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

### ABSTRACT

Self-compacting concrete acts as a crucial position in the concrete industry due to the increasing need for fast infrastructure development for the growing population. However, traditional concrete requires a large amount of cement, which leads to CO<sub>2</sub> emissions in the production stage. Therefore, a new and innovative self-compacting geopolymer concrete (SCGC) eliminates cement usage in concrete production and meets self-compacting characteristics such as flowability, passing ability and filling ability with hardened properties. However, self-compacting behaviors are influenced by superplasticizers (SP) dosage, which has significance in improving the workability of SCGC. The four SCGC mixes were prepared at a 2% interval of SP (0 to 6%) with fly ash 450 kg/m<sup>3</sup>, and the ratio of Na<sub>2</sub>SiO<sub>3</sub> to NaOH mixture (1:2.5). The alkali solution to binder ratio was 0.45 with additional water (54 kg/m<sup>3</sup>). The effect of SP dosage on workability behaviors and mechanical strength was investigated in SCGC mixes. The study results show that the 2% SP dosage was optimized at 12 molarity of NaOH on rheological and strength properties. Hence, it is recommended that the SP dosage in SCGC be optimized at 2%.

**Keywords:** Self-consolidating geopolymer concrete, Coal fly ash, Superplasticizers, MasterGel nium SKY8233.

### 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-free concrete [3]. However, concreting in the congested reinforcement is much more difficult to pore without voids. Insufficient compaction can lead to voids and poor bonding with aggregates and cement paste, which leads to honeycombing 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 concrete affect the protection of embedded steel reinforcement [7]. However, Self-Compacting Concrete (SCC) has the potential to take up these challenges and overcome the insufficient compaction in the concrete [8]. Recently, SCC has been the most important development of building construction due to flowability behavior which can fill in heavy reinforcements. As a result, the concrete does not require external vibration to be compacted to reach its strength and the bonding between coarse aggregate and fine aggregate can be enhanced also, it can be used in pre-cast applications or for concrete placed on site [9, 10].

On the other hand, pollution is the most critical problem in the modern world due to fast-growing industries, urbanization, and changes in lifestyles which emit lots of pollutants [10]. Among all,

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the cement and concrete industries are contributing significantly which accounts for 6 to 8% of global CO<sub>2</sub> 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 byproducts as 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 aggregate grades can help to gain optimum compaction by reducing voids 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 can be

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 behavior of SCGC, particularly, NaOH molarity of 12 M. The fresh properties of SCGC were assessed by flow ability tests like slump flow test, T<sub>50cm</sub> 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.

Table 1. Chemical composition of FA

S. No	Chemical composition	FA
1	SiO <sub>2</sub>	63.16
2	Al <sub>2</sub> O <sub>3</sub>	29.69
3	K <sub>2</sub> O	1.85
4	TiO <sub>2</sub>	1.60
5	CaO	1.41
6	MgO	0.99
7	P <sub>2</sub> O <sub>5</sub>	0.97
8	Fe <sub>2</sub> O <sub>3</sub>	0.35
9	Na <sub>2</sub> O	0.21
10	SO <sub>3</sub>	0.16
11	PbO	0.02

The major quantitative chemical compositions of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> 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<sub>2</sub>O<sub>3</sub>), as shown in Figure 3. The alkaline solution composed of NaOH and Na<sub>2</sub>SiO<sub>3</sub>(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 superplasticizer 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.

