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Investigation of superplasticizer influence on rheological and strength properties of self-compacting geopolymer concrete

ABSTRACT

Self-compacting concrete plays a crucial role in the concrete industry due to the increasing demand for rapid infrastructure development to accommodate the growing population. However, traditional concrete requires a large amount of cement, leading to significant CO_2 emissions during production. To address this issue, an innovative self-compacting geopolymer concrete (SCGC) has been developed, eliminating the need for cement while maintaining key self-compacting properties such as flowability, passing ability, and filling ability, along with desirable hardened characteristics.The self-compacting behavior of SCGC is influenced by the dosage of superplasticizers (SP), which significantly improves its workability. Four SCGC mixes were prepared with varying SP dosages at 2% intervals (ranging from 0% to 6%), using 450 kg/m³ of fly ash and a Na_2SiO_3 to NaOH ratio of 1:2.5. The alkali solution-to-binder ratio was maintained at 0.45, with additional water at 54 kg/m³. The effect of SP dosage on workability and mechanical strength was analyzed in the SCGC mixes. The results indicate that an SP dosage of 2% was optimal at a NaOH molarity of 12, yielding the best rheological and strength properties. Based on these findings, it is recommended that the SP dosage in SCGC be optimized at 2%.

Keywords: *Self-consolidating geopolymer concrete, Coal fly ash, Superplasticizers, Master Gelnium SKY 8233.*

1. INTRODUCTION

Globally, concrete is the most popular construction material because of its versatility, strength and longevity [1]. Furthermore, it is a commonly used material on Earth after water and construction projects require around 30 million tons and increase four times higher in 2050, which shows a significant demand for concrete in construction activities [2].Traditional concrete has many problems such as skilled labourers required for compaction, and mechanical vibrators required to attain void-f ree concrete [3]. However, concreting in the congested reinforcementis much more difficult to pore without voids. Insufficient compaction can lead to voids and poor bonding with aggregates and cement paste, whichleads tohoneycombing and concrete strength reduction [4]. Furthermore, uncompacted concrete allows water and other aggressive substances to penetrate more easily, resulting in increased permeability and reduced durability of the structure [5].

The quality and durability of concrete structures can be adversely affected by insufficient compaction in construction [6]. For instance, the voids of concreteaffect the protection of embedded steel reinforcement [7]. However, Self-Compacting Concrete (SCC) has the potential totake upthese challenges and overcome the insufficient compaction in the concrete [8]. Recently, SCC has been the most important developmentof building constructiondue to flowability behaviorwhich can fill in heavy reinforcements.As a result, the concrete does not require external vibration to be compacted to reach its strengthand the bonding between

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coarse aggregate and fine aggregate can be enhancedalso, it can be used in pre-cast applications or for concrete placed on site [9,10].

On the other hand, pollution isthe most critical problem in the modern worlddue to fast-growing industries, urbanization, and changes in lifestyles which emit lots of pollutants [10].Among all, the cement and concrete industries are contributing significantly which accounts for 6 to 8% of global CO_2 emissions [11]. Therefore, immediate attention and action are needed to reduce pollution and maintain sustainability [12].Geopolymer concrete and alkali-activated concrete can be used as the primary binding material rather than Portland cement [13]. Also, utilization of alternative materials like fly ash (FA), GGBS, or other industrial byproductsas binders through chemical reactions [14]. Also, GPC is famous for its lower environmental impact than traditional concrete [15]. Moreover, FA and GGBS are used to improve the concrete properties, such as strength, durability, and workability [16]. In order to enhance the workability and flowability of the concrete mix without compromising strength and longevity, water-reducing admixtures, such as superplasticizers (SP) can be used [17]. In addition, the proper aggregategrades can help togain optimum compaction by reducingvoids and segregation during placement which can improve the fluidity and cohesion of the concrete mix and promote self-compaction [18].

