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Experimental Study of Self-Consolidating Concrete in Partial Replacement of OPC with Mineral Additives and Industrial Waste

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A B S T R A C T

The qualities of self - consolidating concrete (SCC) made through various mineral additives and liquid-to-solid proportions were explored experimentally. The blends were manufactured using four aspects of fly ash as a component in place of cement and were developed for M60 concrete grade. They were primed through three stages of GGBS and silica dust injection. With the use of common tests, the fresh characteristics were investigated. The fracture elongation and bending trials was conducted over the course of 28 days, and compression strength was identified at various ages. According to study results for SCC mixtures, fly ash concentration enhances flowability whereas a higher water-binder ratio reduces compressive strength. The findings were collected to indicate a link between the characteristics of pure and solidified HSSCC concrete. Considering the outcomes of this research, it is concluded that fine aggregate substitution with fly ash, silica dust, and G.G.B.S. in HSSCC may be effectively employed to create a long-lasting, ecologically conscious construction supplies for a brighter tomorrow.

Keywords: Mineral Admixtures, water-binder ratio, Fine Aggregate, SCC, GGBS, Fly Ash, Silica Powder, recyclable materials.

1. Introduction

Self- Compressing Concrete is described as the aptitude of a material to compress by itself in a heightened state of gravity or it weighs itself while vibrating, bleeding, or segregation. It will adopt the shape of any complex formwork without pores, allowing air to pass through while also properly covering the reinforcement.

To assist and assure adequate jamming and high structural performance of constrained regions and extensively rebar structural components, it is retailed through a perturbation auction (Aswathy, 2015) [1].

Due to the certain benefits of this functional mix, it provided prominently to construction sites. Such concrete needs a considerable slump, which may be easily attained by including a superplasticizer in the mix and maintaining the right mix proportions. (Okamura and Ouchi, 1999) [2].

It is costly to employ organic additives in SCC, and doing so might raise the components' cost. Labour cost reductions might make up for the greater price. Also, fly ash, blast furnace waste, or silica dust are examples of mineral additives that might be used to improve the unsullied qualities of tangible without hiking the price of the composition. Further, due to its ability to lower the water-heating process of the cement, fly ash usage improves the rheological qualities of tangible and minimises its inclination to fracture. (Anil and Chowdary, 2017) [3].

The rheological parameters of SCC's flowing ability significantly improved with the mineral substitution of additives. Cement, micro packings, and sand, which are required in great amounts in S.C.C., are less necessary when mineral additives are used (Okamura, 1997) [4].

Concrete must have the potential to fill spaces, travel through obstructions, and withstand separation in order to be self-compacting (Pai et al., 2014) [5].

Cutting the amount of coarse aggregate, utilising less liquid to flour mix, and adding super plasticizers help achieve these characteristics (Siddique, 2011) [6].

Mineral ingredients are frequently used in significant quantities to SCC to improve the flowability in the fresh stage and longevity in the solid concrete. According to a research, IS 10262 (2009) criteria, S.C.C. with 5% silica powder and 20% and 30% artificial sand substitute of stream sand regarded as fresh SCC (Khurana and Saccone, 2001) [7].

As a pozzolanic additive imitator in concrete, silica powder is employed. When silicone or ferrosilicon amalgam is being produced, it is produced by reducing high transparency quartz and charcoal in an electric arc kiln. More than 90% of the silicon dioxide in concentrated silica dust is silicon dioxide in a non-transparent state (“Khayat et al., 2005”) [8].

The dust is very finely ground and has fragments that are inferior to one micrometre in length and have a mean diameter of around 0.1 micrometre, which is roughly 100-fold lower than the normal cement grain. Due of its large contact area, cement and aggregate adhere to it more easily, improving the bond's ability to increase power (Ahmed et al., 2017) [9].

The process of producing sleek, shining, crystalline ground granulated blast furnace slag (GGBS), which is subsequently dried and crushed into a fine dust, involves condensing liquefied iron waste from a kiln in liquid or vapour (Mokal et al., 2015) [10].