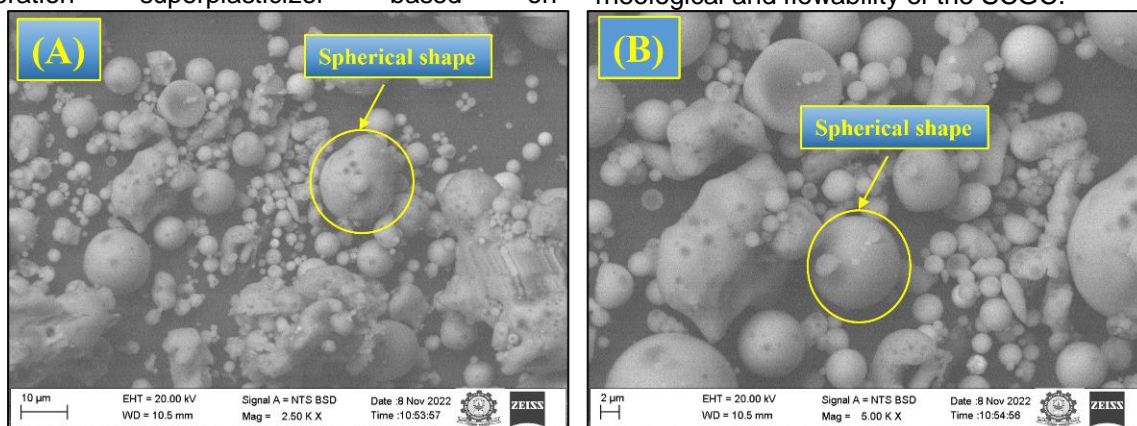


Figure 1. Scanning electron micrograph of FA(A&B)

