

# Influence of Activator Solution and Binder Composition on the Characteristics of Self-Compacting Geopolymer Concrete

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**Abstract** Self-compacting geopolymer concrete (SCGPC) being an innovative material synergizes the added advantage of self-compacting concrete and geopolymer concrete. While the field of self-compacting geopolymer is still evolving and the study explores the effect of standard consistency, setting time, rheological characteristics, and compressive strength. This research study involves two grades of single activator solutions (Ms 1.99 and Ms 2.92) and diverse binders, viz: fly ash, rice husk ash (RHA), and ground granulated blast furnace (GGBFS). This study examined the performance characteristics of SCGPC, particularly focusing on ternary blended binders with single activator alkaline solutions. The research study delves into both fresh and hardened states to assess flowability, passing ability, segregation resistance and compressive strength. The fresh properties of SCGPC are evaluated adhering to EFNARC guidelines for tests J-Ring, V-Funnel, V-T<sub>5minutes</sub>, slump flow, and T<sub>50cm</sub> to evaluate fresh properties of SCGPC. Compressive strength characteristics of SCGPC at the hardened state are scrutinized at 3, 7 and 28 days using single activator solutions (Ms 1.99 and Ms 2.92). The findings portrayed that replacement of GGBFS with RHA has noticeable effects on workability properties, and an optimum RHA replacement level of 5% is identified, considering the

suitable physical and mechanical characteristics of SCGPC. This research study emphasizes the complex interplay between binders, activator solutions and the resulting properties of SCGPC. This extensive research on SCGPC makes a significant contribution by elucidating the performance of this novel concrete under varied conditions.

**Keywords** Self-compacting Geopolymer Concrete, Rice Husk Ash, Single Activator Solution, Fly Ash, Compressive Strength

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## 1. Introduction

The infrastructure development in developing countries has been experiencing rapid growth across several sectors. To meet the growing requirements of various industries, there has been a tremendous response to the increasing demand for development in cities. The construction sector has experienced rapid growth, resulting in a significant rise in the utilization of cement concrete. According to a scholarly source [1], it is projected that the global production of cement will reach approximately 4800

million metric tons by the year 2030. The escalating utilization of cement contributes to a rise in atmospheric CO<sub>2</sub> emissions and is a significant factor in the occurrence of air pollution. According to Heweidak, et al [2], the production of a metric ton of cement results in the release of an equivalent amount of carbon dioxide (CO<sub>2</sub>) into the surrounding environment. Simultaneously, the utilization of raw materials in cement manufacture leads to a depletion of natural rock reserves. The production of cement necessitates a high temperature of approximately 1500 °C for the calcination process of lime, resulting in significant energy consumption. Hence, it is imperative to employ alternative binding materials to foster a sustainable environment, thereby minimizing land and air pollution, as well as preventing the depletion of significant environmental assets. Industrial and agricultural waste/by-products viz: Fly Ash, Metakaolin, GGBFS, RHA and silica fume (SF) are found in plentiful in India and around the world. The improper disposal of these waste products on land affects significantly the contamination of land. These waste/by-products exhibit pozzolanic properties and can be utilized as supplementary ingredients in cement for a long-term improvement in flexibility, strength, and durability of concrete [3, 4]. Jagadesh, et al [5] investigated the feasibility of using Fly Ash as an alternative for Portland cement for use in Self-Compacting Concrete (SCC). The inquiry focused on evaluating the workability, hardened properties, and durability characteristics of SCC when Fly Ash was incorporated at levels of 35% and 80%. The findings of the study indicated that the utilization of Fly Ash in SCC resulted in improvements in both fresh and hardened characteristics of concrete. The components FA, GGBFS, RHA and SF possess an amorphous structure. When these materials are activated with alkaline activators, such as sodium hydroxide and silicate of sodium, are utilized. They exhibit a desirable binding feature known as geopolymeric gel. The resulting material is referred to as geopolymer concrete.