GPC with self-compaction offers dual benefits such as waste minimization and environmental concern in the construction industry. Geopolymer precursors, obtained from industrial secondary products, can significantly reduce carbon dioxide emissions associated with cement production and utilizing waste materials [19,20].Additionally, self-compacting properties eliminate the need for mechanical vibration during placement, reducing labour requirements and construction time [21]. Generally, self-compacting geopolymer concrete (SCGC) must have good resistance to segregation to maintain the uniformity and homogeneity of the entire mix, ensuring consistent properties and performance in the finished structure [22,23]. The flowability of the SCGC depends on the dosage of SP which helps to flow through narrow gaps, around obstacles or through densely packed reinforcement without clogging and segregation [24,25]. The inclusion of superplasticizers (SP) improves the self-compacting properties [26]. In addition, SP can act as a high-degree water reducer and improve the workability of the SCGC [27]. Hence, optimization of SP dosage on the SCGC helps to achieve workability [28]. There are various SPs like polycarboxylate ether, sulfonated naphthalene formaldehyde, naphtha and mother liquor [29]. Among these, commercially available SP, one of the polycarboxylic ether polymers, namely, MasterGlenium SKY 8233 can improve the rheological character of concrete mixes, such as slump, flow rate and filling capacity [30].Also, it enhances the consistency and uniformity of the mix, resulting in improved handling and paving speed [30]. This superplasticizer canbe compatible with cementitious admixtures, such as FA and GGBS [31]. It can be used in a variety of concrete mixes without adversely affecting setting time or strength development [32]. In this study, the effects of superplasticizer on fresh and hardened behaviors of SCGC, particularly, NaOH molarity of 12 M. The fresh properties of SCGC were assessed by flow ability tests like slump flow test, T_{50cm} Slump flow, V-funnel, and L-box were conducted with FA at 100% and the superplasticizer from 0 to 6%. Also, the compressive strength (CS), split tensile strength (STS) and flexural strength (FS) of SCGC were examined at all ages (7 days and 28 days).

2. MATERIALS AND METHODS

2.1. Fly ash

The class F-based FA was collected from the Tamilnadu Thoothukudi power plant with a specific gravity of 2.1. The crystalline structure of FA was analyzed by Scanning Electron Microscope (SEM). The SEM micrographs show that smooth surface with ball-shaped FA particles, as shown in Figure 1.(A&B) [33]. These SEM images confirm the original morphological structure of FA. Elemental analysis of FA was performed by X-ray diffraction, which is presented in Figure 2. Silica and alumina are the main elemental compositions shown in the EDAX spectrum. The qualitative and quantitative analysis of material composition was performed by XRF spectroscopy and presented in Table 1. The major quantitative chemical compositions of SiO_2 and $Al_2O_3$are 63.16% and 29.69%, respectively. X-ray diffraction (XRD) was done to evaluate the crystallite of FA for quartz (silicon dioxide) and aluminum oxide (Al_2O_3), as shown in Figure 3. The alkaline solution composed of NaOH and Na_2SiO_3(1:2.5), which were mixed and stirred well, 24 hours before casting and had specific gravities of 1.48 and 1.7, respectively. The 12.5 mm of coarse aggregate with a specific gravity of 2.83 was used and manufacturing sand (M-sand) was used as fine aggregate with a specific gravity of 2.73 and fineness modulus of 2.65. The new generation super plasticizer based on polycarboxylic acid ethers, MasterGlenium Sky 8233 from Astra Chemicals, Chennai with a relative density is around 1.08 is used to improve the rheological and flowability of the SCGC.

