150 mm slump. Previous research has demonstrated that 1.5% PEG addition to self-curing concrete results in improved and improved characteristics. As a result, it was regarded as a nominal blend in the research. Table 3 displays the planned mix fraction and the materials used for the mix.

Table 3. Mix proportion of materials per m³

Details of mix	Grade – M50
Designed mix proportion	1:1.28:2.45
Cement content	437.57kg/m^3
Fine aggregate content	613.26kg
Coarse aggregate content	1174kg
Water cement ratio	0.33
Amount of water	144.39ml
PEG	1.5% by weight of cement

2.3 Preparation of Specimen

The preparation of molds, materials, weighing, and casting of cubes, beams, and cylinders were carried out in accordance with IS 10086:1982 [28]. Cubes (150×150×150 mm), beams (100×100×500 mm), and cylinders (300×150 mm) were cast to evaluate the modulus of elasticity, splitting tensile strength, compressive strength, and flexural strength of the mixes. The specimen nomenclature used for identification is shown in Table 4.

Table 4. Mix designation for specimen

Specimen	Description
P15	1.5% PEG specimen
F05	Sample containing 0.5% of steel fiber
F10	Sample containing 1.0% of steel fiber
F15	Sample containing 1.5% of steel fiber
F20	Sample containing 2.0% of steel fiber

3. TESTING OUTCOMES AND COMMENTS

3.1 Compressive Strength Test

Fibers in varying percentages of 0.5%, 1.0%, 1.5%, and 2% were incorporated into the self-curing concrete. Cube specimens measuring 150 mm by 150 mm by 150 mm were subjected to a compression test using a machine that complies with IS 516: 1959 [29]. The surfaces of the specimens were cleaned of sand and debris, and the bearing surface of the machine was thoroughly prepared. The specimen was positioned in the machine so that, contrary to the arrangement shown in Figure 1, the load was applied to the opposing faces of the cubes. The load was gradually increased at a consistent rate until the specimen could no longer withstand the rising load and failed. The maximum load applied to the specimen was recorded. Compressive strength is calculated by the Equation (1),

$$\sigma c = P/A \tag{1}$$

Where P denotes the highest load.
A is the cross-sectional area

Figure 1. Compression test on a Fiber reinforced self-curing concrete cube

The test results for fiber-reinforced self-curing concrete cured for seven (7) and twenty-eight (28) days are presented in Table 5. On the seventh day, the nominal mix containing 1.5% PEG exhibited a compressive strength of 42.97 N/mm², which increased to 59.03 N/mm² by the twenty-eighth day. Experiments on fiber-reinforced self-curing concrete indicate that the compressive strength increases with higher fiber content. The fibers help mitigate fractures by evenly distributing the stresses resulting from compression, shrinkage, and the inherent tendency of concrete to crack. Consequently, steel fibers enhance the load-bearing capacity of the structures. The optimal compressive strength for self-curing concrete reinforced with fibers is achieved at 2% fiber content. Notably, the compressive strength of fiber-reinforced self-curing concrete was 5.42% greater than that of self-cured concrete. Figure 2 illustrates the variation in compressive strength for fiber-reinforced self-curing concrete.

Table 5. Compressive strength of fiber-reinforced self-curing concrete on days seven and twenty-eight

Specimen	7th day compressive Strength (N/mm²)	28th day compressive Strength (N/mm²)
F05	36.88	56.35
F10	39.02	57.13
F15	42.49	59.14
F20	45.59	62.23