An alkaline solution performs a chemical reaction with silicon (Si) and Al (aluminum) in the environment of FA forming inorganic binders that were first given the name geopolymer by Davidovits [6]. As the production of geopolymer-based concrete does not include the use of cement, it leads to a reduction in CO<sub>2</sub> emissions and, as a result of this, a reduction in the quantity of energy that is required for calcinations. The geopolymer source materials must have a significant amount of silicon and aluminum, and alkaline liquids are the two most critical components of the geopolymer. It was able to use waste products such as the GGBFS, fly ash, RHA, SF, and naturally occurring minerals like kaolinite and clay, as potential sources of the elements. The production of carbon dioxide by geopolymeric cement is five to six times lower compared to that of standard Portland cement [7]. Because of this, the geopolymer technology not only reduces the amount of CO<sub>2</sub> emissions that cement manufacturers produce, but it additionally deploys use of the wastes and residues of

industrial processes that are composed of aluminum silicate and converts them into ecologically acceptable construction materials. The application of geopolymer additive in the construction sector is an absolute requirement for the continuation of an ecologically sustainable environment.

Most studies conducted on geopolymer concrete have utilized fly ash (FA) as the primary aluminosilicate supply material. The process of geopolymerization of FA necessitates curing in high-temperature ovens, typically ranging from 60 to 90-degree C. However, this procedure results in significant energy consumption [8, 9]. According to Guo et al. [10], their findings indicated that an extended curing period has the potential to disrupt the granular structure of the geopolymer mixture, which refers to the arrangement and distribution of particles within the mixture, leading to a reduction in its overall strength. Rovnanik's research also found that exposure to high temperatures during the early stages of geopolymer concrete development results in the formation of larger pores, leading to an increase in pore volume and negatively impacting the material's properties [11]. On the side, it was also observed that raising the curing temperature from 60 to 70 degrees Celsius resulted in a noticeable increase in the compressive strength of the geopolymer. Finally, it should be noted that temperatures exceeding 70 °C led to a decrease in compressive strength [12]. Owing to this, several studies investigated the substitution of fly ash (FA) with ground granulated blast furnace slag (GGBFS) in varying proportions, ranging from 10% to 100%. These studies have consistently found that such substitution eliminates the need for temperature curing, resulting in a significant improvement in compressive strength. The use of 100% GGBFS in concrete accelerates the rate at which the geopolymer paste solidifies, reducing the time required for proper placement and compaction [13, 14].

Memon, F. A et al. [15] concluded that an increase in the amount of slag incorporated into concrete results in a reduction in both the consistency of the mix and the movement of the mortar, as observed. Vibration is essential to achieve optimal compaction in the conventional geopolymer concrete production process. But, the use of vibrations in concrete production contributes to noise pollution. Self-compacting concrete (SCC) is an alternative that eliminates the need for external compaction methods. SCC can uniformly fill all corners of the formwork solely through the force of its own weight. Self-compacting concrete (SCC) provides several benefits, including the ability to easily fill confined and narrow spaces, improved compaction, strong reinforcement bond, and low maintenance requirements, expedited building process, increased concrete quality, and lower overall construction costs [16]. The incorporation of GGBFS, SF, and FA is commonly practiced in the production of concrete with outstanding strength and performance due to its favorable engineering characteristics [17]. The experimental verification involved identifying the presence of

calcium-rich C-A-S-H gel in the interfacial transition zone. The study determined that the incorporation of fly ash and GGBFS resulted in the successful creation of stable geopolymer concrete, which demonstrated exceptional mechanical strength and durability [18].

