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MECHANICAL PROPERTIES OF HIGH STRENGTH SELF COMPACTING CONCRETE BASED ON RHEOLOGICAL MIX PROPORTIONING

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Abstract

The main problem is to raise the standard of construction, rethinking concrete's expanding potential as a construction material. The scarcity of river sand as a fine aggregate ingredient is currently a widespread issue for many concrete plants. As a result, quarried stones that were accessible locally were used as fine aggregate. Crushed Rock Particles, also known as crushed sand, performs better in terms of fresh characteristics since there are more fines present in CRF than in river sand. The current study additionally examines the relationship between plastic viscosity and the fresh and hardened SCC properties. As a partial substitute for Ordinary Portland Cement, Fly Ash and Ground Granulated Blast Slag blends are used to generate binary and ternary. The experimental tests satisfactorily validate the suggested blend design. The results shown that SCC mixture with ternary blend, binary blend with GGBS, fly ash, and blend with pure OPC are suitable for creating fresh characteristics. Additionally, it was found that a cohesive and workable mix was produced when 100 % CRF was used in place of sand.

Keywords:

Rheological mix proportion;
High strength self compacting concrete;
Crushed rock particles;
Fly ash;
Ground granulated blast slag.

1 Introduction

It is a significant challenge for the designer to produce a sustainable and environmentally friendly concrete considering the need for high rise constructions. Utilizing the materials that are readily available locally is another crucial component of making concrete. Concrete is used mostly in building across the world. Therefore, implementing novel approaches to improve the usability of concrete is essential. Concrete's raw ingredients are crucial to achieving the appropriate qualities that meet a site's or a lab's criteria. This introduces the use of High-Performance Concrete (HPC), a concrete mix that combines performance and uniformity. When it comes to casting, curing, and durability, traditional concrete falls short compared to HPC. Self-compacting concrete (SCC) produces structural parts with exceptional performance and durability because it can flow through the small crevices between reinforcement bars and fill formwork with its weight without bleeding or segregation. Increased powder content and decreased gravel to water-to-powder volume ratio (VW/VP) in the presence of a high-efficiency polycarboxylate super plasticizer result in SCC's excellent fluidity and segregation resistance [1]. When some concrete possesses high levels of strength, durability, and dependability, it is referred to be HPC [2].

In terms of achieving desirable workable mixes, Self-Compacting Concrete (SCC) is one form of HPC that has favourable features. It has become difficult for researchers and the building sector to produce effective mixes that satisfy both fresh and hardened qualities since the notion of SCC was introduced to the industry. Utilizing materials that are readily accessible locally to minimize the project's overall cost is one of the more difficult parts of most building projects. Because of a recent shortage of river sand in India, numerous building projects have gone over budget. This is because many of the construction projects had to be stopped. By using locally accessible materials like stone dust, artificial sand, and crushed rock fines that are supplied from quarries, situations like these may be avoided.