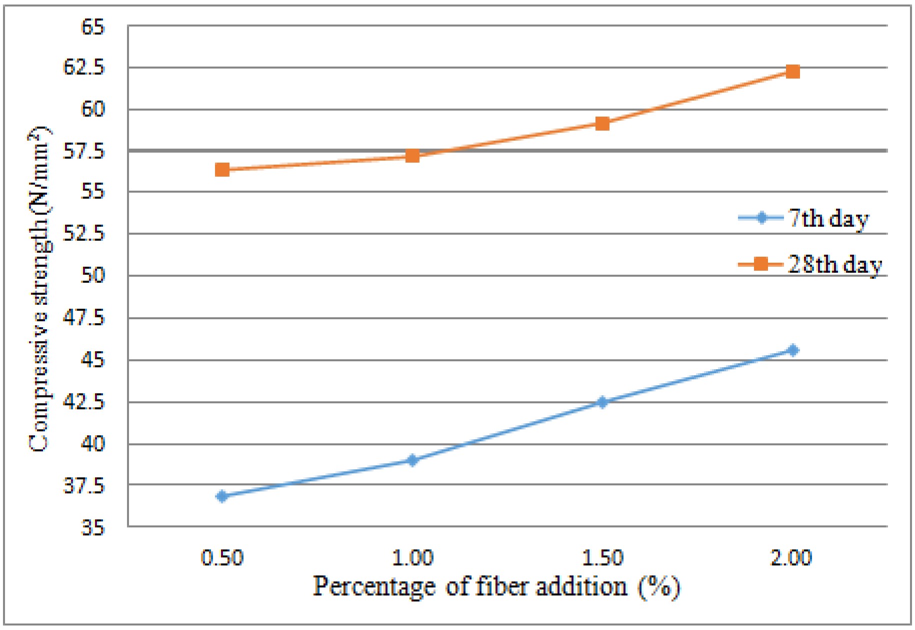

Figure 2. Impact of different steel fiber inclusion percentages on self-curing concrete's compressive strength

3.2 Split Tensile Strength

As per IS 5816:1999 [30], the Split Tensile Strength Test was conducted on cylindrical specimens measuring 150 mm in diameter and 300 mm in length. Specimens were cast for each concrete mix percentage and tested using a universal testing machine after seven and twenty-eight days. The results are presented in Figure 3.

Figure 3. Split tensile test configuration for self-curing fiber-reinforced concrete.

The cylinder was loaded up until it failed along its vertical diameter. Equation (2) can be used to calculate split tensile strength by applying the maximum load to the universal testing equipment.

$$fct = \frac{2P}{\pi \mathrm{dl}} \tag{2}$$

where P is the maximum load applied to the specimen in Newtons
d = the specimen's cross-sectional dimension (in millimeters);
l = the specimen's length (in millimeters).

The cylinder's split tensile strength was examined on days seven and twenty-eight, with the test findings recorded as indicated in Table 6. On the seventh and 28th day, the nominal mix containing 1.5% of PEG had a split tensile strength of 2.34N/mm^2 and 3.86N/mm^2. As seen in Figure 4, a graph was created by linking the split tensile strength values of various percentages of steel fibers measured on the seventh and 28th day.

Table 6. Split tensile strength of fiber reinforced self-curing concrete

Specimen	7th day Split TensileStrength (N/mm^2)	28th day Split TensileStrength (N/mm^2)
F05	3.11	4.97
F10	3.24	5.17
F15	3.40	5.25
F20	3.5	5.34