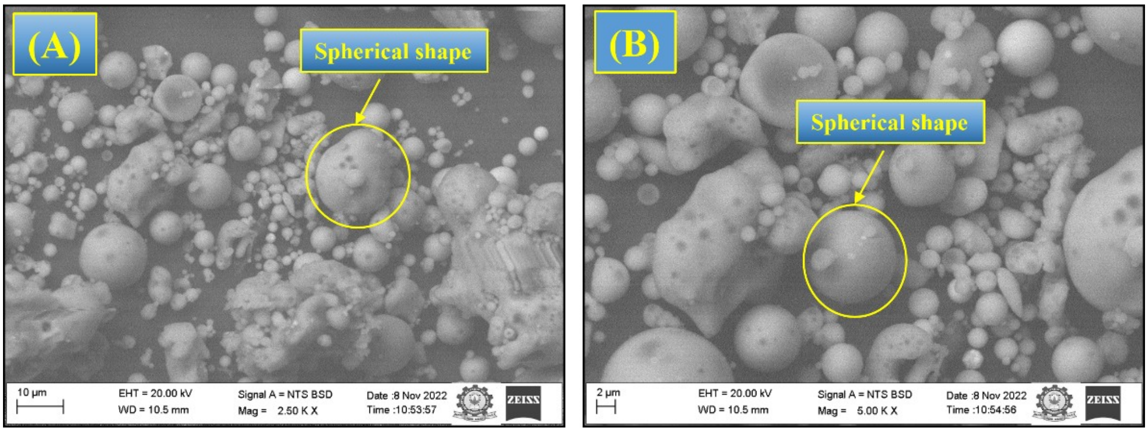

***Figure 1**. Scanning electron micrograph of FA (A&B)*

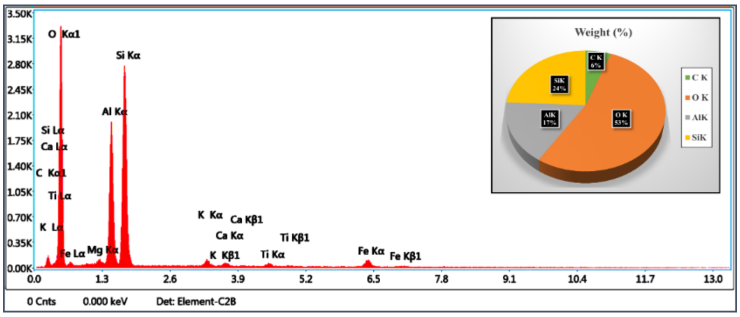

***Figure 2**. Energy-dispersive X-ray (EDX) of FA*

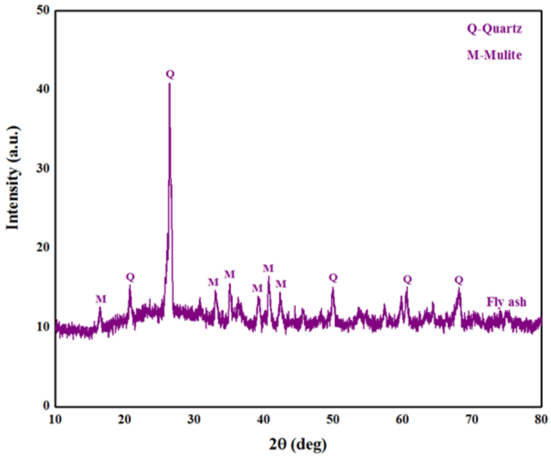

***Figure 3.** XRD pattern of FA*

2.2. Mix Proportion

The SCGC mixes were carried out as per the SCCstandard guidelines [34].The mix designations are SP-0% to SP-6% with 2% intervalsof SCGC mixes prepared with FA of 450 kg/m^3 as binder content. The ratio of Na_2SiO_3 to NaOH is obtained at 2.5 with twelve molarity of sodium hydroxide with a constant binder to alkaline ratio of 0.45. The quantity of water used at 54 kg/m^3, and the mix details adopted in this study are indicated in Table 2.

***Table 1.** Chemical composition of FA*

S. No.	Chemical Composition	FA
1	SiO_2	63.16
2	Al_2O_3	29.69
3	K_2O	1.85
4	TiO_2	1.60
5	C_aO	1.41
6	M_gO	0.99
7	P_2O_5	0.97
8	Fe_2O_3	0.35
9	Na_2O	0.21
10	SO_3	0.16

11	PbO	0.02

Table 2.*Mix proportion of SCGC*

Mix ID	FA kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	NaOH kg/m^3	Na_2SiO_3 kg/m^3	Molarity	SP (kg/m^3)	Additional water (kg/m^3)
SP-0	450	961.08	786.33	57.86	144.66	12	0	54
SP-2	450	961.08	786.33	57.86	144.66	12	9	54
SP-4	450	961.08	786.33	57.86	144.66	12	18	54
SP-6	450	961.08	786.33	57.86	144.66	12	27	54

