CREEP STRAIN BEHAVIOUR OF TRIPLE-BLENDED STEEL FIBER SELF-COMPACTING CONCRETE

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Abstract: The objective of the research article is to present the experimental results on the creep strain behaviour of steel fiber Self-Compacting Concrete (SFSCC). In respect of binder content, aggregate size, fine-to-coarse aggregate ratio, water-to-cement ratio, and chemical admixtures, Self-Compacting Concrete (SCC) differentiates from conventional cement concrete. Steel fibers are also inserted into SCC at a predetermined percentage to reinforce it. Steel fibers have been shown to contribute to improved strength characteristics, a dense mass of concrete with little or no voids, reduced pores in concrete, a higher Young's modulus, and fewer deflections and strains in concrete. Hence, an investigation was conducted on the creep variation of SFSCC over a longer duration. The test approach follows ASTM C512's standard test method for concrete creep in compression. The test specimens (SFSCC) are standard cylinders that have been cast and cured for 28 days before being tested. Three SFSCC cylinders with 0.80% steel fiber were tested at the same time. The load is applied to just the cylinders in the loading frame and kept constant, producing constant stress. The strains that occur only due to creep, excluding the initial elastic strain, are digitally recorded. As a logarithmic function, the creep strain-time connection was established. The conclusions are observed based on the findings of the experiments and compared with normal cement concrete (NCC).

Key words: Aspect ratio, Mineral admixtures, chemical admixtures, steel fibers, creep strain

1. Introduction

Prof. H. Okamura, developed Self-compacting concrete (SCC) in 1986. Since then, numbers of researchers on the micro-mixing of SCC have worked all over the world. The Bureau of Indian Standards (BIS) has not published a standard approach for SCC mix design. SCC contains the same elements as ordinary cement concrete, such as cement, fine and coarse aggregates, water, and mineral admixtures [1]. Chemicals that reduce the amount of water and improved the workability of concrete (superplasticizers) and agents that modify the viscosity of concrete (Viscosity Modifying Agent) are the part of SCC [2]. These are influenced to they modify the rheological properties of SCC to an extent. The fines content is more in the SCC possessed these properties even with complex reinforcing and thin structural elements. Despite its benefits, self-compacting concrete is however brittle and susceptible to crack propagation, much similar to the conventional concrete. The use of steel fiber in the self-compacting concrete (SFSCC) has created a technical basis for addressing these issues. Steel fiber works as a bridge, reducing the propagation of cracks and enhancing the concrete's characteristics. Steel fibers in concrete have been discovered to enhance tensile and flexural strengths, and also energy absorption and cracking propagation control [9]. The fiber-reinforced cement concrete (FRCC) has been established since the late 1960s, and a considerable research has been done on it. Limited researches contributed their study on the on the creep strain properties of the vibrated cement concrete. The novelty of this experimental work is comparing the creep strain of the steel fiber self-compacting concrete behaviour with the normal cement concrete. The percentage of the steel fiber with limiting aspect ratio (40) adopted in this experimentation was 0.8. Further increase in percentage of the steel fiber will affect the rheological behaviour of the SCC.
2. Literature Review

At the University of Tokyo in Japan, Ozawa K [1] (1989) conducted a study on the design of self-compacting concrete with improved durability is contributing the development of different concrete projects.

Okamura and Ouchi [2] (1999) highlighted two important problems that the international community faces while employing SCC which are suitable to mix design and analytical approaches. Based on paste and cement compatibility with superplasticizers, a mix design technique for SCC was proposed.

On the properties of strength, elastic modulus, creep, and shrinkage on SCC, Bertil Persson et al [3] (2001) conducted a study on eight mix designs with water binder ratios (w/b) ranging from 0.24 to 0.80. The authors examined loading ages ranging from the 2nd to the 90th day. The results show that when compared to normal concrete, the above features do not change substantially.

The tests were carried out by Nahitkumbasar et al [4] (2001) to assess the moment-curvature relation when exposed to axial and cyclic flexural loads. An analytical model that suited the test results was formulated.

Al-Tamimi and Sonebi, M [5] (2003) experimented to evaluate the acid confrontations of self-compacting concrete (SCC) and traditional type concrete (TTC) which were exposed to a solution of sulfuric and hydrochloric acids for up to 18 weeks at a temperature of 200C. The SCC was composed up of components that contained 47 percent carboniferous limestone powder.