The pozzolanic properties are outstanding. Three inert additives and three liquid to powder ratios were taken into consideration in this inquiry.

2. Experimental procedure

2.1 Materials

With a relative density of 3.14, regular Portland cement was employed in this experiment. For this experiment, natural stream particles that exceeded a 4.75 mm filter and were held on a 600 mm mesh were employed in accordance with the "IS 2386 (Part 1) (1963) [12]" norm ("Khan, 2016") [11]. The greatness modulus of the natural stream particles utilized, stayed at 2.95 with relative density of 2.6. For this experiment, granular particles measuring 12.56 mm was employed. Locally accessible fly ash was utilised to prepare the concrete mix. GGBS was acquired from the iron blast- kiln business. The obtained silica dust complies to A.S.T.M. - 1240 (2015) [13] norms. A widely accessible super plasticizer was employed in this experiment. This was put together using Sulfonated naphthalene formaldehyde (SNF) and adapted to IS - 9103 (1999) [14], BS: 5075 Part – 3 [15], and ASTM C-494 (2017) [16] norms. In List 1, the chemical make-up of the components is displayed.

List 1: Chemical configuration of constituents

Sr. no.	*Blend*	*Cement*	*Fly ash*	*Silica Powder*	*G.G.B.S.*
		% weight			
1	SiO_2	*23.8*	*65.93*	*93.4*	*32.6*
2	Al_2O_3	*5.86*	*23.69*	*1.5*	*12.8*
3	Fe_2O_3	*5.47*	*2.82*	*3.0*	*1.3*
4	*CaO*	*63.30*	*3.93*	*0.7*	*4.1*
5	Na_2O	*0.71*	*0.86*	*0.5*	*0.2*
6	K_2O	*0.86*	*2.77*	*0.9*	*0.3*

2.2 Mix Proportions

There were made eleven SCC blends, with traditional SCC. Every batch of concrete was M60 standard. Fly ash was used in place of cement in combinations of FA5, FA10, FA15, and FA20. These mixtures had total cementitious contents of 550 kg/m3 and comprise 5%, 10%, 15%, and 20% fly ash, respectively. The following mixtures were created using 5%, 10%, and 15% GGBS in addition to silica dust in place of OPC. All blend permutations had the same level of super plasticizer (10.8 kg/m^3). The natural stream particles concentration in the typical SCC blend was held at 45% by proportion (911 kg/m3) of mortar in tangible and 39% by proportion (590 kg/m3) of tangible, while the moisture-powder proportion was preserved at 0.30 by mass with an estimated entrapped air of 2%. List 2 provides information on different percentages.

List 2: Combine ratios of SCC

Ingredients (kg/m^3) for 1 m³ of concrete									
Sr. No.	**Mix**	**0.3 w/c**							
		Cement (kg/m^3)	**Fly Ash (kg/m^3)**	**Silica Fumes (kg/m^3)**	**GGBS (kg/m^3)**	**Super Plasticizer (kg/m^3)**	**Coarse Agg. (kg/m3)**	**Fine Agg. (kg/m^3)**	**Water (kg/m^3)**
1	Normal HSSCC	550	0	0	0	10.8	590	911	165
2	FA5 +SF5+GGBS5	468	27.5	27.5	27.5	10.8	590	911	165
3	FA10+SF10+GGBS10	385	55	55	55	10.8	590	911	165
4	FA15+SF15+GGBS15	303	82.5	82.5	82.5	10.8	590	911	165
5	FA20+SF20	330	110	110	0	10.8	590	911	165

Preparation and Casting of Test Specimens

Weighing the necessary amounts of the ingredients yielded these blend amounts. Mineral additives and cement were combined in a dehydrated condition. Uneven and powder aggregates were taken in dehydrated condition disjointedly and then blended together in a blender to acquire consistent combination, after accumulation liquid. The moulding was completed immediately following the blending, and a test was run to assess the material's new qualities. To eliminate superfluous stuff and provide a clean finish, the sample's topmost layer was polished. According to the trial's specifications, the models were taken out of the frame after 24 hours and allowed to therapy in liquid before being tested. All trial measures were occupied as the mean of the three values.

