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Strength and Performance Investigation of Characteristics of Self-compacting Concrete Under High Temperature

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Abstract

Self-compacting concrete (SCC) is known for its high workability and settles, carries and flows by its own weight without any vibration from outside sources. Achieving the good strength without bleeding and segregation of aggregates are most important and tedious process in this concrete. By developing its properties, the well conditioned concrete has been achieved along with high strength of grade M70. Adding mineral substance like fly ash, silica fume, ground granulated blast furnace slag (GGBS) with the cement by 5%, 10%, 15%, 20%, 25% and 30% the qualities of fresh concrete have been investigated. The concrete obeys the guidelines of EFNARC to fulfils the SCC requirements. Numerous mechanical characteristics have been researched, including modulus of rupture, split tensile strength, modulus of elasticity, and compressive strength. From the test results, the concrete has achieved satisfactory performance against the applied load. Also with respect to the durability, higher than normal temperatures of 200, 400, 600, 800 and 1000 (˚C) in order to find the behavior of concrete under elevated temperature. Corresponding to the above temperature, the compressive strength test and moisture in the concrete have been studied. From the test results, if the temperature has been increased, the concrete loses its ductility and the surface cracks also have been increased a lot.

Keywords

Self-compacting concrete, High strength, Fresh concrete properties, Mechanical properties, Durability properties, Elevated temperature

Introduction

Sideris et al. [1] has assessed the effect of polypropylene fiber in the SCC properties, it is exposed to elevated temperature between 300 to 600 ˚C. Experiment results show that, the concrete at highest temperature had the increased surface spalling and it causes the reduction in strength. Ahmad et al. [2] has been conducted the fresh and hardened concrete experiments on SCC with silica fume at the elevated temperature about 200 to 800 ˚C. The spalling of concrete has been occurred before reaching 800 ˚C, but there is a close strength results were found in the concrete at 400 and 600 ˚C.

Jalal et al. [3] has made study on SCC with silica fume of 10% addition, it leads the reduced performance in the workability behavior, the compressive and split tensile strength were improved significantly. Aslani and Samali [4] has studied the relations developed between the normal SCC and high-strength SCC (HSSCC) experienced a fire. The fire performance standards for concrete structures are specified and efficient modelling is provided. Aslani et al. [5-8] has studied the fresh and harden properties of heavy weight and high-performance SCC along with steel and PP fibers. It provides better performance criteria for concrete structures. SCC has the capability to flow under its own weight, there is no settlement in the middle, segregation, even bleeding and filling of extreme corners. Hence, for constructions with extremely crowded reinforcing, it is a suitable structural material. Benjeddou et al. [9] has investigated the behavior of SCC concrete at temperatures as high as 600 °C. Due to its enhanced hydration cementitious matrix, compressive strength increases sequentially between 150 and 300 °C. And reduces the strength when it reaches to 600 °C. Harihanadh et al. [10-12] studied the micro-characterization of materials and concrete to find the chemical constituents and morphology of the materials. Also have completed the different harden properties tests on SCC for the mix of M$_{30}$.

Materials and Method

Materials

The components required to create the M$_{70}$ grade SCC concrete are mentioned below, together with its physical and chemical qualities. The materials used were characterized for their nanoscale properties (Table 1).

In the investigation, ordinary Portland cement of grade 53 has been used to confirm the characteristics of IS:12269-1987 [13]. Natural river sand, which is easily accessible locally, is used as fine aggregate in the concrete compositions. According to IS: 383-1970 [14], the sand confirms to zone II according to the sieve analysis result. The stone crushed that makes it past the sieve with a particle size of 12 mm is used as coarse aggregate and complies with IS 383: 1970 [14] specifications for specific gravity and graded aggregates. The by product from the thermal power plant, by product produced by the ferrosilicon industry and the by product developed from steel manufacturing industry such as fly ash, silica fume, and GGBS have been replaced with cement by 5%, 10%, 15%, 20%, 25% and 30% in order to achieve a good strength and other characteristics of high strength and high-performance concrete. Figure 1, figure 2, and figure 3 shows the typical morphology of fly ash, silica fume, and GGBS, respectively. From the morphology, it is observed that the silica fume and GGBS have angular particles, so it helps to improve the strength. In order to achieve good strength and to reduce the water content, the superplasticizer (SP) (Glenium B233) and to ensure the workability of the concrete, a viscosity modifying agent (Glenium Stream2) was utilized.

Table 1: Admixture's chemical composition.

