COMPARISON OF AUTOGENOUS SHRINKAGE BEHAVIOUR OF CONCRETE WITH AND WITHOUT STEEL FIBERS

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Abstract – *The study presents a comprehensive laboratory investigation into the time-dependent development of autogenous shrinkage in normal concrete when integrated with steel fiber reinforcement. The research encompasses two types of steel fibers - crimped and hooked-ended with volume fraction 0.25% and aspect ratios 60 and 50, studied over 42-days testing period. Additionally, compressive strength of the Steel Fiber Reinforced Concrete (SFRC) was assessed and their correlation with the parameters discussed. The results demonstrate crimped steel fibers prove exceptionally effective in mitigating autogenous shrinkage. Meanwhile, hooked-ended steel fibers outperform regular concrete, particularly in terms of compressive strength. These findings underscore the significant potential of steel fiber reinforcement in elevating the performance and durability of concrete structures. They offer valuable insights for applications in structural engineering.*

Key Words: SFRC, Autogenous shrinkage, Compressive strength, Crimped steel fiber, Hooked steel fiber etc.

1. INTRODUCTION

Concrete is a widely used building material due to its strength, and cost-effectiveness. It has replaced older materials like stone, wood, and brick in many construction contexts. Concrete has excellent compressive strength but relatively weak tensile strength, making it prone to cracking under tensile stresses. To address this, steel bars are embedded in the tensile face, creating reinforced concrete, and significantly enhancing tensile strength. Concrete is prone to losses due shrinkage, which can lead to cracks and weaken the structure. Shrinkage can be categorized as dry and autogenous shrinkage. Dry shrinkage occurs due to moisture loss due to environment. Autogenous shrinkage occurs in concrete shortly after casting due to the hydration process of cement and the formation of C-S-H gel. This gel has a smaller volume than the combined volume of water and cementitious binders, leading to pore pressures and tensile forces within the concrete matrix. At early ages, concrete strength is minimal, making it more susceptible to tensile stresses and micro cracking. Micro cracking accelerates water loss, resulting in dry shrinkage. Wider cracks in concrete pose a risk as corrosive agents may attack steel reinforcing bars, compromising their strength and integrity. This is particularly concerning for structures like dams, water tanks, and pools, which are susceptible to leakage and potential structural failure. In heavy and prestressed structures, autogenous shrinkage can lead to changes in length over time, affecting concrete performance and the structural integrity of the prestressing system. Steel Fiber Reinforced Concrete (SFRC) is an innovative composite that incorporates steel fibers into the concrete mix. The addition of steel fibers improves the mechanical properties of concrete, including compressive, tensile, and flexural strength, while also reducing cracking (Singh, H. 2016). SFRC can be used in both rebar concrete and plain concrete applications. Notably, SFRC effectively distributes and prevents cracking, mitigating the issue of autogenous shrinkage in concrete (Zheng, X., et.al 2019). Steel fibers act as micro-reinforcement, narrowing cracks and reducing their width, leading to a reduction in autogenous shrinkage.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Cement: 43 grade Ordinary Portland Cement was used in accordance with Indian Standards. The physical properties of cement are tested in accordance with IS 269:2015 given in Table 1.

Coarse aggregate: two sizes of coarse aggregate, 20mm and 10mm were used. The distribution of various aggregate sizes was carefully thought out with 60% of the coarse aggregate volume consisting of 20 mm particles, while the remaining 40% comprised 10 mm particles. The physical properties of the coarse aggregate used in the investigations are tested in accordance with IS 383:2016 given in Table 2.

Fine aggregate: Locally available riverbed natural sand was utilized, and its properties as per the IS 383:2016 standard have been documented in Table 3.

Steel fiber: two types of steel fibers, namely crimped and hooked ended steel fibers, were employed are shown in Fig -1. They possess aspect ratios of 60 and 50, respectively, at a volume fraction of 0.25%. and its properties are given in Table 4

Water: tap water

Table-1: Physical properties of OPC 43 grade cement

Properties	Observations	Required value as per IS 269:2015
Consistency, %	30	-
Fineness, %	5.5	<10%
Initial setting time, min	46	>30
Final setting time, min	263	<600
Specific gravity	3.13	3.0-3.15

Table-2: Physical properties of coarse aggregates

Properties	20 mm	10 mm
Type	Crushed	Crushed
Fineness Modulus	6.97	6.44
Specific Gravity	2.72	2.65
Water Absorption (%)	1.7	1.7