2.4 Trail of Specimen

2.4.1 Features of New Concrete

Tests like slump flow, T50 cm time, V-funnel flow times, L-box block proportion, and U - box variance in altitude were done to figure out the features of self- tamping capability. After blending for 30 minutes, the qualities of blends in their new condition were assessed.

After a typical collapse funnel has been released, the slumped movement signifies the mass of concrete's middling diameter. Two non - parallel measurements of the diameter were taken. The slumped movement deemed necessary for tangible to self- dense is between 500 mm and 700 mm. (Bharali, 2015) [17]. Concrete may isolate at a depth of more than 700 mm, and at a depth of less than 500 mm, it is thought that its movement is inadequate to pass through heavily populated reinforcing. The V-designed cone trial was used to assess the SCC blends constancy. It is suggested that a concrete succeed for an SCC with a cone trial drift time of under six seconds.

2.4.2 Mechanical Properties

According to Bureau of Indian Standards, IS 516 (1959) [18] norms, crushing capacity was calculated after 1, 3, 7, 14, 28, and 90 days. At the period of 28 days, fracture elongation and bending trials were performed. Castings of 150-mm blocks, 300-mm x 100-mm tubes, and 100-x-100-x-500-mm prisms stayed used to measure the crushing force, fracture elongation force, and bending power of the materials accordingly.

3. Outcomes and Analysis

3.1 Qualities of Recently Poured Concrete

In the given List 3, Each blend has a slump flow rate of 623 and 886 mm, while the European Guideline for Self - compressing Tangible suggests 551 to 851 mm should be the slump flow region. With an 886 mm diameter and a water–cement proportion of 0.4, Blend FA20 has the greatest significance of slump flow. The lowest slump flow is 623 mm while using SF15 with a water–cement proportion of 0.3. The slump flow value rises as the water–cement proportion rises. The quantity of mineral additives has increased, the valuation steadily declines. The decrease in flow is caused by the existence of mineral additives and can have an effect on the liquidity of new concrete's properties.

For the majority of the mixtures, the slump flow duration 500 mm as the final diameter was between 2.5 and 7.3 seconds. Fly ash blends slump in 2–6 seconds, silica fume blends in 4–7 seconds, and GGBS blends in 6–7 seconds. Fly ash has better workability than GGBS, and it is trailed by silica fume.

A V-funnel trial is utilized to appraise the HSSCC's workability and durability with regards to the slump flow trial. Flow times (T10) in the V-funnel were 6–10 seconds. The findings of this experiment's tests revealed that all HSSCC blends satisfied the parameters for permitted flow time in an appropriate manner. The "European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC, 2005) [19]", an SCC should last between 6 and 12 seconds.

For the HSSCC blends, the L-box proportion H2–H1 was greater than 0.9, which is in accordance with EFNARC criteria. The height range between the two sections of a concrete U-box was 20–30 mm. The test data supports these results, indicating that the water-cement ratio aids in enhancing fresh property test outcomes (Bharali, 2015) [17].

List 3: - test data for Slump flow, T50 Time Test, V-Funnel Flow Test, L-Box Test and U-Box Test

Sr. no.	Mix ID	w/c ratio = 0.3				
		Slump flow diameter (mm)	T50 Time Test (s)	V-Funnel Flow Test T10s (S)	L-Box Test (H2/H1)	U-Box Test H1-H2 (mm)
1	Conv. SCC	670	4.3	6.8	0.87	26
2	FA5 + SF 5 + GGBS 5	663	4.7	7.9	0.82	23
3	FA 10 + SF 10 + GGBS 10	652	4.9	8.4	0.83	22

4	FA 15 + SF 15 + GGBS 15	642	5.8	8.7	0.84	21
5	FA 20 + SF 20	648	5.5	8.35	0.83	23

Figure 1 New features of SCC blend (a) Slump Test 0.3 w/c proportion (b) L- box 0.3 w/c proportion (c) T_5 min slump 0.3 w/c proportion (d) U - box 0.3 w/c proportion