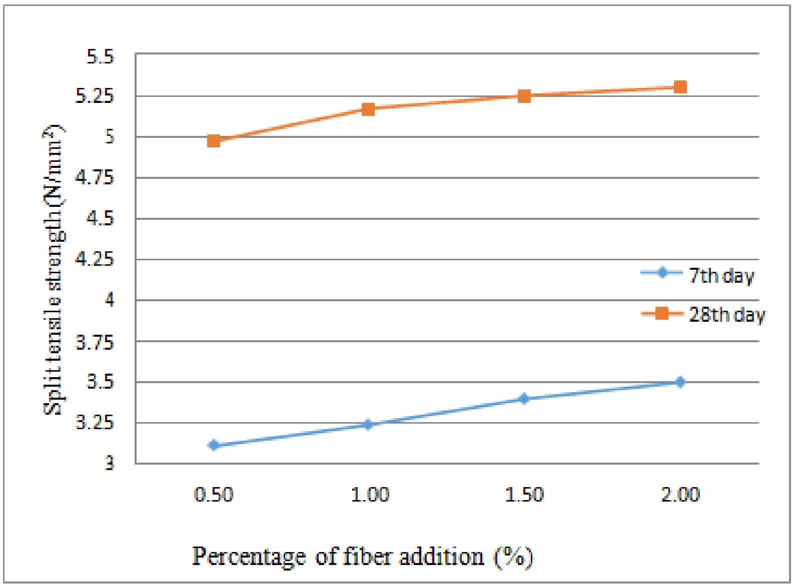

Figure 4. Split tensile strength of fiber-reinforced, self-curing concrete at days seven and twenty-eight, with different proportions of steel fiber

3.3 Research has shown that the split tensile strength of concrete can be significantly improved by incorporating fibers. It was observed that as the fiber content in concrete increases, its tensile strength also rises, with an optimal steel fiber content identified at 2%.

The fibers facilitate a stress transfer mechanism that enables the structure to bear additional weight even in the event of a failure. When the fibers deform, stress is transferred from the matrix to the fibers due to their interlocking, allowing for shared stress until the matrix ultimately fractures. At that point, the stress is gradually transferred entirely to the fibers [13]. Hook-end steel fibers are particularly effective in bonding with concrete, as they begin to take effect immediately upon being pulled out [14].

3.4 Flexural Strength

A concrete beam measuring 100 mm x 100 mm x 500 mm was employed to evaluate the material's flexural strength. Concrete beams with four different percentages of steel fibers were cast for each concrete mix proportion and tested after seven and twenty-eight days, with the crack patterns documented. A four-point flexural testing apparatus was used for the test. The experimental setup is illustrated in Figure 5. The flexural strength was calculated using Equations (3) and (4), taking into account the location of the fracture in relation to the nearest support, as depicted in Figure 6.

Figure 5. Flexural strength testing of fiber reinforced self-curing concrete

Figure 6. Crack pattern of fiber reinforced self-curing concrete after flexural test

The flexural strength is given by

$$fb = Pl/bd^2 \tag{3}$$

when $a > 13.3$ cm for 10 cm specimen, or

$$fb = 3Pa/bd^2 \tag{4}$$

when $a < 13.3$ cm but > 11.0 cm

Where, a = the separation between the fracture line and the closer support.
b = specimen's width (mm).
l = supported length (mm)
d= depth of failure point (mm)
P = maximum load (kg)

The crack pattern of the flexural beams was examined and measured, revealing that the distance from the line of fracture to the nearest support, taken along the center line of the tensile side of the specimen, was greater than 13 cm. Consequently, the flexural strength calculations were performed using the first equation. The average flexural strength of the fiber-reinforced self-cured concrete beams tested after the 7th and 28th days of curing is presented in Table 7. A graphical representation of the results can be found in Figure 7. The nominal mix containing 1.5% PEG demonstrated flexural strengths of 3.52 N/mm² and 5.37 N/mm² on the 7th and 28th days, respectively.

Table 7. Flexural strength of fiber reinforced self-curing concrete with varying percentage of steel fiber addition tested on 7th and 28th day

Specimen PEG-600	7th day flexural Strength (N/mm²)	28th day flexural Strength (N/mm²)
F05	4.51	7.46
F10	4.57	7.79
F15	4.62	7.8
F20	4.77	8.03