Chemical composition	Cement	Fly ash	Silica fume	GGBS
CaO	62.90%	3.20%	-	-
SiO_2	20.60%	49.90%	98%	-
Al_2O_3	4.50%	31.40%	-	12.60%
Fe_2O_3	2.90%	10.30%	-	-
SO_3	2.80%	0.09%	0.90%	2.40%
MgO	1.20%	1.11%	-	5.70%
Na_2O	0.60%	0.40%	0.33%	-
Total chloride	0.02%	-	-	-
K_2O	-	0.40%	0.17%	-
SrO	-	< 0.10%	-	-
TiO_2	-	1.80%	-	-
P_2O_5	-	0.60%	-	-
Mn_2O_3	-	0.20%	-	-
Total alkali	-	0.60%	0.40%	-
Cl	-	-	0.15%	0.01%
Sulfhuric anhydride	-	-	0.83%	-
S	-	-	-	0.40%
FeO	-	-	-	0.80%
MnO	-	-	-	0.10%
Insoluble residue content	-	-	-	0.20%

Mix design

The mix design has been prepared for to fulfil the fresh concrete properties as per EFNARC and the strength requirements as per IS for the grade of M70. The mix proportion and mix designation are shown in table 2.

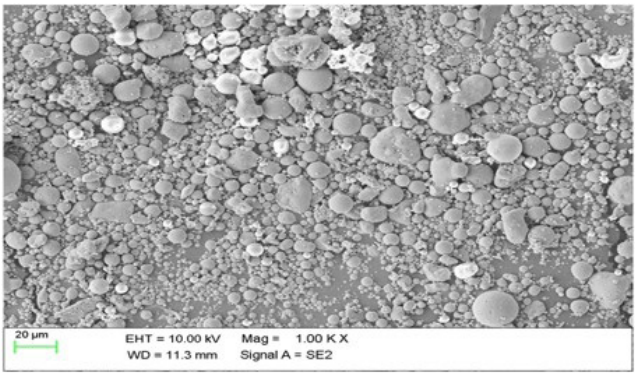


Figure 1: SEM – Morphology of fly ash.

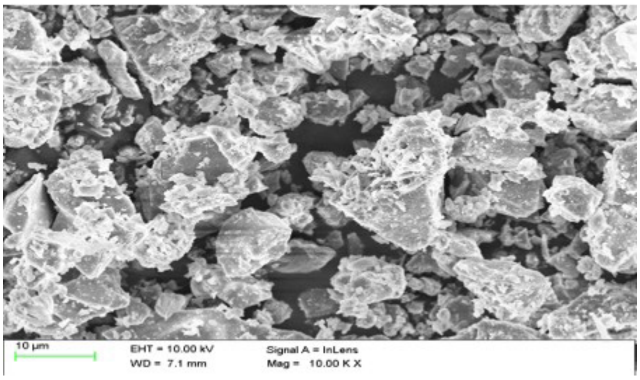


Figure 2: SEM – Morphology of silica fume.

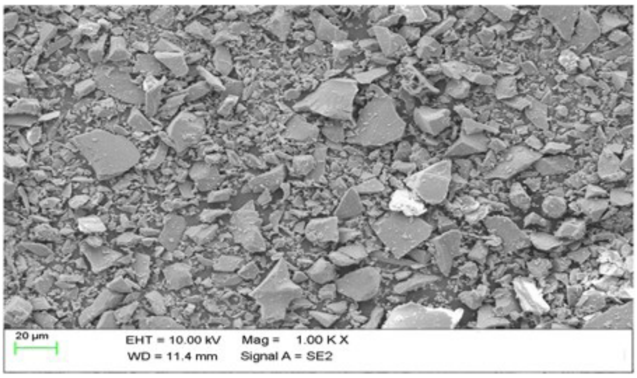


Figure 3: SEM – Morphology of GGBS.

Methodology

EFNARC requirements were followed for testing fresh concrete for filling capacity, passing ability, and flow ability utilizing slump cone, V-funnel, L-box, and U-box.

In accordance with Indian standards the mechanical qualities of the hardened concrete have been tested at elevated temperatures and during durability tests.

Results and Discussion

Characteristics of fresh mixed concrete

The slump cone, V-funnel, L-box, and U-box tests are used to determine the parameters for flow, filling, and passing the required amount of SCC by performing the marsh cone test by which the ideal dosage of SP was determined. Table 3 displays the test results. All of the test findings meet the EFNARC SCC criteria.

Harden concrete properties

Concrete's hardening characteristics, including its modulus of elasticity, split tensile strength, modulus of rupture strength, and compressive strength, have been determined and are shown in table 4. From the mechanical properties' tests, the behavior of concrete when fly ash, silica fume, and GGBS are substituted by 20%, 10%, and 15%, respectively, has shown improvement throughout the category.