Dimitri Feys et al [6] (2008) presented an investigative study on the sturdiness features of SCCs (self-compacting concrete) with increased bulk replacements with pulverized fuel ash. Pulverized fuel ash was employed for self-compacting concrete of several potency levels. In reference to various mixtures of NVCs, pulverized fuel ash percentages 0, 10, 30, 50, 70, and 85 were preferred.

Christina Frazao et al. [7] (2013) examined further the durability of steel fiber reinforced self-compacting concrete and made several significant proposals.

The results of SCC and NCC exposed to higher temperatures ranging from 150°C to 300°C were reported by Utkarsh Kumar, Yadav et al [8] (2015). When subjected to greater temperatures, the authors concluded that SCC performs better than Normal Cement Concrete (NCC).

S.R.R. Teja Prathipathi and C B K Rao [9] (2021) were investigated on “A study on the Uni-Axial compressive behaviour of graded fiber reinforced concrete using glass fiber/steel fiber”, from the study authors are concluded that graded fibers has proved to be advantageous in enhancing the Uni-axial compressive behaviour of the concrete.

Yeswanth Paluri et al [10] (2021) were investigated on, “Flexural Fatigue Behavior of Steel Fiber-Reinforced Reclaimed Asphalt Pavement–Based Concrete: An Experimental Study”.The results indicated that a decrease in flexural fatigue life with an increase in the RAP (Reclaimed Asphalt Pavement) content at all the stress levels. There is a substantial enhancement in fatigue life when steel fibers are added to RAP based concrete.

Srikanth.K et al [11] (2021) were presented their work titled, “Mechanical behavior of triple-blended hybrid fiber-reinforced concrete: an experimental and numerical study”. From their experimental and numerical study results, they concluded that the addition of hybrid fibers into the concrete improved both the pre-peak and post-peak behavior of the concrete.
3. Research Methodology

The research methodologies adopted in this experimental investigation were shown in the form of the schematic flow as mentioned below.

Check the Rheological requirements of SCC, Design SCC mix

Check the crushing strength of the cylindrical sample with steel fiber at the optimum percentage and limiting aspect ratio

Place the samples in axial compression creep testing machine and Apply load at 40% of its strength

Note the creep strain in the digital data collector, plotted the variation of the creep strain with time in hours.
The conclusions are drawn by comparing the creep strain of NCC with SFSCC

4. Materials Used

Ordinary Portland cement (OPC) conforming to BIS -10269-2015[16] and mineral admixtures such as flyash(FA) and condensed silica fume(CSF) were adopted here is for not only to increase the flow properties of the fresh SCC, but also to get better strength at the hardened stage. The percentages of replacements of these mineral admixtures (FA and CSF) are at 20 and 10 respectively by weight of the cement.

The physical and chemical properties of the admixtures are shown in Tables 1 and 2 respectively. The fine aggregate adopted here is river sand conforming to Zone-II, Fineness modulus and specific gravity of the fine aggregate are noted as 2.88 and 2.62 respectively. The coarse aggregate is 12mm sieve size passing and 10mm size retained was used. The Fineness modulus and specific gravity of the coarse aggregate are observed as 6.80, 2.68 respectively. All the properties of these aggregates are fulfilling the specifications of BIS-383-2016 [17].

| S.No | Characteristics                          | Flyash (FA) | Condensed silica fume(CSF) |
|------|------------------------------------------|-------------|----------------------------|
| 1    | Specific gravity                         | 2.30        | 2.20                       |
| 2    | Specific surface area (cm²/gm)           | 3500 to 3800| 15000 to 20000            |
| 3    | Colour                                   | Grey        | Dark grey and blackish    |
| 4    | Structure                                | Mostly globular | Non-crystalline         |
Table 2. Chemical composition of various Mineral Admixtures (Percentages)

| S. No | Oxides                   | Flyash(FA) | Condensed silica fume(CSF) |
|-------|--------------------------|------------|---------------------------|
| 1     | Silicon dioxide SiO₂     | 55         | 90                        |
| 2     | Aluminum oxide Al₂O₃    | 20-70      | 1                         |
| 3     | Ferric Oxide Fe₂O₃      | 10-15      | 0.03                      |
| 4     | Calcium Oxide Cao       | 1.63       | 0.10                      |
| 5     | Magnesium and other oxides | 3.96     | 0.20                      |
| 6     | Sulfur trioxide SO₃     | 0.65       | 23                        |
| 7     | Loss on Ignition        | 2.66       | 3.6                       |
| 8     | Insoluble residue       | 2.66       | 3.6                       |

In addition to the above mineral admixtures, chemical admixtures such as superplasticizer (GLENIUM B233) and Viscosity modifying agent (VMA-GLENIUM STREAM-2) are used at 1 and 0.15 percent of the weight of the cement. The mild steel wire of diameter 1mm and aspect ratio 40 was employed as fiber reinforcement. The steel fiber is 0.8 percentage of the volume of the SCC. Beyond the 40 aspect ratio and 0.8 percentages of steel fibers, the rheological properties of the SCC such as flowability, passing ability, and segregation resistance were not satisfied. The percentage of steel fiber and aspect ratio adopted are optimum. The physical properties of the steel fibers are shown in Table 3.