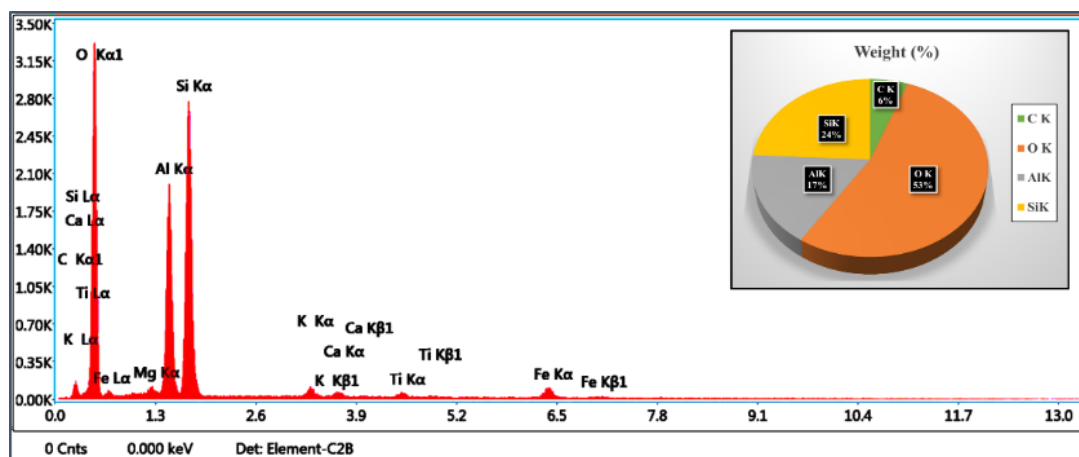


Figure 2. Energy-dispersive X-ray (EDX) of FA

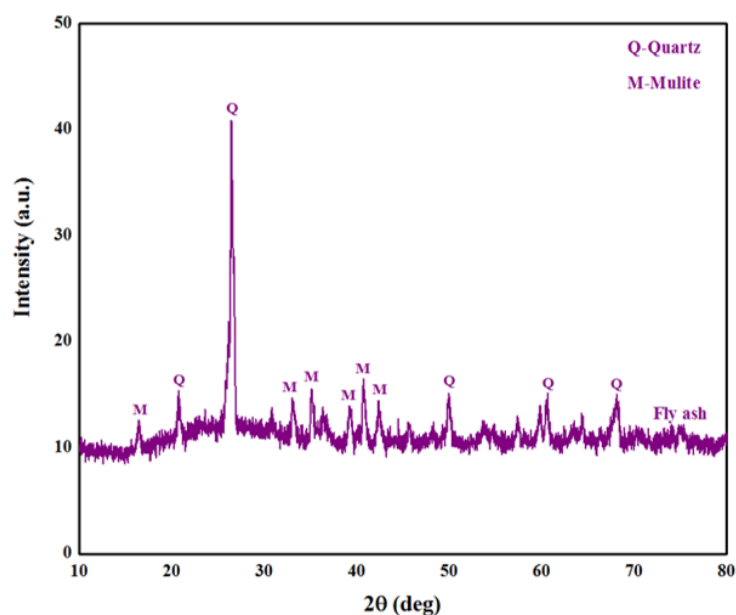


Figure 3. XRD pattern of FA

## 2.2. Mix Proportion

The SCGC mixes were carried out as per the SCC standard guidelines [34]. The mix designations are SP-0% to SP-6% with 2% interval of SCGC mixes prepared with FA of 450 kg/m<sup>3</sup> as binder content. The ratio of Na<sub>2</sub>SiO<sub>3</sub> 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<sup>3</sup>, and the mix details adopted in this study are indicated in Table 2.

Table 2. Mix proportion of SCGC

Mix ID	FA kg/m <sup>3</sup>	Fine aggregate kg/m <sup>3</sup>	Coarse aggregate kg/m <sup>3</sup>	NaOH kg/m <sup>3</sup>	Na <sub>2</sub> SiO <sub>3</sub> kg/m <sup>3</sup>	Molarity	SP (kg/m <sup>3</sup> )	Additional water (kg/m <sup>3</sup> )
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

## 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.

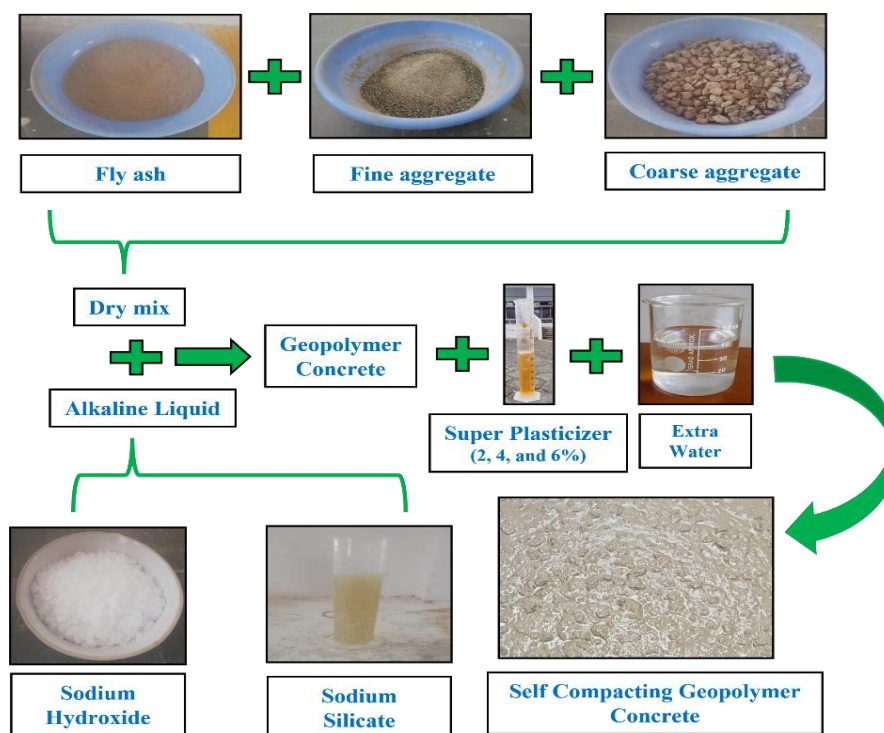


Figure 4. SCGC production process

## 3. EXPERIMENTAL PROGRAMS

### 3.1. Rheological properties

A slump flow test (SFT) was done to estimate the fresh flowability 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<sub>50cm</sub> slump flow test measures the time taken for the mixture to attain a 50cm diameter after being released from a mould that assesses the flowability of the concrete. The vertical section (H<sub>1</sub>) and the horizontal components (H<sub>2</sub>) 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 geopolymer concrete 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 test as 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 flowability 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.