The idea of SCC was initially introduced in 1986 by Okamura, thereafter by Ozawa [3]. At the University of Tokyo, a prototype was created in 1988 [3]. Self-Compacting Concrete manufacturing has increased significantly during the past 20 years. SCC is superior to conventional concrete in many ways, including a) lower labour costs, less noise pollution, and shorter construction times; b) the ability to fill structural members that are heavily loaded; c) increased structural durability; and d) improved structural performance. In order to produce 1 metric ton of cement, 1 ton of carbon dioxide must be released into the environment (Concrete Fact Sheet 2008). In order for SCC mixes to be sustainable, there must be a decrease in the quantity of cement used in the concrete mixtures, resulting in a large decrease in CO_2 emissions. The use of fly ash (FA) and other supplementary cementitious materials (SCMs), including ground granulated blast slag (GGBS), will reduce CO_2 emissions and increase the sustainability of the mix. The stability and flow capacity of SCC are its primary qualities. The amount of natural sand resources that are readily available is constrained by the exponential rise of construction activity. The marble industry has produced enormous amounts of garbage recently, and this waste is growing drastically over time. Marble trash is frequently a highly contaminated type of industrial waste, posing serious health dangers to the environment due to its extremely alkaline content as well as its manufacturing and processing procedures [4]. A by-product of the manufacturing processes for steel and iron is slag. Fine mill scale, coarse boulders, and dust are the three types of material produced, however coarse boulders are the most troublesome since they build up over time and harm the environment. When making concrete, these boulders can be utilised as aggregates after being crushed up into tiny pieces [5]. The effects of replacing natural coarse or fine aggregates with coarse or fine SSA on SCC were examined by [6]. With a 12.5 % increment percentage, several replacement ratios between 0 and 50 % were tried. Fresh-state testing, hardening state tests, and durability characteristics tests were all included of the study. The test findings showed that adding SSA to SCC mixes increased their mechanical strength and durability. Along with this, the improvements were more noticeable when greater ratios of steel slag were added, as well as when coarse SSA was used to replace the coarse natural aggregate rather than fine SSA. Self-compacting concrete, or SCC, is a distinct type of concrete composition because of the concrete's high flow capacity. Self-compacting concrete fills formwork and encloses reinforcement while compacting under its own weight and spreading in empty places. It does not cause excessive bleeding or segregation. Additionally, mechanical consolidation is not necessary [7-8]. In order to maintain a specific viscosity fresh mixture and a satisfactory yield value, self-compacting concrete frequently contains a sizeable amount of powdered material. Using fine ingredients. It is necessary to use materials, such as fly ash, silica fume, and powdered granulated blast-furnace slag, to create SCC that complies with European Guidelines for Self-Compacting Concrete, or (EFCAA), according to earlier research [9-10]. The desired compressive strength & plastic viscosities of the SCC mix were used to create a mix design procedure by [11]. Target compressive strength and plastic viscosity of the SCC mix are the inputs used in this technique. This idea was used to construct a range of mixes with plastic viscosities values varies from 3 to 15 Pa s and concrete compressive strength values varies from 30 to 80 MPa [12]. Based on the data gathered above, design charts were also created to facilitate the design process. The resilience necessary for developing SCC blends was discussed [13]. They investigated how the volume of the paste affected the proportion of water to powder. Results indicated that mixtures with low yield stress and high plastic viscosity have lower resilience [14]. Additionally, they stated that since plastic viscosity contributes to the stability of mixtures, robustness might be decreased by increasing the water to powder ratio. In order to preserve ecological sustainability [15], Long *et al.* [16] suggested an appropriate mix design of SCC based on optimal packing density. Their suggestion reduced the amount of necessary binder by 16 %, the amount of CO_2 emitted by 33.98 %, and the cost of materials by 6.24 % [17]. Concrete's decreased workability caused by CRF can be made more workable by reducing the aggregate size and adding mineral admixtures such fly ash. According to [18], the aggregate's physical characteristics, such properties as its specific gravity and water absorption, which vary from 2.6 to 2.7 and 0.5 to 1 %, respectively, are nearly equal to those of natural sand [19]. The decay of concrete might be brought about by the seriousness of the earth or by the interior changes with the solidified concrete [20].

Self-compacting concrete (SCC) provides various advantages over conventional concrete in terms of manufacture and installation, including less need for internal or external vibration for compaction, improved flowability, workability, and pumpability, as well as improved bonding with crowded reinforcing.

2 Experimental program

The mechanical properties of high-strength self-compacting concrete have been the subject of the current experimental investigation, which was based on rheological mix proportioning cubes, cylinders and prisms through how plastic viscosity affects the fresh and hardened characteristics of SCC. The research was targeted to study the fresh and hardened concrete characteristics as partial substitute for Ordinary Portland Cement, SCC mixes are made by combining Fly Ash (FA) and Ground Granulated Blast Slag (GGBS) in binary and ternary blends at various ratios of (OPC). The experimental tests satisfactorily validate the suggested blend design. According to the results, SCC mixes well with ternary blends, binary blends with GGBS, fly ash, and pure OPC are excellent for achieving fresh qualities. Additionally, it was found that a cohesive and workable mix was produced when 100 % CRF was used in place of sand.