Table 3 Properties of steel Fibers

| S.No | Type of fiber | Density Kg/m³ | Elastic modulus Mpa | Diameter | Length in mm |
|------|--------------|---------------|---------------------|----------|--------------|
| 1    | Mild steel   | 7650          | 2.10 x 10⁵          | 1mm      | 40           |

5. Experimental Investigation

After getting the SCC design mix as per Nansu et al [12] and fulfilling the rheological properties as per EFNARC [13]. Sample of standard cylinders of 150mm diameter and 300mm height were cast and cured for 28 days. These samples were subjected to axial compression as shown in Fig 1 and the loading was applied load at 40 percent of its crushing strength constantly over stipulated time. By using Vibrated Wire (VM) strain gauges as shown in Fig 2, the strain gauge reading was digitally recorded by the arrangement of the VM stain gauges embedment into the cylindrical sample is shown in Fig 3. Cylindrical specimens with VW stain gauges are shown in Fig 4.

Fig 1. The testing set up for creep measurement
Fig 2. VW strain gauge embedment type with the gauge length of 125mm
The test procedure follows ASTM C512 [14], which is the standard test method for concrete creep in compression. This test technique is used to estimate the creep of concrete cylinders that have also been subjected to a sustained longitudinal compressive load of 40% of the ultimate load. Up to a period, the creep strain-time relationship could be assumed to be logarithmic. Standard cylinders (150mm diameter and 300mm height) were cast and cured for 28 days before being tested in the hardened form. Three SFRSCC cylinders with 0.80% steel fiber were tested at the same time. With a gauge factor of 2.487 micro strains per digit, the strain gauge enables a measuring range of 1500 micro strains. The load is applied to the cylinders in the loading frame and kept constant, resulting in constant stress. The strains that occur only due to creep, excluding the initial elastic strain, are digitally recorded. The average of three readings collected at the same time is recorded. Table 4 indicates the digitally recorded creep stains for the three cylindrical samples for steel fiber reinforced self-compacting concrete (SFRSCC) along with the average value.

Creep coefficient is defined as the ratio of ultimate creep strain (Øu) by elastic strain (Øe) given in Equation (1)

\[
Cc = \frac{\Omega_u}{\Omega_e}----------Equation (1)
\]

The creep coefficient varies with the duration of loading time and after one year it is 1.10 times the elastic strain showing an increase of 10%. The creep coefficient (Ø) is given in equation (1). The creep behaviour of steel fiber reinforcement SCC is investigated in this experimental study. In terms of binder composition (including mineral admixture), aggregate size, water to cement ratio, and chemical admixtures, SCC is different from conventional cement concrete. Steel fibers were also added to SCC at 0.8 percentages with an aspect ratio of 40.

6. A Mathematical Model For Creep Strain for steel fiber self-compacting concrete (Ø)

A Regression equations was developed as Equation (2)

\[
\Omega =0.003 \ln (t) +0.0112 --------Equation (2)
\]

R² =0.9326

In the above equation (2), ’t’ is the time in hours, and ‘Ø’ is the creep strain.

In Fig. 5 shows the variation of creep strains, the theoretical and experimental data with each other to form a logarithmic profile. Hence, it is a reasonable agreement.
Table 4 Creep strains of SFSCC taken from the data taker instrument