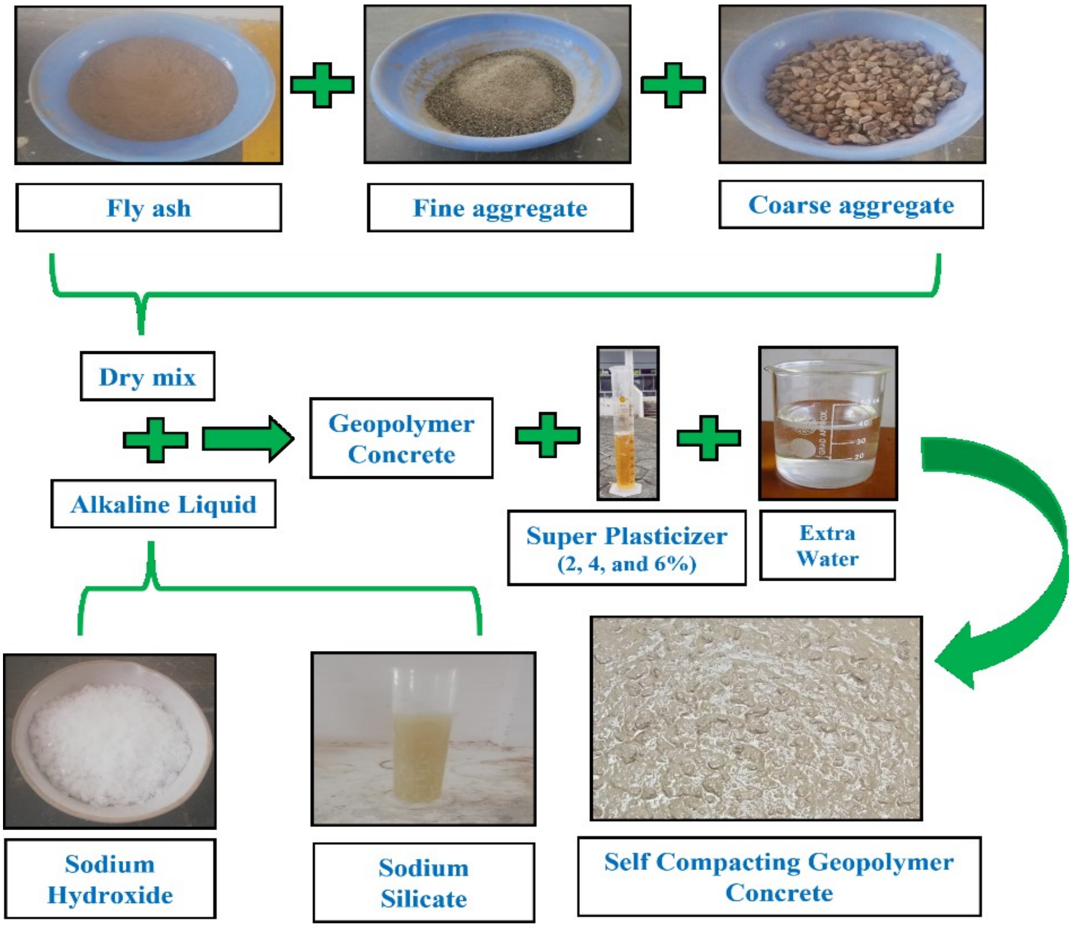

Figure 4. *SCGC production process*

2.3. Blending, casting, process, and curing

FA, aggregates in the saturated surface dry state are mixed by 3 minutes in 100-liter pan mixers. This blending process ensures the uniform distribution of aggregates and FA. After blending, a liquid mixture with alkali activators, SP with additional water is mixed into the mixer. This blending continued for an additional 4 minutes to ensure thorough incorporation of the liquid mixture into the dry ingredients. The SCGC wet mix was placed in the moulds and the molds were then placed in an oven without delay and cured at 70°C for 24 hours. After 24-hour curing period, the moulds were demoulded, and the test specimens were carefully removed.The specimens were then stored at room temperature until they were ready for testing all ages of curing. SCGC production process was depicted in Figure 4.

3. EXPERIMENTAL PROGRAMS

3.1. Rheological properties

A slump flow test (SFT) was done to estimate the fresh flow ability of mixed SCGC with the spread diameter of the concrete as it slumps after being released from a conical mould. It indicates the workability and filling capacity of the concrete mixture. The T_{50cm} slump flow test measures the time taken for the mixture to attain a 50cm diameter after being released from a mould that assesses the flow ability of the concrete. The vertical section (H_1) and the horizontal components (H_2) lead to the concrete flow heights considered in the L-box test (LBT), which helps to measure concrete resistance to the reinforcement. The V-funnel test (VFT) evaluates the flowability and consistency of the concrete by measuring flow with a funnel from standardized opening. It provides information about the flow characteristics and workability of the concrete mixture.

3.2. Hardened properties

The geopolymerconcrete were analyzed for CS, STS and FS after 7- and 28-days curing. Concrete cubes (100*100*100mm) were cast for CS testing. Geopolymer cylinders with radius of 50 mm and 200 mm height with aspect ratio as 2 were cast for STS testing.Prismatic specimens (100*100*500mm) were cast for FS testing. The cubes were tested using CTM as per IS: 516-1959 [35] and the cylinder specimens were tested for STS testas per IS: 5816 -1999 [36]. The prism were tested in a 100 T computerized UTM as per IS 56-1959 [35].