2.1 Materials

Design mix proportions are considered as per IS: 10262-2019 and presented in Table 2. Table 2 demonstrates the constituents required for 1 m^3 of concrete utilization in creating the concrete mix to get a target mean compressive strength of 59.9 N/mm^2. Table 3 presents, both the tensile and compressive strengths of the concrete mixture, showcasing nine standard cubic specimens 150 mm x 150 mm x 150 mm, that were cast and evaluated for compressive strength at ages of 3, 7, and 28 days in accordance with IS 456:2000. Nine cylinders samples with a height and diameter of 300 mm and 150 mm respectively were tested using procedure of the splitting tensile test, according to is 456:2000. The mechanical properties of the mild steel used are as per IS 1608 (part 1), and values are summarized in Table 3 are confirmed to the provision of IS 1786 2008. Tests were conducted on ordinary Portland cement, fine and coarse aggregate used according to the ASTM C-150 3.

Cement: The present study employs use of 53-grade Ordinary Portland Cement (OPC). Tables 1 and 2 display the physical and chemical characteristics.

Fly ash: The Ramagundam, Telangana-based National Thermal Power Coal Plant provided Category F Fly ash with a low calcium content for the current inquiry. Tables 1 and 2 display the physical and chemical characteristics.

GGBS: Sources for ground granulated blast slag include Jindal Steel Works, Vijayanagar, and Karnataka. Tables 1 and 2 display the physical and chemical characteristics.

Fine aggregate: For the current study, Crushed Rock Fines (CRF), which are locally accessible, are employed as a fine aggregate. It was an IS 383: 1970 confirmation. To make sure that the organic contaminants are kept to a minimum, CRF was used over river sand. 2.67 is the specific gravity that was employed in this investigation. Zone II is indicated by the obtained fineness modulus of 2.

Coarse aggregate: For the current experiment, coarse aggregate of the basalt type with a maximum particle size of 20 mm is employed. All of the mixes used in the current investigation combined aggregates of 10 mm and 20 mm in size. The aggregates utilized in the current study's specific gravity and water absorption were 2.72, 4.7 % for 10 mm, and 1.7 % for 20 mm, respectively.

Admixture: Master Glenium Sky 8233, a new generation water reducer superplasticizer based on modified polycarboxylic ether, is employed in the current investigation. It is a light brown liquid. It is determined to utilize a 1.07 specific gravity at 250.

Water: Based on its typical good performance, for mixing and curing tasks, potable tap water is used.

Proportioning of mixes: In addition to the control mix with pure OPC, SCC with two binary mixes and one ternary mix are considered for the experimental research. In addition to cementitious ingredients, other materials are employed, and their corresponding proportions are indicated, including fine aggregate, coarse aggregate, water, and superplasticizer.

Mixing, casting and curing: The raw components are mixed in the necessary amounts using a forced type of pan mixer. For each mix, the full mixing process takes 10 minutes to complete. For the whole experimental investigation, four combinations of mixtures are adopted with three assumed plastic viscosities.

Table 1: Chemical properties of ordinary Portland cement, fly ash and GGBS.

Mix proportions [kg/m^3]			
Chemical composition [%]	**OPC**	**Fly ash**	**GGBS**
CaO	65.23	1.78	40.64
SiO_2	18.63	60.13	35.15
Al_2O_3	5.71	28.37	19.60
Fe_2O_3	4.53	5.10	0.53
SO_3	4.32	0.11	1.89
K_2O	0.59	2.16	0.40
T_iO_2	0.49	1.42	0.92

Table 2: Physical properties of ordinary Portland cement, fly ash and GGBS.

	OPC	**Fly ash**	**GGBS**
Specific gravity	**3.15**	**2.18**	**2.89**

2.2 Plastic viscosity based proportioning of SCC mixes

1) Selecting the appropriate grade of concrete is the first stage. The water to cement ratio is then determined depending on the grade of concrete.

2) Based on the water to cement ratio discovered in step 1, the plastic viscosity of the paste is to be adopted (1). The values of the paste's plastic viscosity are determined either by measurement with a Brookfield viscometer or from readily available standard literature. These results were acquired using a Brookfield Viscometer for the current investigation.