Table-3: Physical properties of fine aggregate

Properties	Observations
Grading Zone	II
Fineness Modulus	2.61
Specific Gravity	2.55
Water Absorption, %	1.06

Table-4: Properties of steel fiber

Properties	Crimped steel fiber (CRSF)	Hooked ended steel fiber (HESF)
Length, mm	30 and 50	30 and 50
Diameter, mm	0.5 and 1	0.5 and 1
Aspect ratio	60 and 50	60 and 50
Tensile Strength, MPa	1100	1100

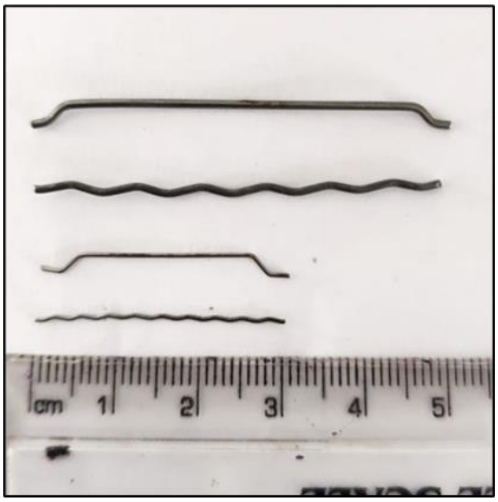

Fig-1: Steel fiber shape and dimensions

2.2 Mix proportion

M25 grade concrete was used for the experimental work, as per the guidelines outlined in IS code 10262-2019. For steel fiber reinforced concrete, the two type of steel fiber was added crimped and hooked ended with aspect ratio 60 and 50 with optimum dosage of 0.25% by volume of concrete, the corresponding mix proportions are presented in Table 5

Table-5: Concrete mix proportion for M25 grade

Mix name	Cement (kg/m^3)	Coarse Agg. (kg/m^3)	Fine Agg. (kg/m^3)	Steel Fiber (kg/m^3)	Water (L/m^3)
NC	383.16	1140.0	655.04	-	192
CRSF(S) 0.25	383.16	1140.0	655.04	98.125	192
CRSF(L) 0.25	383.16	1140.0	655.04	98.125	192
HESF(S) 0.25	383.16	1140.0	655.04	98.125	192
HESF(L) 0.25	383.16	1140.0	655.04	98.125	192

2.3 Test methods

2.2.1 Autogenous Shrinkage

The autogenous shrinkage was assessed using prismatic beam specimens measuring 100 mm × 100 mm in cross-section and 500 mm in length, as shown in Fig-2. These specimens, designated for autogenous shrinkage measurement, were meticulously sealed with a double layer of aluminum foil to prevent any moisture loss. Following the guidelines outlined in the EN 12390-16:2019 standard, the assessment of concrete autogenous shrinkage was conducted at 3-day intervals over a period of 42 days, commencing 24 hours after casting. This assessment was facilitated using dial gauges with a precision of 0.001 mm. The temperature was maintained at 27±2℃, with a relative humidity of 70±5%. Throughout the 42-day duration, the dial gauges consistently provided precise displacement readings, allowing researchers to elucidate the autogenous shrinkage behavior of the concrete.

Fig-2: Set up of free autogenous shrinkage test

2.2.1 Compressive Strength

To measure the compressive strength of concrete specimens the test is conducted in accordance with IS 516 (Part 1/Sec 1): 2021.The test was conducted on cubical specimens of size 150×150×150 mm after 28 days of curing on compressive strength machine of capacity 2000 kN as shown in Fig-3.

Fig-3: Compression Strength test setup

3. RESULTS AND DISCUSSION

3.1 Autogenous Shrinkage

The relationship between autogenous shrinkage strain and time reveals the trends and comparisons between concrete formulations with and without steel fiber reinforcement over a 42-day period is given in Fig-4 and Fig-5. These visual representations offer a clear understanding of how different types of Steel Fiber Reinforced Concrete (SFRC) perform in reducing autogenous shrinkage in contrast to normal concrete.

Notably, both Crimped Steel Fiber Reinforced Concrete (CRSF) and Hooked Ended Steel Fiber Reinforced Concrete (HESF) demonstrate commendable performance in reducing autogenous shrinkage strain when compared to Normal Concrete (NC). Upon closer examination, it becomes evident that among these, CRSF concrete exhibits the highest efficacy.

Further scrutiny reveals that within the same fiber type, specifically comparing CRSF0.25(S) to CRSF0.25(L) and HESF0.25(S) to HESF0.25(L) concrete formulations, the results indicate that CRSF0.25(S) and HESF0.25(S) stand out as the most effective in mitigating autogenous shrinkage strain.