4. RESULTS AND DISCUSSION

4.1. Slump flow test

The SFT was conducted to assess the flow ability and workability of SCGC. The flow spread diameter of the concrete mixture increased with the increase in the SP dosage up to 4% and then decreased as shown in Figure 5.

Slump flows from SP-0 to SP-6 were attained as 620mm,695mm,735 mm, and 640mm respectively and fall within the EFNARC range of 650 mm to 800 mm [37]. The maximum flow was achieved as 735mm at SP-4 and the minimum flow was obtained as 620mm for SP-0.

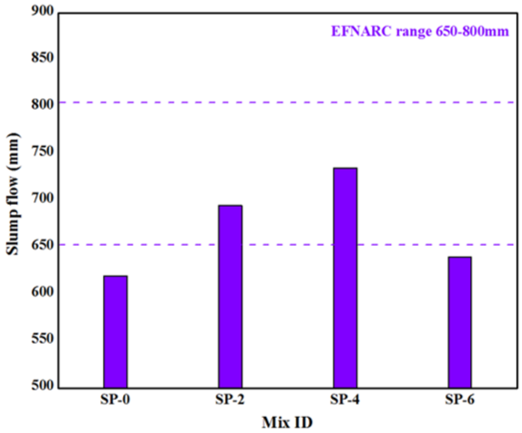

Figure 5. *Slump flow test result*

4.2 T_{50cm} flow time

The time needed for the concrete to spread at a diameter of 50 cm is analyzed by the T_{50cm} test. This test shows the viscosity of the uniaxial flow rate of the SCGC mixture. The results are shown in Figure 6.

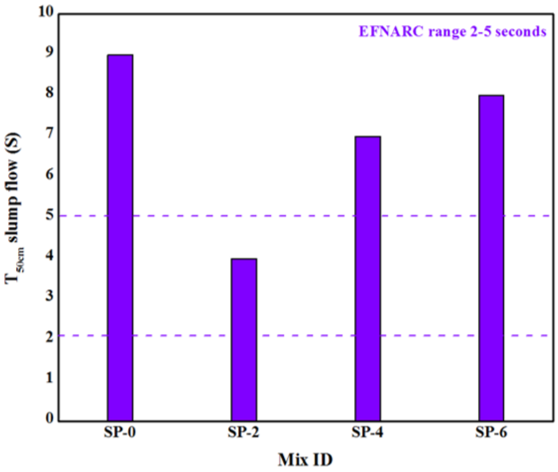

Figure 6. *T_{50cm} flow test result*

According to EFNARC guidelines, for SCGC, the T_{50cm} value should fall within the range of 2 to 5 sec [38].The flows from SP-0 to SP-6 were 9, 4, 7, and 8 sec respectively.The lowest T_{50cm} slump test of 4 sec for SP- 2 and the highest T_{50cm} slump test of 9 sec were recorded for SP-0.

4.3 V-funnel flow time

The VFT is another crucial method for evaluating SCGCfilling ability.The obtained flow values are shown in Figure 7.

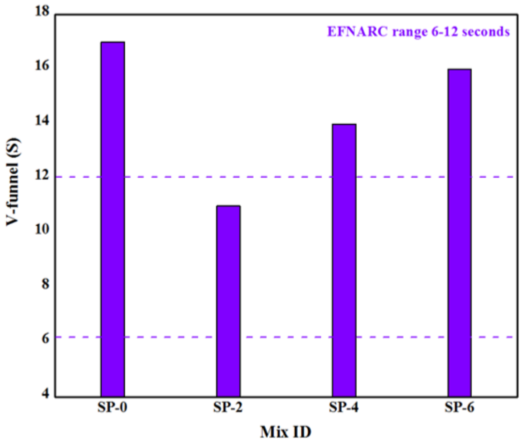

***Figure 7**. V-funnel test result*

According to EFNARC guidelines, an acceptable flow time for SCGC generally falls within 6-12 sec [39]. The flows of SP-0 to SP-6 were obtained as 17, 11, 14, and 16 sec respectively. The minimum flow was11 sec at SP-2 and the highest flow of 17 sec was obtained for SP-0.