3) A trial plastic viscosity of the mixture must be selected based on the desired workability of the mix. T50 time grows in line with the mix's increasing plastic viscosity. The plastic viscosity of the mixture will be on the greater side with the addition of fibres.

4) Depending on the overall workability of the mix, adopt an appropriate water content between 150 and 210 kg/m^3 as per the normal EFNARC recommendations.

5) Total cementitious content must be determined using the known water to cement ratio and water content. Depending on whether there are binary or ternary additions, the total cementitious content is made up of a mix of OPC, fly ash, and GGBS.

6) For binary blends and ternary blends, the percentages of GGBS and fly ash to replace OPC are set as shown below.

Table 3: Physical characteristics of GGBS, fly ash, and ordinary Portland cement.

OPC	**Fly ash**	**GGBS**
100	0	0
70	20	10
70	30	0
70	10	20
70	0	30

7) To ensure the SCC mix has the necessary workability, a trial super-plasticizer dose of a percent of the cementitious material is employed.

8) Individual ingredient quantities, such as the amounts of coarse and fine aggregate to be added, can be calculated using the volume fractions of the materials derived from equation (2) and (3). A random selection of t_1 and t_2 is made such that t_1 x t_2 = 1. Each one of them is a factor that denotes the volume proportion of fine and coarse aggregate.

$$\eta_r = 1 + 2.5\phi\left(1 + \frac{25\phi}{4a_1^3}\right), \tag{1}$$

$$\eta_r = 1 + [\eta]\phi + B\phi^2 + C\phi^3 + ... \tag{2}$$

9) 1 m^3 should make up the entire volume of the mixture. To guarantee that the overall volume is equivalent to 1 m^3, the necessary changes must be done.

10) Using the determined raw material proportions, equation (1) is utilised to calculate the plastic viscosity of the mixture. The calculated plastic viscosity and the expected plastic viscosity from step 3 should deviate by no more than 5 %. If the difference is greater, other volume fraction settings for the elements in the solid phase, such as the fine and coarse aggregates, must be chosen, and steps 9 and 10 must be repeated.

$$\eta_{mix} = \eta_{paste} * \left(1 - \frac{\phi_{FA}}{0.63}\right)^{-1.9} * \left(1 - \frac{\phi_{CA}}{0.74}\right)^{-1.9}. \tag{3}$$

3 Results and discussions

Concrete that has been hardened on cubes, cylinders, and prisms has been tested for compressive strength, split tensile strength, and flexural strength. The slump flow, v-funnel result and j-ring results on fresh concrete have been assessed through experimental work.

3.1 Fresh properties

To verify for filling, passing, and segregation resistance criteria, the characteristics of SCC in its fresh form are evaluated. All tests are conducted in accordance with the European recommendations provided in EFNARC. According to EEFNARC recommendations, the typical range of values for fresh characteristics are presented in Table 3. The characteristics that were looked at were slump flow diameter, slump flow time T50, and V-funnel flow time. Table 4 displays the qualities of recently placed concrete.

Table 4: Fresh concrete properties.

	Slump Flow [mm]	T50 [s]	V-Funnel [s]
Minimum	650	2	6
Maximum	800	5	12

Fly ash combinations have better deformability than mixes containing GGBS because of their weight. Due to the spherical form of the fly ash particles, a partial cement substitution will result in an increase in paste content, which will improve the mix's cohesiveness and workability. Slump flow reduced as the mix's plastic viscosity increased. A decrease in paste content along with an increase in solid content for a rising plastic viscosity may lessen sludge movement.

The reported slump flow time (also known as T50) for each SCC mix is between 1.5 and 2.4 seconds, Fig. 1. A close indicator of the mix's viscosity is T500. It grew when the mixture's plastic viscosity improved. When a good surface smoothness is required, this attribute serves as a useful indicator. Considering that the suggested mix design is based on the plastic viscosity of the mix, the computed values for T500 are in good agreement with the viscous behaviour of SCC mixtures.

Fig. 1: Slump flow test set up.

The distance of lateral flow of concrete is measured using a J-Ring and a slump cone mould to evaluate the passage capacity of SCC mixtures. When J-Ring spread is tested, results range from 665 mm to 710 mm, Fig. 2.