The advantages of geopolymer technology, coupled with the construction industry's growing preference for self-compacting concrete (SCC), have spurred the development of an innovative concrete that amalgamates the merits of both. Currently, there exists a limited body of research exploring the characteristics of self-compacting geopolymer concrete (SCGPC). In a series of studies, Memon et al. crafted SCGPC using fly ash (FA) as its primary raw material. They meticulously scrutinized the influence of various parameters on the properties of SCGPC, encompassing the molarity of sodium hydroxide, the ratio of sodium silicate to sodium hydroxide, curing temperatures, curing durations, the dosage of superplasticizer, and the quantity of alkali activator. These investigations were carried out under controlled temperature curing conditions [19,20]. In a separate line of research by Viswam, et al. [21], it was revealed that ground granulated blast furnace slag-based SCGPC achieved an impressive peak compressive strength of 40 MPa after 56 days of curing at room temperature. Conversely, FA-based SCGPC exhibited a comparatively lower compressive strength of 16 MPa. In his recent research, Kiran Kumar investigated the influence of Ground Granulated Blast Furnace Slag (GGBS) on the performance of Self-Compacting Geopolymer Concrete (SCGPC) in both its fresh and hardened states. The study also examined the microstructural properties of the concrete. The results of the study revealed that it was possible to substitute up to 40% of Fly Ash (FA) for GGBS as a precursor binder in SCGPC, which led to the production of concrete with excellent fresh and mechanical properties that met the EFNARC standards for Self-Compacting Concrete (SCC). However, it should be noted that as the quantity of GGBS in the binder increased, the workability of the fresh GGBS-blended SCGPC decreased [22]. Endow Ayar Mazumder [23], in their research study, studied geopolymer concrete specimens subjected to controlled fire conditions at various temperatures. The mechanical properties of these specimens after exposure to fire have been assessed and compared with those of conventional concrete members exposed to the same conditions [23].

The primary reason for this phenomenon can be attributed to the quicker reactivity of calcium and the angular shape of the slag, which contrasts with the spherical shape of fly ash particles. When compared to the control self-compacting geopolymer concrete (SCGPC) with 100% fly ash (100FAG0), the mix containing 40% ground granulated blast furnace slag (GGBS) in SCGPC (60FAG40) exhibited the highest compressive strength increase, showing improvements of 40.26% after 7 days and 33.97% after 28 days. Additionally, as the GGBS content increased from 0% to 50%, both the splitting

tensile strength and flexural strength of the GGBS-blended SCGPC saw enhancements of approximately 33.59% and 31.05%, respectively. An X-ray diffraction-based microstructural analysis of the SCGPCs revealed a reduction in the number of crystalline phases as the GGBS was used as a partial substitute for fly ash. Consequently, there was a decrease in porosity while the density and the formation of C-A-S-H gel (calcium, nitrogen, aluminum, silicate, and hydrogen gel) were enhanced. As observed through scanning electron microscopy (SEM) and energy-dispersive X-ray analysis (EDAX), the presence of GGBS increased the degree of polymerization and polycondensation in the material, leading to improved densification of the entire system and an increase in its overall strength.

Rice Husk Ash (RHA), an amorphous supplemental material derived from agro-industrial waste produced by rice mills, is abundantly available in India, a country known for its agricultural activities. India produces approximately 30 million metric tons (Mt) of rice husk annually. The primary constituent of RHA is amorphous silicon oxide, typically comprising 83% to 90% of its composition [24]. Previous studies have shown that substituting RHA for fly ash, GGBFS, and red mud can enhance both microstructural and mechanical properties of conventional geopolymer concrete when certain additives are incorporated [25].

The focus of research on Self-Compacting Geopolymer Concrete (SCGPC) has often been on fly ash as the primary supply material for alumina-silicate. High-temperature curing is crucial to initiate the process of polymerization that occurs naturally in geopolymer-based fly ashes. Nevertheless, this type of concrete is restricted to buildings that can apply heat for curing, limiting its usefulness in utilizing existing structures. Therefore, there is a strong need for further research efforts to develop geopolymer concrete that can be cured at room temperature. Several existing pozzolanic compounds are produced through combustion and disposal methods, which worsen environmental issues. Rice Husk Ash (RHA) is a valuable source of not very dense, reactive amorphous silica. This study examines the combination of fly ash, ground-granulated blast-furnace slag (GGBFS), and the RHA as binding materials for SCGPC.

This project aims to explore self-compacted geopolymer paste. The precise objectives are:

- i) **Material Properties:** Self-compacted geopolymer paste consistency, initial setting time, and final setting time are investigated. This study will examine how single activator solutions affect these essential material properties with different binders.
- ii) A thorough analysis of the rheological characteristics of self-compacted geopolymer paste is crucial to this research. Different amounts of binders and single activator solutions will be

tested to determine how they affect paste flow and deformation.