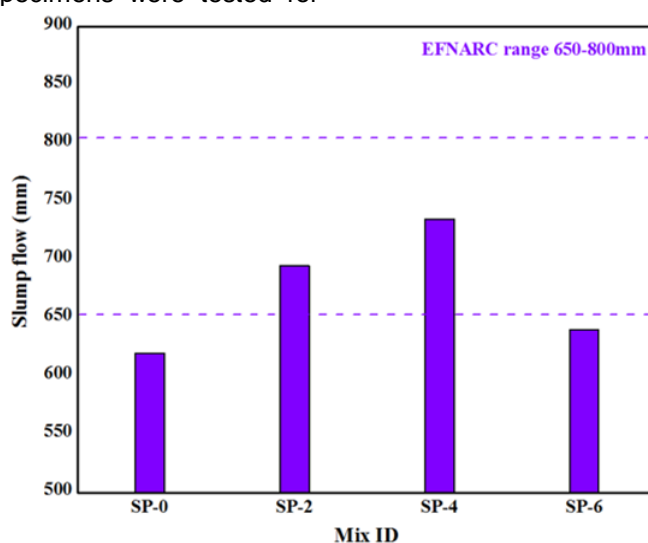


Figure 5. Slump flow test result

### 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.

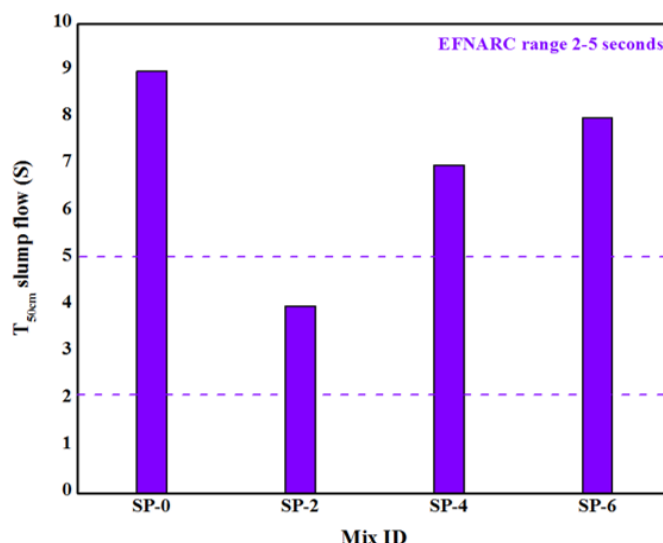


Figure 6.  $T_{50cm}$  flow test result



According to EFNARC guidelines, for SCGC, the  $T_{50\text{cm}}$  values 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  $T_{50\text{cm}}$  slump test of 4 sec for SP-2 and the highest  $T_{50\text{cm}}$  slump test of 9 sec were recorded for SP-0.