Fig. 2: J-ring test set up.

Because the majority of the aggregate utilized is smaller than 20 mm, the mix has a good spread that enables it to travel through the reinforcement-shaped barriers with minimal blockage. The difference between slump flow and J-ring flow for all combinations is less than 25 mm in good compliance with (ASTM C 1621/C 1621M), indicating that the concrete has a strong capacity to pass, Fig. 2. The V-funnel test is used to examine viscosity and filling capacity in terms of the amount of time the mix flows. The measured V-funnel times for SCC mixtures were between 6 to 10 seconds, Fig. 3, which is in excellent accord with EFNARC recommendations.

Fig. 3: V-funnel setup.

The V-funnel time for SCC mixes demonstrates the dependability and compliance of the proposed mix design based on plastic viscosity with the existing standard criteria. Because of the decreased paste concentration, mixtures with rising plastic viscosity had longer flow times. The use of 100 % CRF as fine aggregate is another component that contributes to the mix's improved performance.

3.2 Hardened properties

Concrete's compressive strength is calculated using a 200 ton compressive Testing Machine. Compressive strength is always influenced by a variety of variables, including the quantity of coarse aggregate, the kind of cement replacement material, the water to cement ratio, the plastic viscosity of the paste, and the anticipated plastic viscosity of the mix. Fig. 4 displays the concrete cube's compressive test results. Fig. 5 depicts the split tensile strength test for concrete. Fig. 6 depicts the flexural strength of concrete beams.

Fig. 4: Compressive test of concrete cube.

Fig. 5: Split tensile strength of concrete.

Fig. 6: Flexural strength of beams.

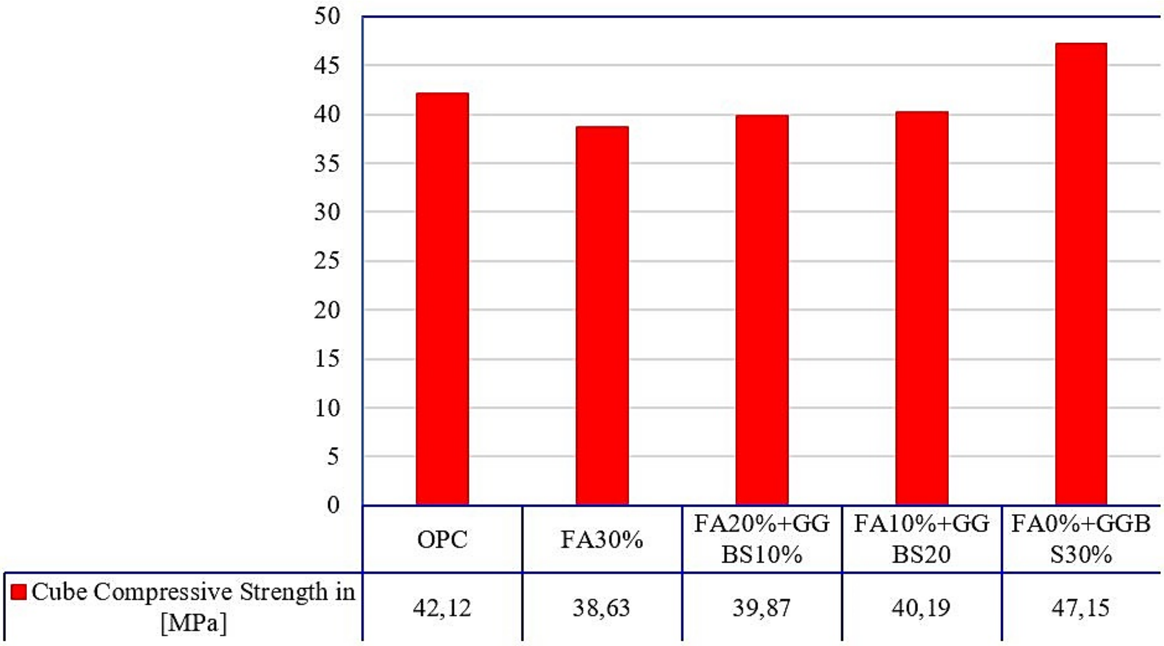

Fig. 7: Blended concrete cubes compressive strength in MPa (7 Days).