- iii) **Compressive Strength:** The study examines how binder proportions and single activator solutions affect specimen compressive strength. The assessment will be done after 3, seven, and 28 days of room-temperature curing. This extensive study examines the mechanical strength of geopolymer paste under various conditions and extended cure times.

## 2. Materials and Methodology

The selection of materials used in the manufacturing of self-compacting geopolymer-based concrete (SCGPC) plays a crucial role in determining its effectiveness and qualities. The components utilized in the production of SCGPC have a substantial impact on the final characteristics. The materials employed in the SCGPC include fly ash, GGBFS, and RHA as binding materials, natural river sand for fine aggregates and crushed granite for coarse aggregates, single activator solutions to replace water as an alkaline activator, and the addition of superplasticizers to enhance the paste's properties

### 2.1. Binder

The materials utilized in this investigation consist of fly ash, ground-granulated slag from blast furnaces (GGBFS), and rice husk ash (RHA). The fly ash utilized in the research's material was collected at India's Ramagundam thermal power location. In addition, the utilization of GGBFS and rice husk ash (RHA) was received from Astrra Chemical Solutions in Chennai, India. The specific gravity (S.G) values for fly ash, slag and RHA are 2.25, 2.83, and 2.14, while their corresponding fineness measurements are the values expressed in namely 360 m<sup>2</sup>/kg, 400 m<sup>2</sup>/kg and 192 m<sup>2</sup>/kg. The chemical composition of fly ash,

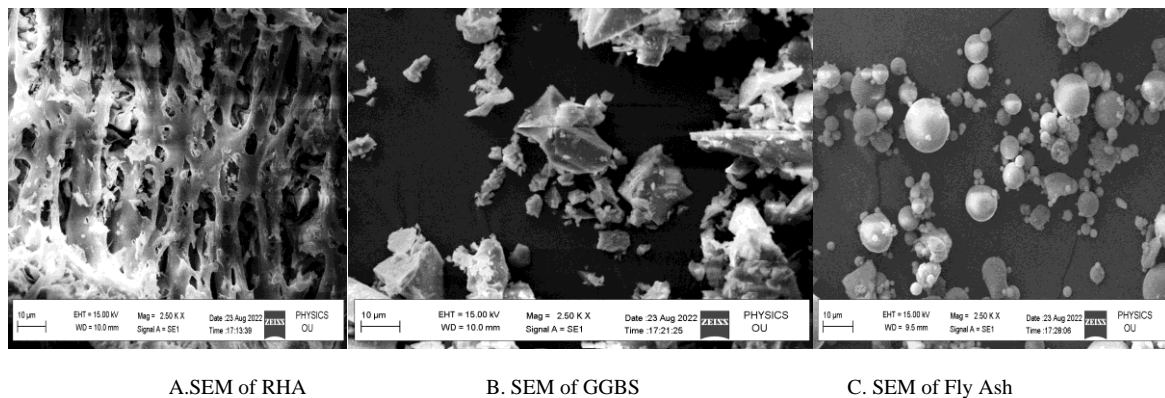
ground-granulated blast furnaces slag and rice husk ashes are presented in Table 1.