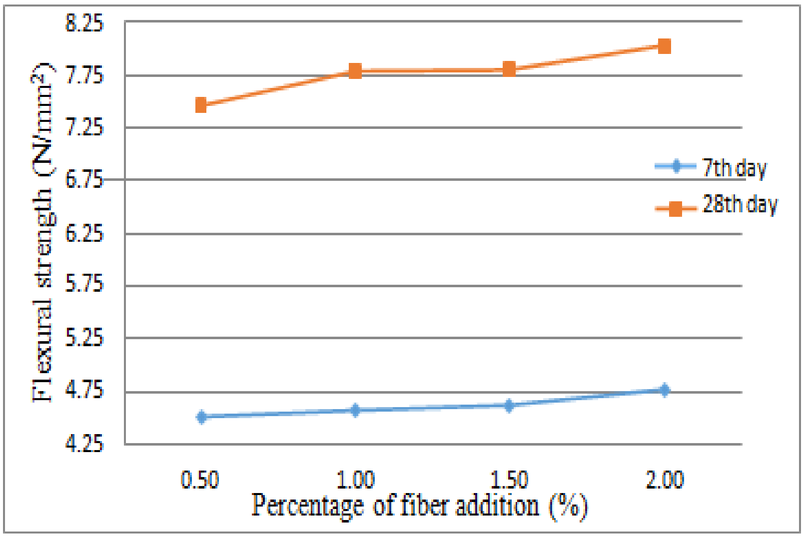

Figure 7. 7th and 28th day flexural strength of fiber reinforced self-curing concrete with varying percentage of steel fiber addition

3.5 The fibers function as crack arresters, effectively preventing the initial crack from propagating, which enhances the overall flexural strength of the structure. As steel fiber-reinforced concrete hardens, shrinks, or endures service loads, the uniformly distributed fibers within the composite intercept and halt the development of fractures, thereby improving the structure's energy absorption capacity. Higher fiber dosages greatly enhance the material's response to cracking [15]. Following the initial crack, the concrete's residual strength also increases. The inclusion of hooked-end steel fibers has improved both the pull-out resistance and toughness of the concrete. However, exceeding a fiber content of 2% was found to be ineffective, as it caused the fibers to clump together, rendering the dosage impractical [12].

3.6 Modulus of Elasticity

The modulus of elasticity of concrete is a crucial parameter for structural analysis, as it is essential for determining strain distributions and displacements, especially when the design of the structure is based on elasticity considerations. A cylinder measuring 150 mm in diameter and 300 mm in length was utilized for the test. For the 28-day evaluation, cylindrical specimens with four different proportions of steel fibers were cast. The experimental test setup is illustrated in Figure 8. A stress-strain graph was generated using the data collected from each concrete cylinder under load, as shown in Figure 9. In this graph, the strain and stress values are plotted on the X and Y axes, respectively. A linear line connecting the maximum points is drawn, and the slope of this line represents the modulus of elasticity. A steeper slope indicates a lower modulus of elasticity.

Figure 8. Modulus of elasticity test set up of self-curing concrete

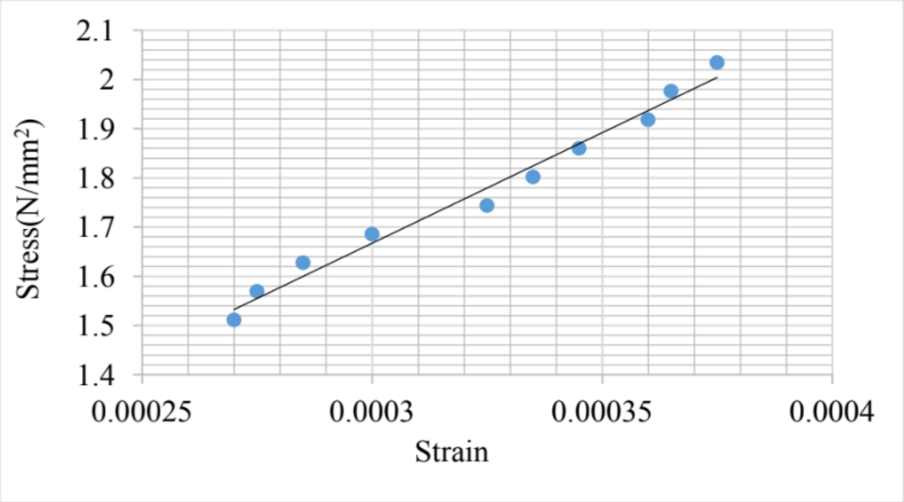

Figure 9. Stress strain graph of 2% of fiber reinforced self curing concrete

Table 8. Modulus of elasticity of fiber reinforced self-curing concrete with varying percentage of fiber addition