According to the hardened properties test findings, the SCC specimen's compressive strength is 75.90 N/mm^2. The substitution of fly ash obtains the maximum strength at 20% and the value of strength is 76.80 N/mm^2. This strength is 1.19% more than the strength of SCC specimen. Similarly, silica fume of 10% attains the strength of 78.40 N/mm^2. This strength is 3.29% more than the strength of SCC specimen. And GGBS with 15% replacement attains the maximum strength of 77.80 N/mm^2, and 2.50% more than the strength of SCC specimen.

The SCC specimen has the value of split tensile strength is 3.65 N/mm^2. The replacement of fly ash obtains the maximum strength at 20% and the value of strength is 3.76 N/mm^2. This strength is 2.94% more than the strength of SCC specimen. Similarly, silica fume of 10% attains the strength of 3.70 N/mm^2. This strength is 1.29% more than the strength of SCC specimen. And GGBS with 15% replacement attains the maximum strength of 3.69 N/mm^2, and 0.91% more than the strength of SCC specimen.

The SCC specimen has the value of modulus of rupture strength is 5.93 N/mm^2. The replacement of fly ash obtains the maximum strength at 20% and the value of strength is 6.00 N/mm^2. This strength is 1.18% more than the strength of SCC specimen. Similarly, silica fume of 10% attains the strength of 6.03 N/mm^2. This strength is 1.63% more than the strength of SCC specimen. And GGBS with 15% replacement attains the maximum strength of 6.02 N/mm^2, and 1.54% more than the strength of SCC specimen.

The SCC specimen has the value of modulus of elasticity strength is 43211.82 N/mm^2. The replacement of fly ash obtains the maximum strength at 20% and the value of strength is 43686.35 N/mm^2. This strength is 1.10% more than the strength of SCC specimen. Similarly, silica fume of 10% attains the strength of 44050.53 N/mm^2. This strength is 1.94% more than the strength of SCC specimen. And GGBS with 15% replacement attains the maximum strength of 43925.75 N/mm^2, and 1.65% more than the strength of SCC specimen.

Because of its angular shape and pore filling, silica fume and GGBS help to improve the compressive strength of the concrete. But the fly ash does not help that much, due to its rounded shape of morphology. The angular shape and pores

Table 2: Mix design of HSSCC.

Mix ID	Cement	Fly ash	Silica fume	GGBS	Fine aggregate	Coarse aggregate (12 mm)	Water	SP	VMA
CSC-70	420	-	-	-	862	769	168	4.2	1.68
SCF70-5	399	21	-	-	862	769	168	4.2	1.68
SCF70-10	378	42	-	-	862	769	168	4.2	1.68
SCF70-15	357	63	-	-	862	769	168	4.2	1.68
SCF70-20	336	84	-	-	862	769	168	4.2	1.68
SCF70-25	315	105	-	-	862	769	168	4.2	1.68
SCF70-30	294	126	-	-	862	769	168	4.2	1.68
SCS70-5	399	-	21	-	862	769	168	4.2	1.68
SCS70-10	378	-	42	-	862	769	168	4.2	1.68
SCS70-15	357	-	63	-	862	769	168	4.2	1.68
SCS70-20	336	-	84	-	862	769	168	4.2	1.68
SCS70-25	315	-	105	-	862	769	168	4.2	1.68
SCS70-30	294	-	126	-	862	769	168	4.2	1.68
SCG70-5	399	-	-	21	862	769	168	4.2	1.68
SCG70-10	378	-	-	42	862	769	168	4.2	1.68
SCG70-15	357	-	-	63	862	769	168	4.2	1.68
SCG70-20	336	-	-	84	862	769	168	4.2	1.68
SCG70-25	315	-	-	105	862	769	168	4.2	1.68
SCG70-30	294	-	-	126	862	769	168	4.2	1.68

Table 3: Fresh concrete properties of HSSCC.