**Table 1.** Fly ash, GGBFS, and RHA chemistry (as a mass)

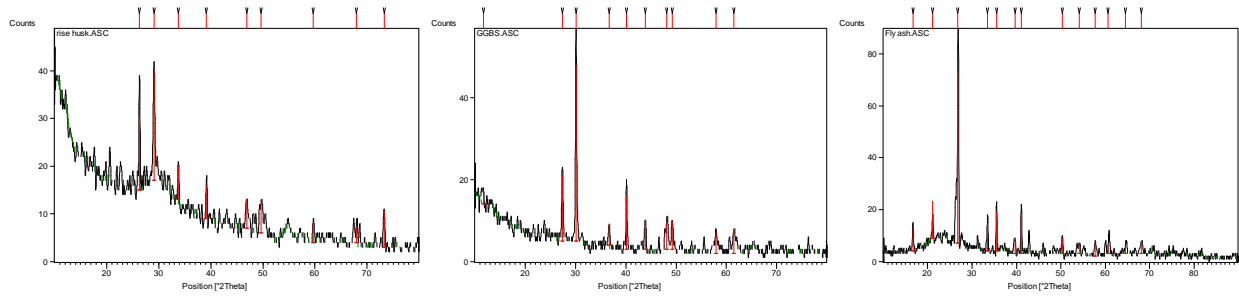
Structures of chemicals	Fly -Ash (%)	GGBFS (%)	RHA (%)
SiO <sub>2</sub>	58.00	34.07	92.30
Al <sub>2</sub> O <sub>3</sub>	26.62	20.00	0.4
CaO	3.6	32.50	0.700
Fe <sub>2</sub> O <sub>3</sub>	3.58	0.80	0.450
SO <sub>3</sub>	1.80	0.90	0.045
Na <sub>2</sub> O <sub>3</sub>	2.00	NIL	0.700
MgO	1.91	7.89	0.850
Loss on ignition	2.00	NIL	3.150

SEM images of RHA (Fig. 1A), GGBFS (Fig. 1B), and FA (Fig. 1C) were examined to identify the size, shape, and texture of these binder materials. It was observed that RHA particles primarily consist of silicon and have amorphous forms, like Cristobalite and crystalline quartz. These particles are naturally solid, and subjecting them to high-temperature calcination results in the formation of crystalline RHA in amorphous forms. The uneven size distribution of RHA particles can be attributed to the high combustion temperature used during processing.

SEM images, providing particle forms, of GGBFS indicate that it contains angular shapes with varying sizes suitable for mixing procedures and geopolymer production. Furthermore, a scanning electron microscopy (SEM) analysis of class-F fly ash reveals that the large particles produced as a byproduct of combustion include fine solid microspheres with spherical forms, which contribute to the formation of geopolymer.



**Figure 1.** SEM analysis (1A RHA, 1B GGBFS and 1C Fly ash)



A. XRD of RHA B. XRD of GGBFS C. XRD of Fly ash

**Figure 2.** XRD analysis (2A RHA, 2B GGBS and 2C Fly ash)

Based on the X-ray diffraction (XRD) analysis, the graph shows that Rice Husk Ash (Fig. 2A) predominantly exists in an amorphous state, as indicated by the large peak observed at an angle of  $2\theta = 22^\circ$ . In the GGBS sample (Figure 2B), the primary peaks correspond to calcite and quartz, with peak positions at 28, 35, and 37 degrees for calcite, and 21 and 42 degrees for quartz. The X-ray diffraction (XRD) examination also revealed that the primary prominent peak observed in Fly ash (Figure 2C) corresponds to quartz, exhibiting significant intensity at  $2\theta = 27^\circ$ . Additionally, Mullet was found as the secondary major peak in fly ash, appearing at various  $2\theta$  values (17, 32, 33, 42, 50, and  $61^\circ$ ).

**2.2. Aggregates**

The fine aggregate consisted of dry river sand that had been thoroughly cleaned. A 4.75-millimeter sieve was used to separate it, ensuring the removal of all rocks. The sand's saturated surface dry specific gravity was measured and found to be 2.64, indicating that it meets the criteria for zone II as outlined in BIS-383-2016. Crushed granite with a maximum size of 16 millimeters and a specific gravity of 2.72 was used for the coarse aggregate. For both fine and coarse aggregates, the fineness modulus is 6.25, while that of fine coarse aggregates is 2.54. Table 2 shows the Sieve Analysis of Fine Aggregate.