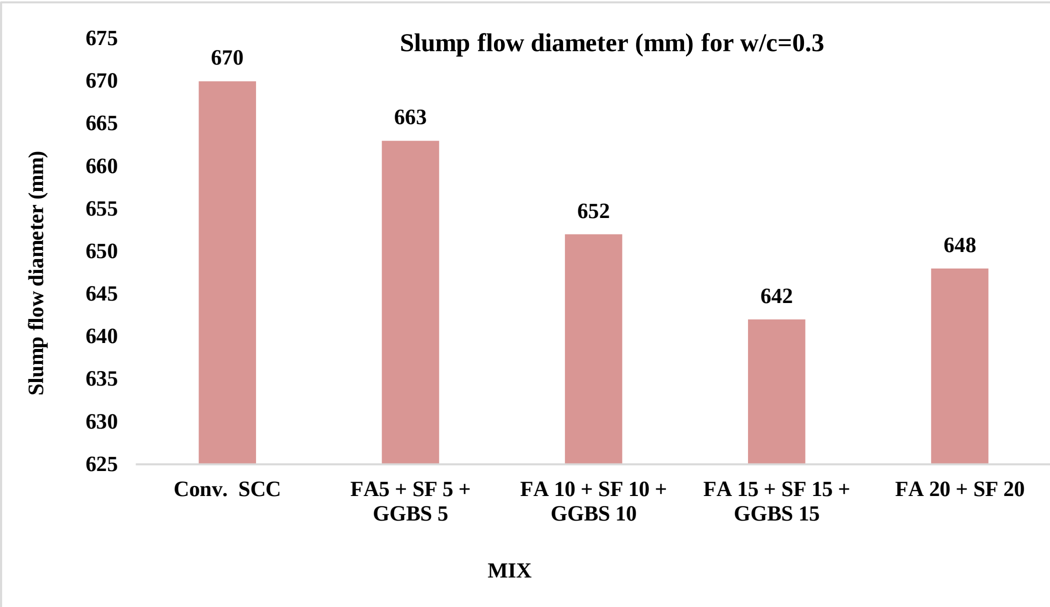

Fig A: - Slump flow diameter (mm) for w/c=0.3

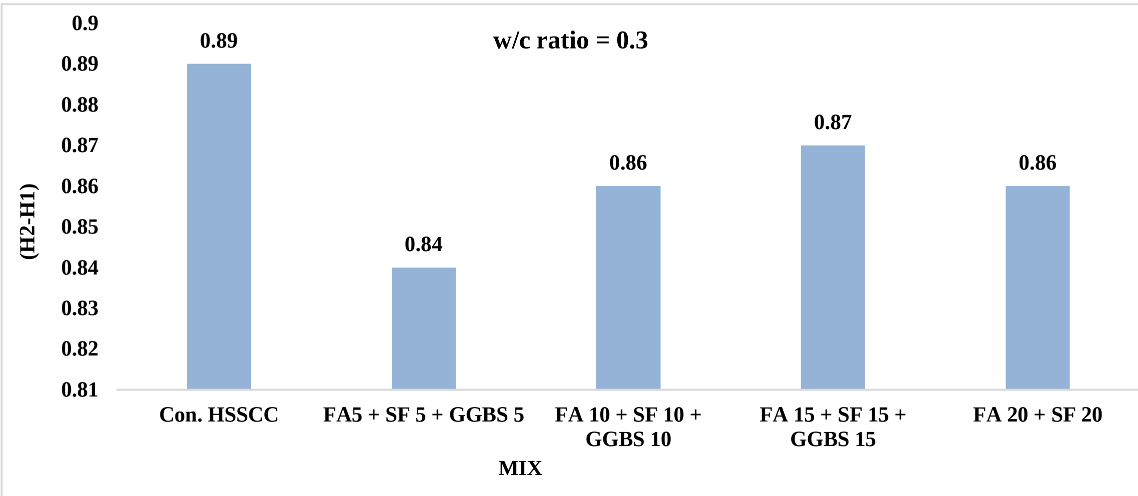

Fig. B.: - L- box 0.3 w/c proportion

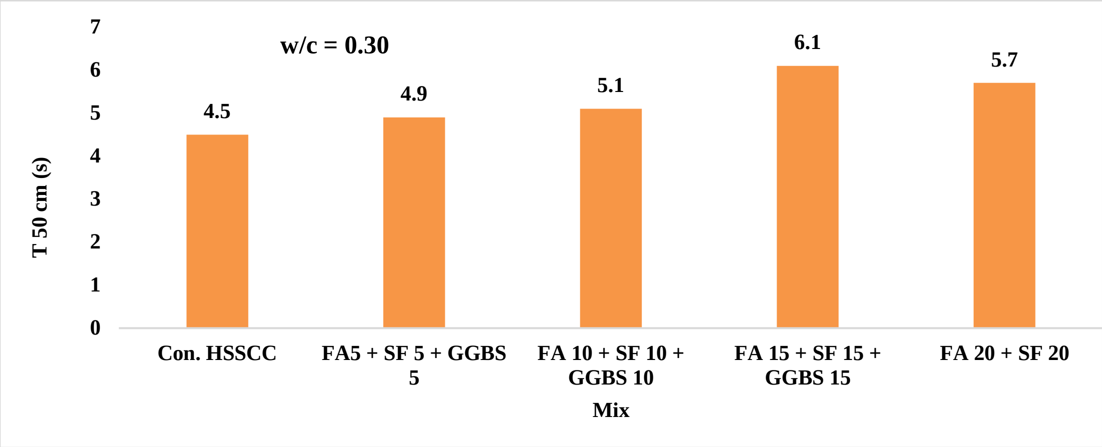

Fig. C.: - T5 min slump 0.3 w/c proportion

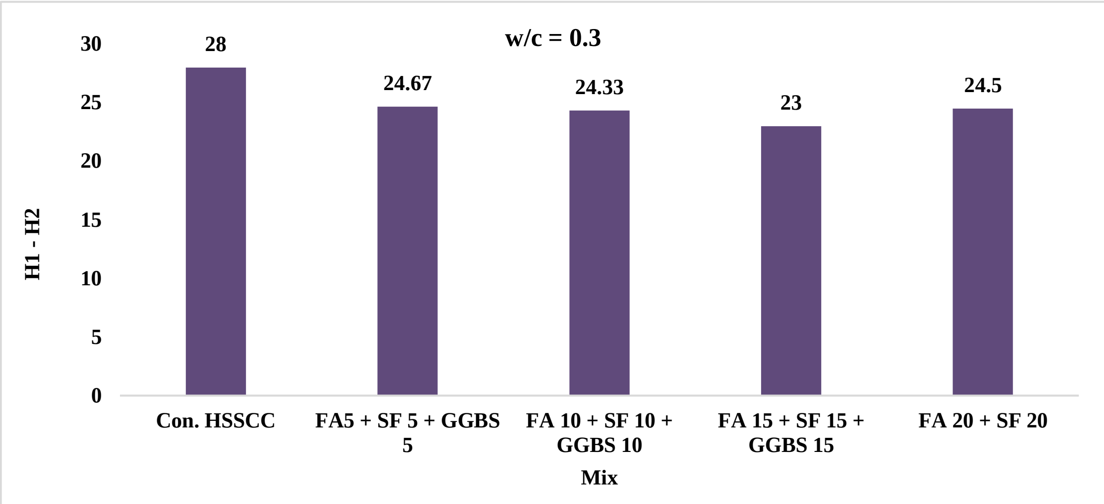

Fig. D.: - U-box 0.3 w/c proportion

3.2 Mechanical Features

3.2.1 Crushing Strength

With a liquid to powder ratio of 0.3 the trials were run for 1, 3, 7, 28, and 90 days, respectively. The realistic makes it abundantly evident that FA20 generates the highest crushing strength at a liquid to powder ratio of 0.3. The inclusion of silica powder boosts the strength over the first 7 days. Although both fly ash and silica dust are cementitious materials, silica dust reacts more quickly than fly ash due to its finer powder, that is cement grain are 100–150 times tinier. The force of SF15 is 27.8% greater than the regulated blend.