Specimen	Modulus of elasticity (GPa)
F05	38.75
F10	39.62
F15	40.4
F20	42.13

Figure 10 displays the values obtained for the fiber-reinforced self-curing concrete graphically. The graph makes it evident that the modulus of elasticity tends to increase as the amount of fiber added to the concrete increases. It was shown that when compared to other percentages, concrete containing 2% steel fiber addition typically had a greater modulus of elasticity. On the 28th day, the nominal mix containing 1.5% PEG displayed an elasticity modulus of 38.54 GPa.

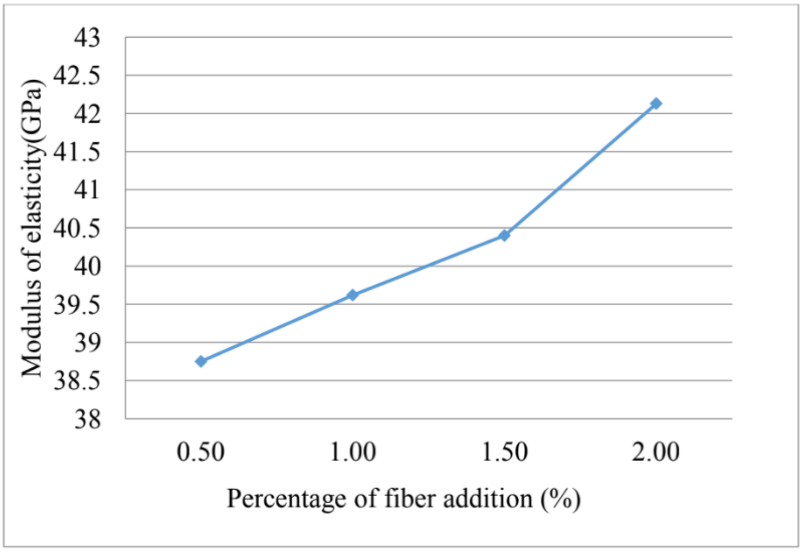

Figure 10. Modulus of elasticity of fiber-reinforced self-curing concrete with different fiber addition percentages

The increased modulus of elasticity observed in fiber-reinforced self-curing concrete suggests that steel fiber doses can absorb more stress. The addition of steel fibers to the mixture affects the elastic modulus of self-curing concrete, primarily influenced by two factors: fiber volume and stiffness [16]. Steel fibers have a higher modulus of elasticity compared to other types of fibers and help prevent shrinkage cracks, resulting in fewer initial shrinkage issues. This may explain why the modulus of elasticity tends to increase with higher fiber content. When steel fibers are incorporated, concrete becomes more ductile in the event of compression failure, rather than simply enhancing compressive strength [17].

4. CONCLUSION

The building industry relies heavily on concrete, which must reach the required strength within 28 days. By adopting the concept of self-curing, the shortcomings of traditional curing can be circumvented. Concrete that has self-cured has enhanced mechanical qualities and promotes sustainable growth. when steel fibers are inserted. The experimentation on fiber-reinforced self-curing concrete leads to the following conclusions:

- Addition of hooked end steel fibers have increased the properties of self-curing concrete especially its tensile responses. As the volume fraction of fiber increases, properties of concrete were found to be increasing and fiber reinforced self-curing concrete show an optimum percentage of hooked end steel fiber addition (with aspect ratio 50) at 2%.
- Compressive strength of fiber reinforced self-curing concrete was increased by 5% with respect to self-curing concrete.
- Flexural strength and split tensile strength of fiber reinforced self-curing concrete had a comparatively greater increment in their values at 2% volume fraction of steel fiber by 49.53% and 38.34% respectively
- Modulus of elasticity of fiber reinforced self-curing concrete was increased by 9.3% due to the fiber addition.

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