#### 4.3. V-funnel flow time

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

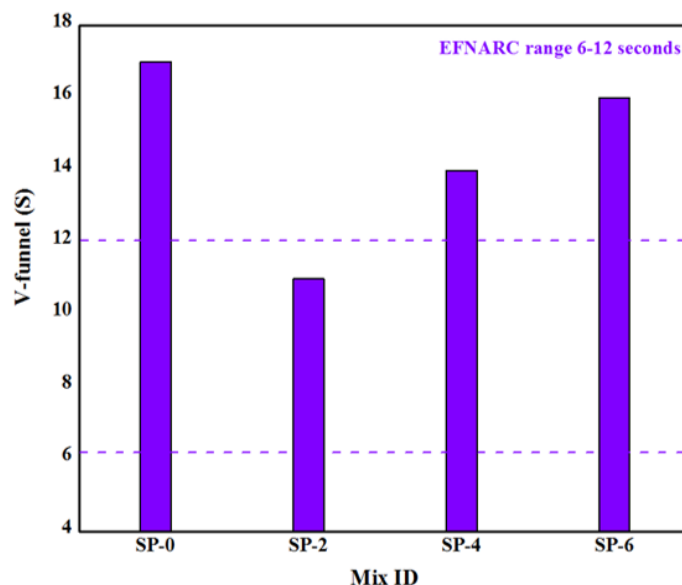


Figure 7. V-funnel test result

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 was 11 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.

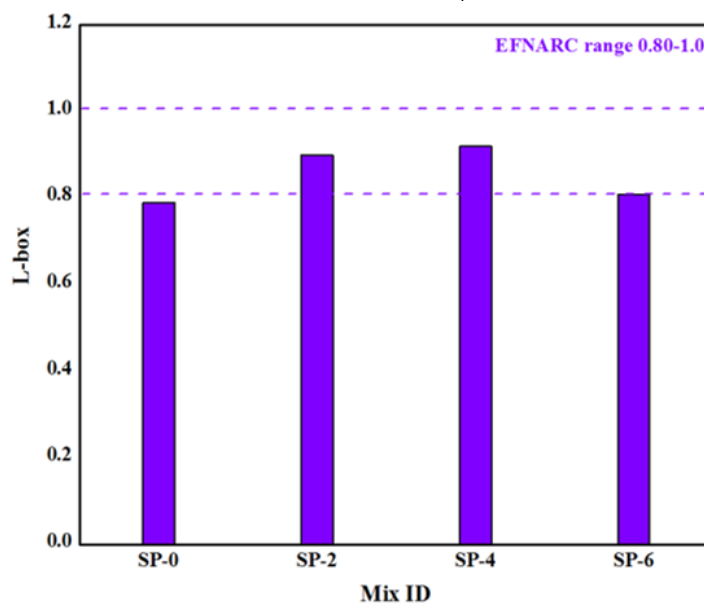


Figure 8. L-box test result

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.

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.