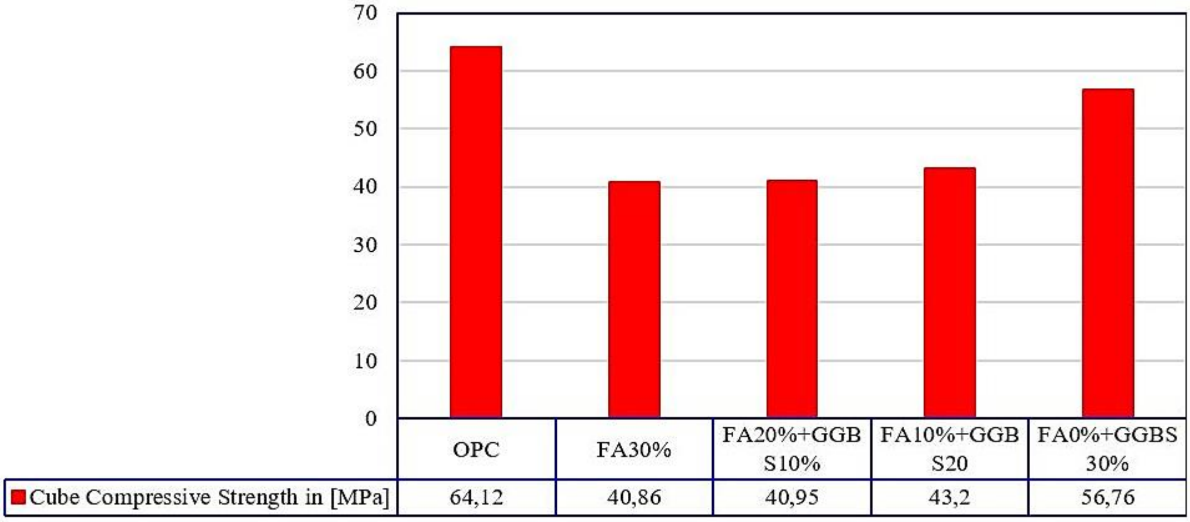

Fig. 8: Blended concrete cubes compressive strength (28 days).

The blended concrete cubes compressive strength at 7 days curing is shown in Fig. 7 and Fig. 8 shows the blended concrete cubes compressive strength at 28 Days curing. From Fig. 7, it is noticed that self-compacting concrete (SCC) mix with 100 % OPC produced maximum compressive strength of 42.12 MPa, whereas 30 % fly ash replacement has obtained compressive strength was 35.36 MPa. The replacement of 20 % fly ash + 10 % GGBS was obtained 36.5 MPa. The replacement of 10 % fly ash + 20 % GGBS has obtained 36.8 MPa compressive strength and 30 % GGBS replacement has shown 43.17 MPa of compressive strength for 7 days. From Fig. 8, it is observed that, 100 % OPC has shown 64.12 MPa of compressive strength, whereas 30 % fly ash replacement has shown compressive strength was 40.86 MPa. The replacement of 20 % fly ash + 10 % GGBS has shown 40.95 MPa of compressive strength. The 10 % fly ash + 20 % GGBS has shown 43.2 MPa compressive strength and 30 % GGBS replacement has shown 56.76 MPa of compressive strength for 28 days. The compressive strength of SCC mixes with 30 % fly ash substitution decreases by 8.29 % after 7 days and by 36.36 % after 28 days. The compressive strength of SCC mixes with 20 % fly ash + 10 % GGBS substitution decreases by 5.34 fly ash+ 20 % GGBS replacement decreases by 4.56 % after 7 days and by 32.62 % after 28 days. Whereas the compressive strength of SCC mixes with 30 % GGBS replacement increased by 11.95 % after 7 days and decreased by 11.47 % after 28 days as shown in Fig. 7 and 8.