**Table 2.** Sieve Analysis of Fine Aggregate

Sieve size (mm)	% Passing recommended by BIS 383	Adopted grading	% Weight retained	Cumulative % Weight retained	Weight retained in grams
10-4.75	100	100	-	-	-
4.75-2.36	90-100	100	-	-	-
2.36-1.18	75-100	90	10	10	100
1.18-0.60	55-90	65	25	35	250
0.30-0.15	35-59	40	25	60	250
0.30-0.15	8-30	10	30	90	300
0.15	0-10	0	10	100	100

**2.3. Alkaline Solution**

The weight ratio of the liquid sodium silicate grades can range from 1.6:1 to 3.85:1, and this ratio is known as the  $\text{SiO}_2:\text{Na}_2\text{O}$  silica modulus (Ms). If the  $\text{SiO}_2:\text{Na}_2\text{O}$  ratio is larger than 2.85:1, the grade is defined as neutral; when the ratio is less than 2.85:1, the grade is categorized as alkaline. In the experiment, two types of single activators were used: the neutral grade single activator with a silica modulus of 2.92, containing 24.88% silicon dioxide, 12.46% sodium oxide ( $\text{Na}_2\text{O}$ ), and 62.66% water ( $\text{H}_2\text{O}$ ) by weight; and the alkaline single activator with a Ms of 1.99, comprising 28.98% silicon dioxide, 9.92%  $\text{Na}_2\text{O}$ , and 61.1%  $\text{H}_2\text{O}$  by weight.

**2.4. Superplasticizer**

The use of a superplasticizer in the appropriate dose is necessary to improve the flow ability of SCGPC mix, since it inherently exhibits a high level of viscosity, leading to lower workability. The utilization of PCE based super plasticizer in self-compacting geopolymer concrete, has been found to enhance the fluidity of the material.

**2.5. Self Compacting Geopolymer Paste**

The different quantities of GGBFS, Fly ash and RHA binders were combined in a non-wetting state using a pan mixer. Subsequently, the activator was introduced into the mixture and agitated for approximately three minutes, resulting in the formation of a uniform coloration. The preparation of self-compacting Geopolymer pastes involved modifying the quantities of calcined source materials, namely fly ash, GGBFS, and RHA. These materials were activated using a single activator solution.

**2.6. Self-compacting Geopolymer Concrete**

Both the coarse and fine aggregates were thoroughly combined with the binder in a dry state for duration of 2 to 3 minutes. Subsequently, the activator was introduced into the dry mixture, followed by the addition of the superplasticizer. A 5% increment of more water was introduced, followed by a 10% combination, and the

mixture was then stirred for duration of 5 to 7 minutes till a homogeneous blend was achieved. The rheological characteristics, including flow ability, passing ability, and filling ability, of freshly mixed concrete were assessed. Subsequently, concrete specimens were fabricated by pouring the mixture into steel cube molds with dimensions of 150 mm x 150 mm x 150 mm. In order to ascertain the compressive strengths at 3, 7, and 28-day intervals, a total of 9 cubes were fabricated in each self-compacting geopolymer mixture. To determine the compressive strength of SCGPC, a total of 54 cube specimens were prepared and subjected to compressive testing to establish a composite value of six mixes. The samples were demolded after 24 hours of casting and thereafter subjected to ambient curing conditions. The specimens were left at ambient curing (Temperature:  $27 \pm 2$  °C and 70% relative humidity) until the testing day.

The parameters that were taken into consideration in this study:

1. The percentage of fly ash remains consistent at 50%, while rice husk ash is substituted with GGBFS at different ratios of 0%, 5%, 10%, 15%, 20%, and 25%.
2. The silica modulus is examined at two levels, namely 1.99 and 2.92.
3. The curing age is investigated at three different time intervals, specifically 3, 7, and 28 days.

## 2.7. Experimental Program

This study primarily investigates the basic characteristics of geopolymer composite paste, specifically focusing on normal consistency (P) as well as setting time, secondly, the characteristics of novel materials, including their workability and material strength. Experimental procedures are designed to assess its compressive strength and establish its ability to resist deformation. Vicat's apparatus is the method of choice for establishing the standard consistency of cement, as stated in IS 4031 (part 4) (1988). The self-compacting geopolymer material was tested using a method that was very similar to the way that was used to test other materials, and activators such as single activator solutions were used to generate self-compacted geopolymer paste of a standard consistency. Using Vicat's apparatus, the IST and FST of the geopolymer paste were evaluated in accordance with the requirements of IS 4031 (part 5) (1988). The setting durations of the self-compacted Geopolymer Paste were determined by utilizing fly ash, GGBFS, and RHA at binder proportions of 500g and 0.85 times the normal consistency value.