Mix ID	Slump flow (mm)	T_{50} slump flow	V-funnel	V-funnel T_5	L-box (mm) (H_2/H_1)	U-box (mm) (H_2-H_1)
CSC-70	684	2	6	7	0.8	16
SCF70-5	680	3	7	7	0.8	18
SCF70-10	679	3	7	8	0.8	18
SCF70-15	678	3	7	8	0.8	19
SCF70-20	678	3	8	8	0.9	20
SCF70-25	675	4	8	9	1	22
SCF70-30	674	4	9	9	1	23
SCS70-5	688	2	8	9	0.8	19
SCS70-10	688	3	8	9	0.8	19
SCS70-15	687	3	8	10	0.9	20
SCS70-20	687	3	9	11	0.9	20
SCS70-25	686	4	9	11	0.9	21
SCS70-30	685	4	10	13	1	22
SCG70-5	682	3	8	9	0.8	20
SCG70-10	680	3	8	9	0.9	20
SCG70-15	678	4	9	10	0.9	21
SCG70-20	678	4	10	12	0.9	22
SCG70-25	676	5	10	13	1	22
SCG70-30	676	5	11	14	1	24

Table 4: Harden concrete properties of HSSCC.

Mix ID	Compressive strength (N/mm^2)	Split tensile (N/mm^2)	Modulus of rupture (N/mm^2)	Modulus of elasticity (N/mm^2)
CSC-70	75.9	3.65	5.93	43211.82
SCF70-5	75.3	3.61	5.89	43040.68
SCF70-10	75.9	3.66	5.93	43342.5
SCF70-15	76.3	3.73	5.97	43500.24
SCF70-20	76.8	3.76	6	43686.35
SCF70-25	76.2	3.73	5.93	43384.43
SCF70-30	75.6	3.65	5.9	43213.29
SCS70-5	77.4	3.68	5.98	43680.71
SCS70-10	78.4	3.7	6.03	44050.53
SCS70-15	77.9	3.69	6.01	43953.97
SCS70-20	77.6	3.68	6.01	43913.29
SCS70-25	77.1	3.66	5.96	43639.88
SCS70-30	76.8	3.67	5.95	43554.9
SCG70-5	76.9	3.67	5.95	43539.4
SCG70-10	77.2	3.67	5.99	43712.11
SCG70-15	77.8	3.69	6.02	43925.75
SCG70-20	77.4	3.68	6	43856.67
SCG70-25	77.1	3.68	5.97	43639.88
SCG70-30	76.9	3.67	5.96	43583.24

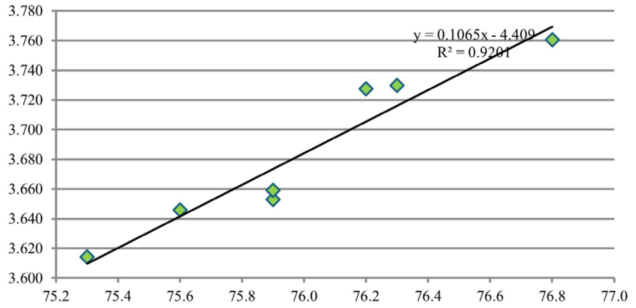


Figure 4: Regression analysis of SCF70 concrete with fly ash.

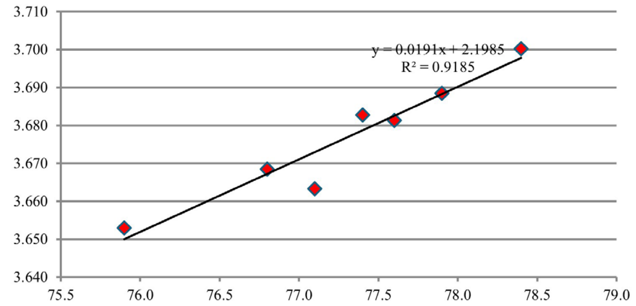


Figure 5: Regression analysis of SCS70 concrete with silica fume.

filing capability of this silica fume and GGBS, have negative reaction when coming to deal with tension loads. And it did not absorb much tension load. Accordingly, the fly ash specimen behaves well in the split tensile strength and rupture modulus tests.

Figure 4, figure 5, and figure 6 shows the regression analysis of the concrete specimen strength corresponding to its compressive strength. It has a close call with conventional specimen and the result obeys almost 92% with the experimental results.

Elevated temperature test

On the conventional cube specimen, the durability qualities of concrete at elevated temperatures were discovered. Table 5 shows the test results for the temperature at which the compressive strength decreases in relation to room temperature, 200, 400, 600, 800, and 1000 °C. After the specimen is heated to a higher temperature, figure 7 displays the compressive strength of concrete. Figure 8 depicts the loss in compressive strength of concrete following specimen heating.

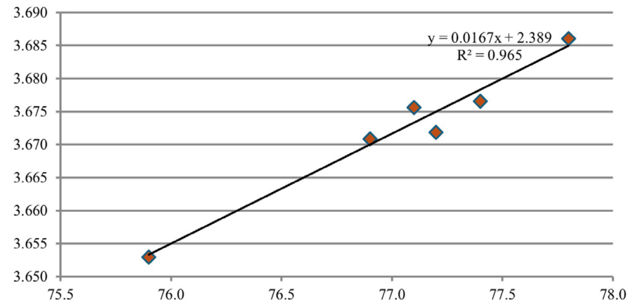


Figure 6: Regression analysis of SCS70 concrete with GGBS.