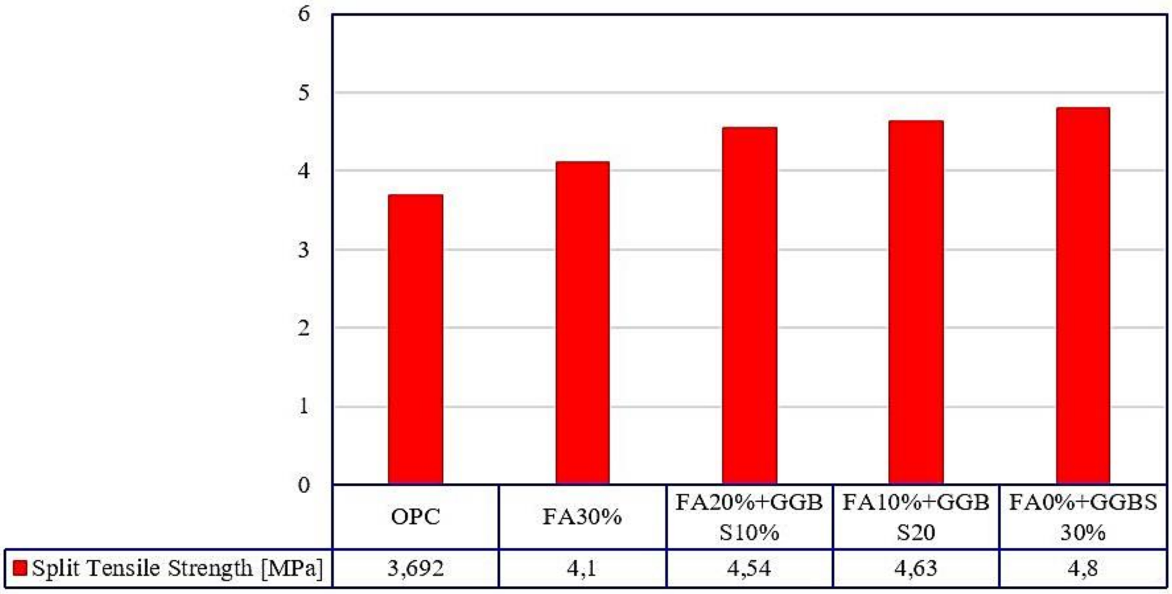

Fig. 9: Split tensile strength of concrete.

SCC mix with 100 % OPC produced maximum split tensile strengths of 3.692 MPa, whereas 30 % fly ash replacement has shown 4.10 MPa of split tensile strength. The replacement of 20 % fly ash + 10 % GGBS has shown 4.54 MPa of split tensile strength, while 10 % fly ash + 20 % GGBS has shown 4.63 MPa and 30 % GGBS has shown 4.8 MPa of split tensile strength for 28 days. The split tensile strength of SCC mixes with 30 % fly ash substitution increases by 11.05 % after 28 days. The split tensile strength of SCC mixes with 20 % fly ash+ 10 % GGBS substitution increased by 22.96 % after 28 days. The split tensile strength of SCC mixes with 10 % fly ash + 20 % GGBS replacement increases by 25.40 % after 28 days. Whereas the split tensile strength of SCC mixes with 30 % GGBS replacement increased by 30.01 % after 28 days as shown in Fig. 9.