The behavior of Fresh's properties in traditional fresh concrete and self-compacting geopolymer concrete is distinctly different. According to the EFNARC Guidelines, concrete can be classified as self-compacted if it meets three specific criteria: filling ability, passing ability, and

flowing power. In this study, various methods, such as the slump test,  $T_{50}$  flow test, J-Ring test, V-funnel test, and  $V_5$ minutes-funnel test, are employed to assess the concrete mix's filling ability, flowing ability, and passing ability. The findings from these tests, along with visual observations, are presented.

The study focuses on the investigation of the self-compacting geopolymer concrete mixtures' mechanical characteristics following the hardening process. A total 54 cubes, for each mix being nine Cubes with dimensions of 150 mm x 150 mm x 150 mm were utilized. The fabricated and subjected to compression testing to ascertain the compressive strength values at 3, 7, and 28-day intervals. The compression test was conducted in accordance with the BIS 516-1959 standard, utilizing a Compressive testing equipment with a capacity of 2000kN. Currently, there is no specific mix design technique available for SCGPC. Therefore, the design mix approach for SCGPC selected is based on the standards provided by the EFNARC (2002) guidelines. The bulk density of the binder was maintained at a constant amount of 500 kg/m<sup>3</sup>. The optimal solution-to-binder proportion for the manufacturing of various concrete mixtures was found to be 0.6. The study indicated that the function of aggregate in self-compacting geopolymer concrete exhibited a similar performance to that observed in conventional ordinary Portland cement, or OPC, concrete. The proportion of fine aggregate compared to coarse aggregate was determined by considering the inert characteristics of the aggregate medium. The selection of a ratio of 0.45:0.55 was based on its ability to yield the highest dry density of the mixed aggregate. The necessary amounts and proportions of material sources, aggregates, and solution components were determined in the manner illustrated below.

## 2.8. Designing Mixture

The mix proportions of different mixes are presented in Table 3 and the calculations are done as below:

Binder was assumed to be 500 kg/m<sup>3</sup> for 1 m<sup>3</sup> of concrete, and the solution/binder ratio was assumed to be 0.6. The determination of the activation solution was achieved by multiplying the ratio of solutions to binder by the quantity of the binder, obtaining a value of 300 kg/m<sup>3</sup> when multiplied by 0.6 and 500. Concrete has a unit weight of 24 kN/m<sup>3</sup> (2400 kg/m<sup>3</sup>).

2400-500-300 = 1600 kg total aggregate 300 = 1600 kg

The fine aggregate/coarse aggregate ratio is 45:55.

800 kg coarse aggregate = 1600 x 0.55

720kg fine aggregate = 1600 x 0.45

The density of the binder component is 500 kg/m<sup>3</sup>, the fine aggregate weighs 720 kg, the coarse aggregate weighs 880 kg, and the solution has a density of 300 kg/m<sup>3</sup>.

Super plasticizer 5% = 0.050 kg, Extra water 10% = 0.100 kg.

**Table 3.** Mix proportions at different binder's content and single activator solutions

Mix ID/ Proportion of binders	Binder			Coarse aggregate Kg/m <sup>3</sup>	Fine aggregate Kg/m <sup>3</sup>	AAS		Ex. water %	SP %	Curing temperature
	Fly ash Kg/m <sup>3</sup>	GGBFS Kg/m <sup>3</sup>	RHA Kg/m <sup>3</sup>			Ms1.99 Kg/m <sup>3</sup>	Ms 2.92 Kg/m <sup>3</sup>			
M <sub>2</sub> F <sub>50</sub> G <sub>45</sub> R <sub>5</sub>	250	225	25	880	720	300	300	10	5	Ambient
M <sub>3</sub> F <sub>50</sub> G <sub>40</sub> R <sub>10</sub>	250	200	50	880	720	300	300	10	5	Ambient
M <sub>4</sub> F <sub>50</sub> G <sub>35</sub> R <sub>15</sub>	250	175	75	880	720	300	300	10	5	Ambient
M <sub>5</sub> F <sub>50</sub> G <sub>30</sub> R <sub>20</sub>	250	150	100	880	720	300	300	10	5	Ambient
M <sub>6</sub> F <sub>50</sub> G <sub>25</sub> R <sub>25</sub>	250	125	125	880	720	300	300	10	5	Ambient