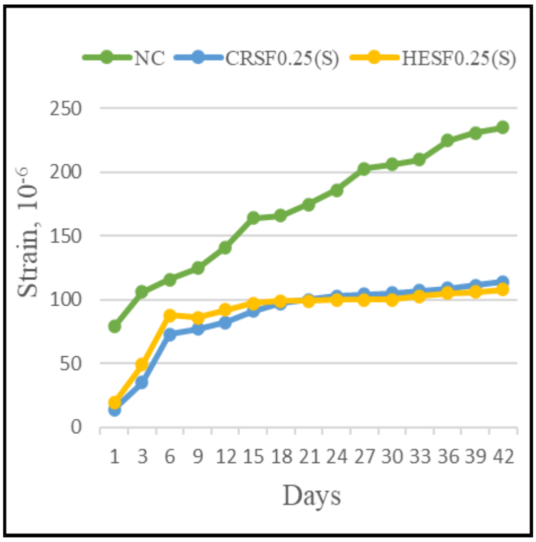

Fig-4: Comparison of autogenous shrinkage response for various concrete samples (with steel fibers of aspect ratio 60) taken in the study

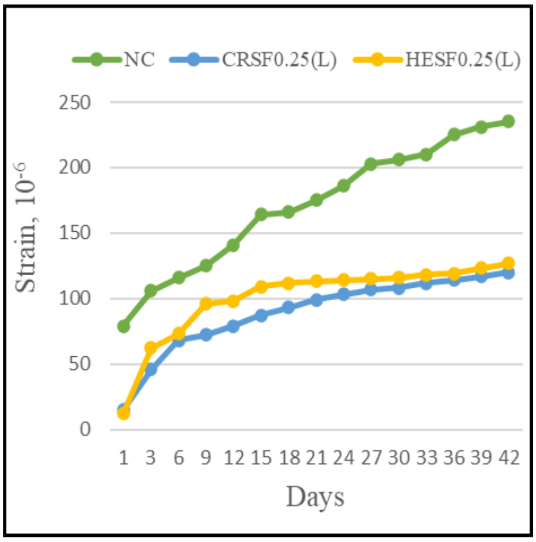

Fig-5: Comparison of autogenous shrinkage response for various concrete samples (with steel fibers of aspect ratio 50) taken in the study

3.2 Compressive Strength

The compressive strength of steel fiber reinforced concrete cube specimens after 28 days curing was determined through a compression test. The results are presented in Fig-5. According to the results, adding steel fibers to concrete, whether crimped or hooked ended, often improves the compressive strength. At the same volume fractions, the HESF types appear to have greater increases in compressive strength than their CRSF equivalents. However, there is no linear relationship, and the percentage increase does not grow uniformly as the fiber volume fraction increases. This could be due to a variety of factors, including workability issues, distribution of fibers or other properties of the mix.

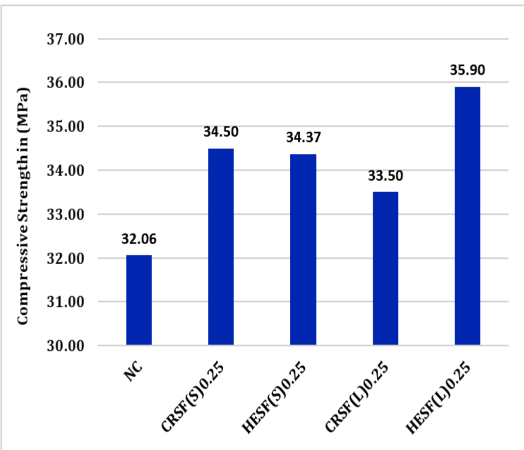

Fig-6: Effects of shape and aspect Ratio of steel fiber on compressive strength

3. CONCLUSIONS

The following conclusions are drawn based on the results of the present study:

1. The addition of both crimped and hooked ended steel fiber to concrete are effective in mitigating autogenous shrinkage.
2. Among both steel fibers, crimped steel fiber is found to be more effective in reducing the shrinkage.
3. Increase in the aspect ratio of the steel fibers lead to a greater reduction in the shrinkage characteristics.
4. Unlike the autogenous shrinkage, the use of hooked end fibers in the concrete is found to be more effective in improving the compressive strength than the crimped fibers.
5. The concrete exhibits better compressive strength with the increase of the fiber length.

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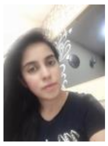

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