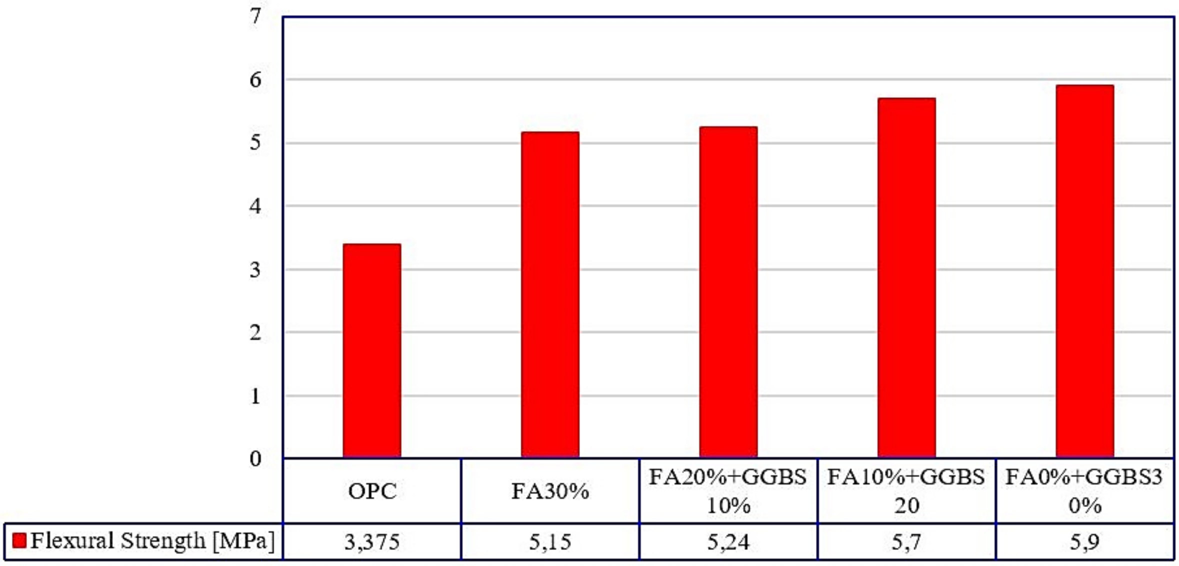

Fig. 10: Flexural strength of beams.

SCC mix with 100 % OPC produced maximum flexural strengths of 3.375 MPa, whereas 30 % fly ash has shown 5.15 MPa of flexural strength, whereas 20 % fly ash + 10 % GGBS has shown 5.24 MPa of flexural strength. The replacement of 10 % fly ash + 20 % GGBS has shown 5.7 MPa flexural strength and 30 % GGBS replacement has shown 5.9 MPa of flexural strength for 28 days. The flexural strength of SCC mixes with 30 % fly ash substitution increases by 52.59 % after 28 days. The flexural strength of SCC mixes with 20 % fly ash + 10 % GGBS substitution increased by 55.25 % after 28 days. The flexural strength of SCC mixes with 10 % fly ash + 20 % GGBS replacement increases by 68.88 % after 28 days. Whereas the flexural strength of SCC mixes with 30 % GGBS replacement increased by 74.81 % after 28 days as shown in Fig. 10.

4 Conclusions

The first successful effort at a plastic viscosity-based mix design strategy for SCC using a mixture of 100 % CRF and ternary mixes has been made. Considering the experimental studies and analytical formulations, the following conclusions have been drawn.

1) It has been noted that the components of the mix are influenced by the paste's plastic viscosity. The type of cementitious material, the proportion of water to cement, and the quantity of superplasticizer are the main determinants.

2) Measurements of the T50 and V-funnel times reveal that both values are in excellent accord with the recommended mix design and the anticipated plastic viscosity of the mix. Plastic viscosity and T50 have a direct relationship.

3) The suggested mix design provides high flowability and stability for SCC mixes as measured by the lump flow diameter and duration, which are comparable to the standard EFNARC recommendations.

4) As the plastic viscosity of the mix grew, Slump Flow, T500, and J-ring spread increased while V-funnel and L-box decreased.

5) Various experiments on the filling and passing properties of SCC mixes revealed that the mixes with CRF performed better than the mixes with river sand. This is explained by the fact that CRF has more particles and river sand contain more silt.

6) For a given plastic viscosity of the mixture, river sand-based SCC mixes showed poorer compressive strength, split tensile strength, and flexural strength as compared to SCC mixes prepared with CRF.

7) Compressive strength, flexural strength and split tensile strength all shown relatively lower values when the mix’s plastic viscosity increased because of the paste's volume being reduced, and the solid’s volume being increased.

8) For all of the chosen plastic viscosities, SCC mixtures with 100 % OPC exhibit the greatest strength.

9) It's also suggested to proportion the chosen M40 grade of concrete using a ternary mix with CRF as the fine aggregate and a plastic viscosity of 9.

5 Future challenges

The following future scope shall be undertaken as future challenges of this current research:

1) Experimental studies on concrete components with elevated temperatures.
2) Studies on concrete components with sulphate attack.
3) Experimental studies on concrete components with durability studies using sulphuric acid.

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