When equated to all other mineral additives at all stages, the application of GGBS exhibits the slowest degree of power gain. At a liquid - cement proportion of 0.3, the 90-day power measurements are 19.5%, 15.96%, and 10.63% heavier than the stabilised blend with the optimum response of fly ash, silica dust, and G.G.B.S., separately. Thus, it implies an increment in the liquid proportion reduces the Ninety days potency. In Figure 2 Outcomes of crushing power of 0.3 w/c proportions shown.

Figure 2 Outcomes of crushing power of 0.3 w/c proportions

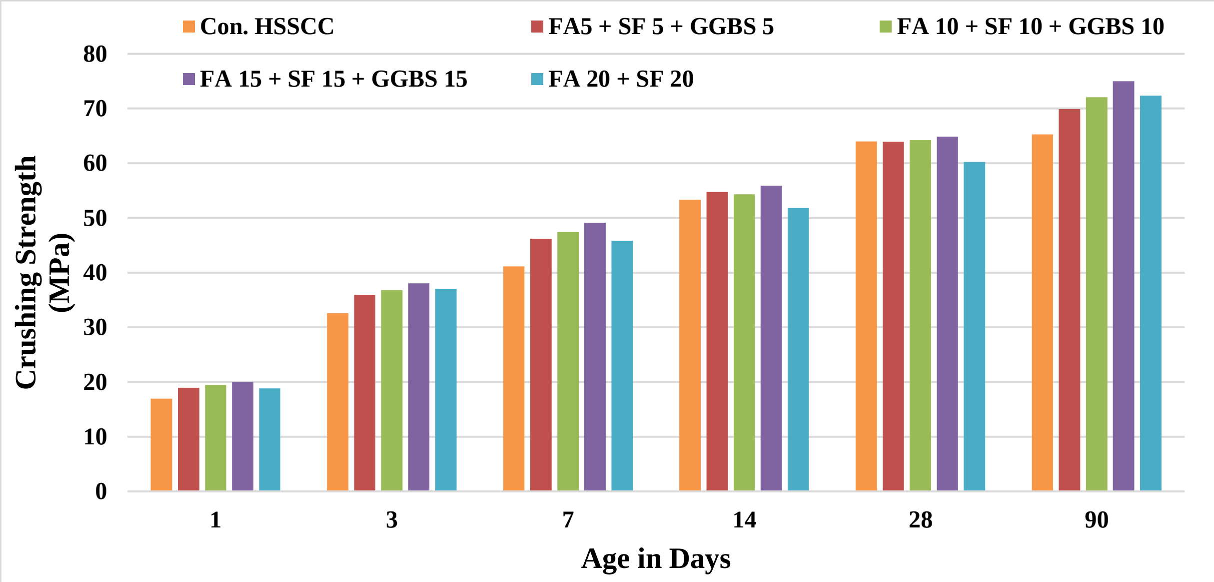

Fig. A: - for w/c ratio of 0.3

3.2.2 Split Tensile Strength

The 28 day fracture tensile power findings are shown in List 4. When differentiated to all other blend proportions, FA 20 is shown to generate the highest fracture tensile power. Regardless of the liquid to powder ratio and the % substitutions of mineral additives, the split tensile strength improves as the crushing power does. All proportions other than SF5 and GGBS5 in SF and GGBS pairings give more potency. Findings for the 28 days fracture tensile power exhibited in List 4. Comparing FA20 to all other blend possibilities, it is shown that FA20 generates the highest fragmented tensile strength. Independent of the liquid ratio and the relative substitutions of mineral additives, the fragmented tensile strength likewise improves as the crushing force does. All proportions other than SF5 and GGBS5 give stronger potency in SF and GGBS pairings.

3.2.3 Flexural Strength

List 4 summarizes the findings of the 28 days flexural power trial. As possibly observed that, FA20 provides its greatest bending power at a liquid to solid proportion of 0.3. The 28 days force readings of GBBS 5, GGBS 10, and GGBS 15 are 1.68%, 0.38%, and 8.20%, respectively, greater as compared to the standard SCC blend at the liquid proportion of 0.3.