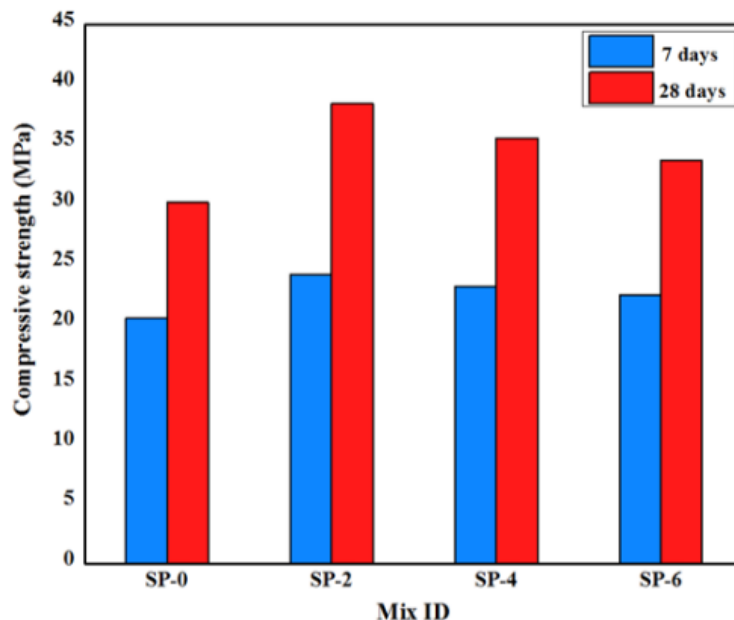


Figure 9. Compressive strength of SCGC

#### 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 at early age and later age respectively.

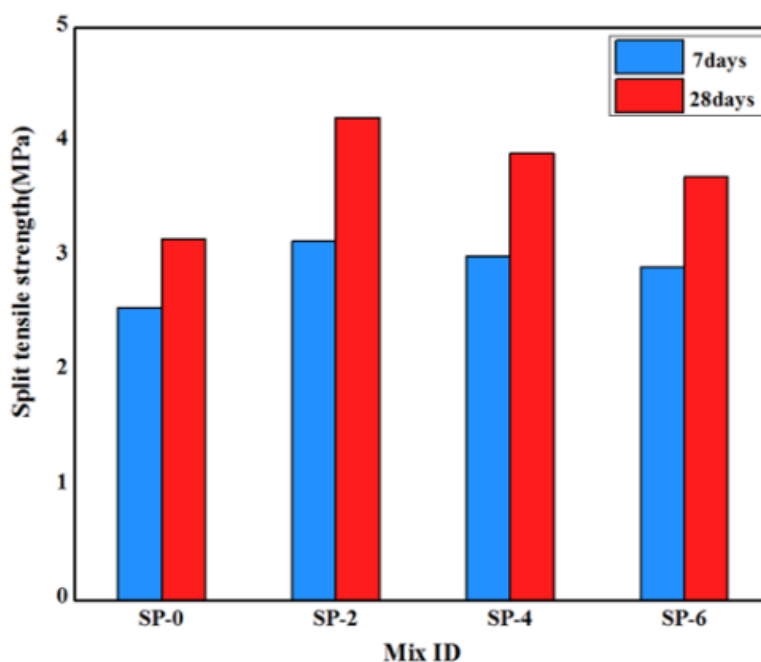


Figure 10. Split tensile strength of SCGC

The 7-day STS for SP-2, SP-4 and 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.

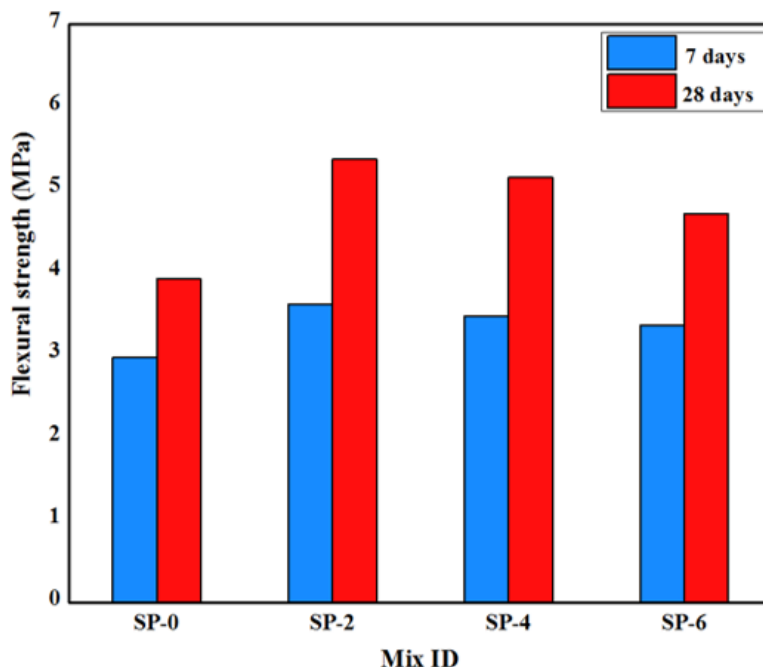


Figure 11. Flexural strength test result

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 workability and 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<sub>2</sub> 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 očvrstnutim 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<sup>3</sup> i odnosom smeše Na<sub>2</sub>SiO<sub>3</sub> prema NaOH (1:2,5). Odnos alkalnog rastvora i veziva bio je 0,45 sa dodatnom količinom vode (54 kg/m<sup>3</sup>). 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 Gelnum SKI 8233.

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