4.4 L-box test

The LBT determines the SCGC fresh property to assess the ability of concrete to flow freely and fill intricate forms without segregation or blocking by reinforcement. The ratio between H_2 and H_1 of SCGCs is shown in Figure 8.

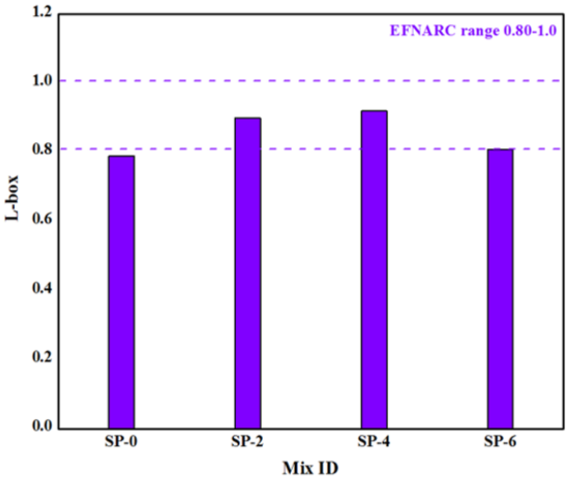

***Figure 8.** L-box test result*

According to EFNARC, the acceptable range for SCGC is between 0.8 and 1.0 [40]. The flow at height ratios obtained from SP-0 to SP-6 were 0.79, 0.90, 0.92 and 0.81 respectively.

4.5. Compressive strength

CS of SCGC evaluated the performance and concrete quality, which is shown in Figure 9.

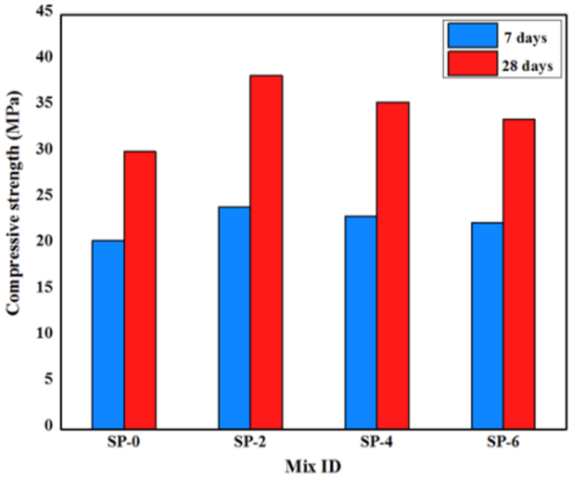

***Figure 9.** Compressive strength of SCGC*

A maximum of 24.17 MPa and 38.42 MPa was observed for SP-2 after 7 and 28 days. The 7-day CS for SP-2, SP -4 and SP-6 developed the strength as 15.18 %, 11.59 % and 8.64% compared to the SP-0. The strength gained was 21.44 %, 15.12 % and 10.41 % compared to the SP-0 for later age. It was observed that 2% of SP enhanced the flowability of SCGC as well as enhanced the compressive strength properties.

4.6. Split tensile strength

The STS with different SP ratios were determined at all ages, which is drawn in Figure 10. The higher STS obtained from SP-2 at 3.14 & 4.22 MPa in early age and later age respectively.

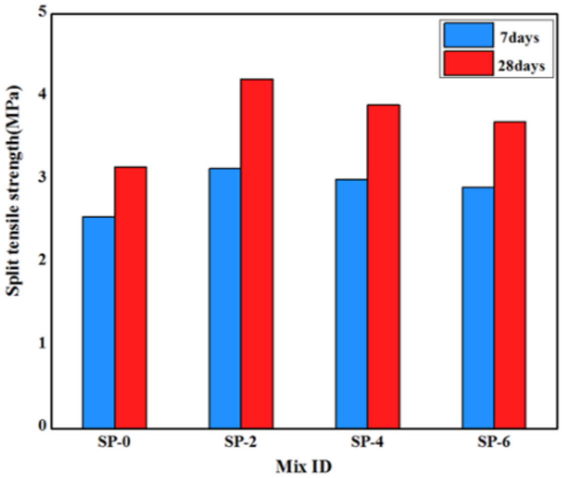

***Figure 10.** Split tensile strength of SCGC*

The 7-day STS for SP-2, SP-4and SP-6 developed an increase in strength of 18.47%, 14.95 % and 12.02% to the SP-0 control specimen. The STS for SP-2 to SP-6 resulted in a strength gain of 25.11 %, 19.18 % and 14.59 % compared with SP-0. The results of the STS test confirm the enhanced behavior of SCGC with a 2% SP.