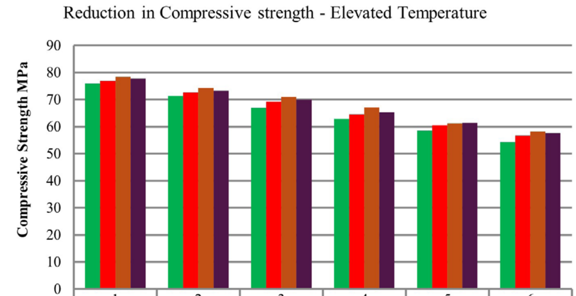
From the test results, the temperature to the concrete increases, it leads to the reduction of concrete compressive strength. It shows the moisture between the molecules have been removed completely and leads breaking of bond between them. So, the concrete loses its strength at some amount. The conventional specimen has lost the strength around 58.54%, SCF70-20, SCS70-10 and SCG70-15 specimen have lost their strength by 26.52%, 25.71% and 25.85% at 1000 °C. The conventional specimen has more loss when compared with other mineral admixture specimen. But the specimen with silica fume has less percentage of reduction in strength, because the silica fume has good in filling the pores of concrete that helps to improve the strength (Figure 9).

Conclusions

The following results have been reached based on substantial experimental investigation.

- The mix design for the M70 grade has been fulfil its SCC requirements as per EFNARC in the fresh state.
- In terms of harden properties tests, the concrete with silica fume performs better under compressive load. The values for its compressive, split tensile, modulus of rupture, and elastic properties are 78.40 N/mm^2, 3.70 N/mm^2, 6.03 N/mm^2, and 44050.5 N/mm^2, respectively. The fragile nature of concrete surfaces has been exposed while it is carrying tension load. When compared to silica fume incorporated in concrete, concrete with GGBS and fly ash performs moderately.

Figure 7: Typical surface after 1000 °C and the failure pattern of cube specimen.



	1	2	3	4	5	6
🟩 CSC-70	75.9	71.323	66.944	62.919	58.458	54.238
🟥 SCF70-20	76.8	72.591	69.135	64.596	60.503	56.644
🟧 SCS70-10	78.4	74.300	71.003	67.063	61.274	58.242
🟪 SCG70-15	77.8	73.233	69.927	65.336	61.383	57.686

Figure 8: Reduction in compressive strength – Elevated temperature.

- Regression analysis proves experimental and theoretical values have the close call between them.
- The concrete specimens on elevated temperature test shows, when the temperature increases, the reduction of compressive strength happens due to its losing bond strength between the molecules.

Acknowledgements

None.

Conflict of Interest

None.

Table 5: Compressive strength test values at elevated temperature.

Compressive strength (N/mm^2) values						
Mix ID	**Room temperature**	**200 °C**	**400 °C**	**600 °C**	**800 °C**	**1000 °C**
CSC-70	75.9	71.323	66.944	62.919	58.458	54.238
SCF70-20	76.8	72.591	69.135	64.596	60.503	56.644
SCS70-10	78.4	74.3	71.003	67.063	61.274	58.242
SCG70-15	77.8	73.233	69.927	65.336	61.383	57.686
Percentage of reduction in compressive strength						
CSC-70	-	0.0603	0.118	0.171	0.2298	0.2854
SCF70-20	-	0.0548	0.0998	0.1589	0.2122	0.2625
SCS70-10	-	0.0523	0.0944	0.1446	0.2185	0.2571
SCG70-15	-	0.0587	0.1012	0.1602	0.211	0.2585

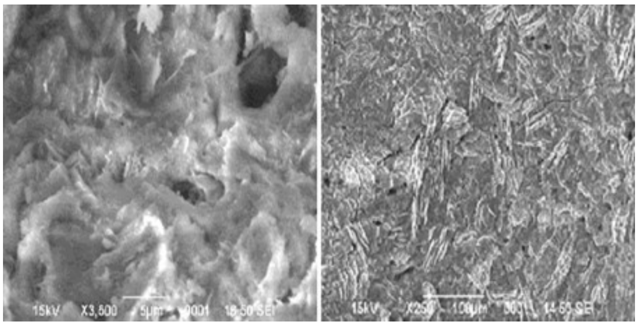


Figure 9: Morphology of silica fume concrete at room temperature and 200 °C.

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