| Age of Loading | Creep strains Sample-1 | Creep strains Sample-2 | Creep strains Sample-3 | Average Creep strains |
|----------------|------------------------|------------------------|------------------------|-----------------------|
| 3 hour         | 0.019181525            | 0.01781225             | 0.01618275             | 0.017725508           |
| 6-hour         | 0.020170325            | 0.0187584              | 0.017459               | 0.018795908           |
| 1-day          | 0.0222841              | 0.020772575            | 0.01923                | 0.020762225           |
| 2-day          | 0.0233159              | 0.0209114              | 0.019775               | 0.0213341             |
| 3-day          | 0.0240396              | 0.022528725            | 0.02044175             | 0.022336692           |
| 4-day          | 0.025135875            | 0.02359675             | 0.0214815              | 0.023404708           |
| 5-day          | 0.025623125            | 0.02404115             | 0.02184                | 0.023834758           |
| 6-day          | 0.0260075              | 0.025976475            | 0.023403               | 0.025128992           |
| 7-day          | 0.0262225              | 0.025997975            | 0.023195               | 0.025138492           |
| 14-day         | 0.0290885              | 0.026112675            | 0.0236525              | 0.026188808           |
| 21-day         | 0.0437775              | 0.027754125            | 0.02486575             | 0.032132458           |
| 28-day         | 0.03181395             | 0.0303059              | 0.026644               | 0.02958795            |
| 2-month        | 0.03594115             | 0.03433425             | 0.029598               | 0.033291133           |
| 3-month        | 0.037660825            | 0.03605455             | 0.0308885              | 0.034867958           |
| 4-month        | 0.038735625            | 0.0372731              | 0.031247               | 0.035751908           |
| 5-month        | 0.0401257              | 0.038807025            | 0.03249475             | 0.037142492           |
| 6-month        | 0.04160175             | 0.040283625            | 0.0335415              | 0.038475625           |

Fig 5 Variation of the Creep Stain (Ø) of the SFRSCC with Age of Loading

\[ \theta = 0.003 \ln(t) + 0.0112 \]

\[ R^2 = 0.9326 \]
The creep strains are gradually increasing. The duration of test time was continued from 7 to 180 days. Sidney Mindess, J.F. Young, and David Darwin [15] (1981) presented the creep variation for plain cement concrete and the same values are also given in table 5 for comparisons.

Three steel fiber reinforced SCC cylinders with 0.8 percent fiber and an aspect ratio of 40 could be tested at a time in the loading frame during the experimental study as shown in Fig 1, and the test lasted for six months after 28 days of curing. The creep testing of SFR SCC was determined following ASTM C-512 [11] and the average creep strains of three different cylinders were recorded. The strains increase with time under sustained loading, as can be observed in Table 5 (up to a maximum of 6 months). When the results are examined, it can be seen that creep strains are quite well controlled in the case of SFRSCC compared with PCC. Creep strains have been reduced by up to 46 percent. Similarly, the rate of creep strain rise is faster in PCC than in SFRSCC, especially during the early stages. Steel fiber has a role in preventing long-term deformations in the SCC.

Table 5 Comparison of creep strains of SFR SCC with plain concrete
(As per Mindess and Young*)

| S.No | Durations In days | Creep strain for PCC Micro strains ($10^6$)* | Creep strains obtained for SFRSCC specimens Micro strains($10^6$) (Average) |
|------|-------------------|---------------------------------------------|--------------------------------------------------------------------------|
| 1    | 7                 | 255                                         | 234                                                                      |
| 2    | 14                | 420                                         | 261                                                                      |
| 3    | 21                | 530                                         | 321                                                                      |
| 4    | 28                | 590                                         | 325                                                                      |
| 5    | 60                | 650                                         | 333                                                                      |
| 6    | 90                | 680                                         | 349                                                                      |
| 7    | 120               | 700                                         | 358                                                                      |
| 8    | 150               | 705                                         | 371                                                                      |
| 9    | 180               | 710                                         | 384                                                                      |

7. Conclusions
1. Smaller-sized coarse aggregate should be used in the mix to enhance the smooth flow of self- compacting concrete (SCC). Chemical admixtures which include high-range water reducers (superplasticizers) and viscosity modifying agents (VMA) are to be used.
2. Steel fiber reinforced SCC can be made with steel fibers (SFRCC). Steel fiber at an optimum percentage of 0.80 with a fiber aspect ratio of 40 can be employed in the production of SFRSCC without interfering with the flow of SCC.
3. In comparison with regular cement concrete, creep strains are lower in fiber-reinforced SCC. When compared to PCC, the creep strain is 65 percent lower after six months. Steel fiber has a role in preventing long-term deformations in the SCC.
4. The logarithmic equations developed for creep is agree well with the experimental values, the experimental creep strain values obtained for SFRSCC are compared with those of PCC over various durations.
5. It can be seen from the experimentation that the creep strains were increasing at a faster rate in the initial periods. But over a longer duration extended up to six months, the rate of increase was lesser and the strains were getting stabilized and the changes are negligible in the case of SFRSCC.
6. It can be seen that the creep strains are very much controlled in the case of SFRSCC compared to ordinary PCC

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