4.7 Flexural strength

The FS test with SP is shown in Figure 11. The maximum FS was found to be 3.62 for SP-2 & 5.37 MPa after early and later age respectively.

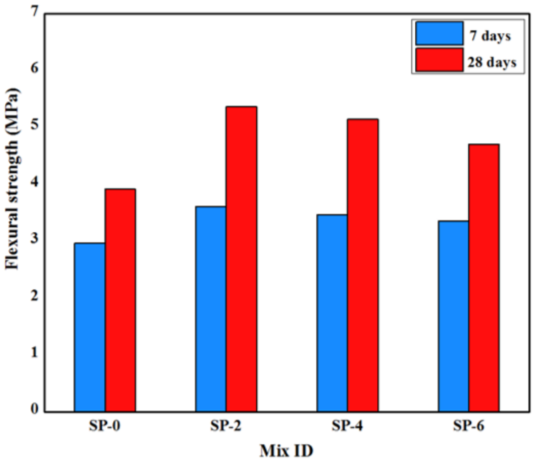

Figure 11. *Flexural strength test result*

The 7-day FS for SP-2 to SP-6 developed a strength increase of 17.95 %, 14.40 % and 11.60 % comparable with SP-0 control sample. FS for SP-2 to SP-6 showed a strength increase of 27 %, 23.88% and 16.77 % from SP-0 at later age. The results of the FS test confirm the enhanced behavior of SCGC with a 2% SP.

5. CONCLUSION

Based on the findings of the research following conclusions were made:

- Fresh properties of the SCGC with dosages of SP (2% and 4%) have compiled EFNARC guidelines from the slump flow test and the lowest T_{50cm} slump test as 4 seconds or SP-2.V-funnel indicated a free flow of 11 sec is attained at SP-2 and the height ratio of fresh SCGC is achieved at 0.90 and 0.92 for SP 2% and SP 4%. Hence, the optimized workability is attained at 2% of SP dosage in the SCGC.
- Hardened properties of the SCGC with 2% of SP dosages obtained the highest CS of 38.42 MPa, STS of 4.22 MPa and FS of 5.37 MPa after 28 days. These findings indicated the mechanical performance of the SCGC mix and its ability to withstand compressive, tensile, and flexural loads with a 2% SP dosage.
- Overall, 2% of SP can be optimized for the FA-based SCGC and it effectively improves workabilityand enhanced the strength, resulting in a concrete mix with satisfactory mechanical properties suitable for various construction applications and infrastructure projects such as buildings, bridges, dams, and roads.

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IZVOD

UTICAJ ALKALNIH VEZIVA NA OBRADLJIVOST I ČVRSTOĆU SAMOZBIJAJUĆEG GEOPOLIMER BETONA

Samozbijajući beton ima ključnu poziciju u industriji betona zbog sve veće potrebe za brzim razvojem infrastrukture za rastuću populaciju. Međutim, tradicionalni beton zahteva veliku količinu cementa, što dovodi do emisije CO_2 u fazi proizvodnje. Stoga, novi i inovativni samozbijajući geopolimer beton (SCGC) eliminiše upotrebu cementa u proizvodnji betona i zadovoljava karakteristike samozbijanja kao što su tečnost, sposobnost prolaska i sposobnost punjenja sa očvrsnutim svojstvima. Međutim, na ponašanje samozbijanja utiče doza superplastifikatora (SP), koja ima značaj u poboljšanju obradivosti SCGC. Četiri SCGC mešavine su pripremljene u intervalu SP od 2% (0 do 6%) sa letećim pepelom 450 kg/m^3 i odnosom smeše Na_2SiO_3 prema NaOH (1:2,5). Odnos alkalnog rastvora i veziva bio je 0,45 sa dodatnom količinom vode (54 kg/m^3). Uticaj doze SP na obradivost i mehaničku čvrstoću ispitan je u SCGC mešavinama. Rezultati studije pokazuju da je doza SP od 2% optimizovana pri 12 molarnosti NaOH. na reološka i čvrstoća svojstva. Stoga se preporučuje da se SP doza u SCGC optimizuje na 2%.

Ključne reči: *samoučvršćujući geopolimer beton, ugljeni pepeo, superplastifikatori, Master Gelnium SKI 8233.*

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