List 4 Outcomes of split-tensile capacity and flexural capacity at day 28

Sr. no.	**Mix ID**	**w/c ratio = 0.3**	
		Split tensile strength (Mpa)	**Flexural strength (Mpa)**
1	**Conv. SCC**	4.2	11.2
2	**FA5 + SF 5 + GGBS 5**	4.2	11.3
3	**FA 10 + SF 10 + GGBS 10**	4.4	9.4
4	**FA 15 + SF 15 + GGBS 15**	4.6	9.9
5	**FA 20 + SF 20**	4.65	13.45

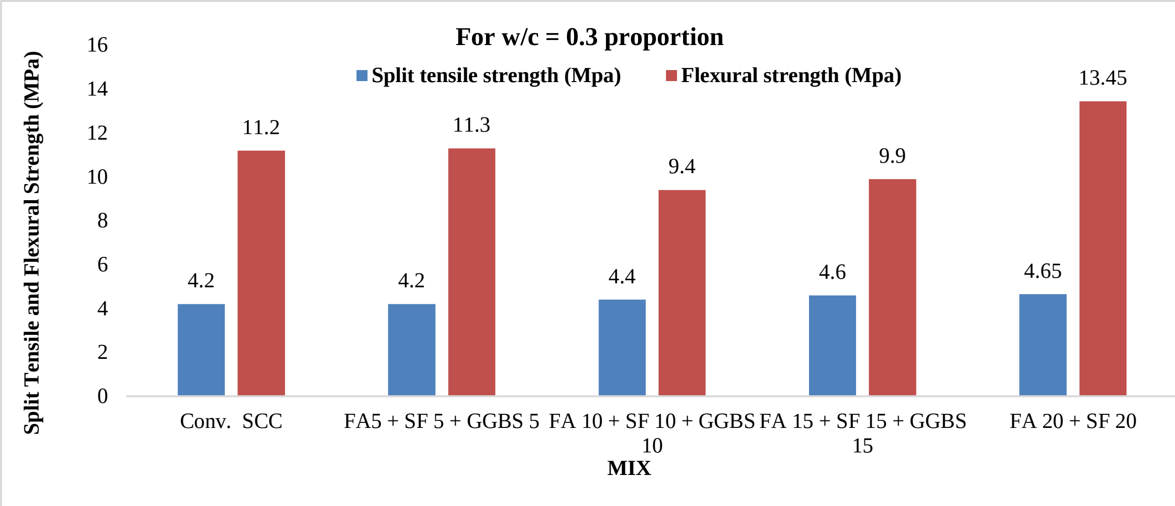

Figure: - Outcomes of split-tensile capacity and flexural capacity at day 28 for w/c=0.3

4. Conclusions

The slump flow limit for the SCC blends is within 624 mm and 800 mm, the inflow duration is under 6 sec., and the V-cone time is within 2.4 and 7.2 seconds. For all blends, the L-box relation is more than 0.8, and the variation between the elevations of the concrete in the two chambers of the U-box limits from 20 to 30 mm. In comparison to GGBS and silica dust blends, fly ash-added assortments have a much better flow property. Following FA20 are GGBS15 and SF15 in terms of increased power-driven qualities relative to all other blends at all stages. The opening-blocking interaction among silica fume and GGBS is what causes the increase in divided tensile strength.

Crushing strengths between 40 MPa and 73 MPa are mixed in the SCC. The characteristics of the SCC in its new and solidified forms are significantly influenced by the mineral admixtures. The findings show that an excellently functioning SCC may be created by utilising fly ash, GGBS, and silica fume, which are all readily accessible in the vicinity. The rheological qualities fell within the recommendations' allowed ranges (EFNARC, 2005) [19]. It is determined that the trial findings support the utilisation of fly ash, silica powder, and G.G.B.S. in the production of SCC. Through the use of G.G.B.S., fly ash, and silica dust to create green concrete on a massive scale, humanity might potentially save the ecosystem and achieve longevity.

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