### 3. Results and Discussion

This paper aims to present a comprehensive overview of the current research on the several mix proportions. In this work, various mixtures of self-compacted geopolymer concrete were formulated to investigate the impact of varied amounts of binder content. Additionally, it was investigated how different single activator solutions affected the settling time, fresh characteristics, and hardened characteristics for self-compacting geopolymer concrete. The results of the tests done are tabulated in Table 4.

#### 3.1. Standard Consistency

The determination of the standard consistency of self-compacting geopolymer paste involves measuring the proportion of activation that can pass through a plunger of Vicat's equipment, which has a diameter of 10mm, the depth ranging from 33 to 35mm to the top and 5 to 8mm from the lowermost part that makes up Vicat's mould. The experimental setup includes a steel needle with a particular weight of (300 ±2) a gram that penetrates the paste. The mechanism of penetration occurs at regular intervals of fifteen minutes, during which the sample is carefully preserved under controlled conditions of temperature (20 ± 3) °C and relative humidity of 90%. The notation M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub> to M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub> represents the utilization of fly ash, GGBFS, and RHA as binders in self-compacted geopolymer mixing. The observation was made that the self-compacted geopolymer paste mix M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub> exhibited a lower demand for activator solutions compared to the self-compacted geopolymer paste mix M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub>. The standard consistency value increases when the GGBS content is reduced in intermediate mixes. It is observed that the incorporation of a small proportion of RHA leads to a substantial enhancement in the normal consistency. This can be attributed to the RHA's ability to absorb more solutions and its amorphous particle morphology, which exhibits low internal friction. Consequently, the Vicat's

plunger experiences unrestricted movement. However, it should be noted that a higher quantity of activator solution is necessary to achieve these effects. On the other hand, the GGBS grains exhibit a distinct morphology characterized by an elongated, straight, flaky shape with angular edges and a rough surface. These unique physical attributes result in more internal friction in comparison to the fly ash and RHA particles. Consequently, a lesser amount of solution is needed to achieve the desired standard consistency when utilizing GGBS. The self-compacted geopolymer mixes, which were activated using a single activator solution with Ms 1.99, exhibited a standard consistency of 38% for the M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub> mix and 45% for the M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub> mix. The standard consistency of the self-compacted geopolymer materials mixes that were activated with Ms 2.92 single activator solutions was 49% for the mix M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub> and 40% for the mix M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub>. Furthermore, compared to the other combinations activated utilizing a medium alkali single activation solution (Ms 1.99), all of the mixes initiated using the neutral grade single activation solution (Ms 2.92) had greater consistency values. The results of the discussion indicate that the normal consistency of SCGPC paste is influenced by the mixes of fly ash, GGBFS, and RHA, as well as the activating solution employed.

#### 3.2. Setting Time

The investigation focused on analyzing the setting behavior of self-compacted geopolymer through the manipulation of proportions of fly ash, GGBFS and RHA. The methodology employed in this study was consistent with the approach utilized for determining the initial and final setting of cement. Table- 3 presents the variation in the initial and final setting time of self-compacted geopolymer paste for various RHA, GGBS, and fly ash combinations. The self-compacted geopolymer blends were activated utilizing a single activation solution a Ms 1.99, exhibited varying initial and final setting times. Specifically, the initial setting time ranged from 360 to 750 minutes for mixes M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub> to M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub>, but for the

same mixes, the ultimate setting times varied between 700 and 1300 minutes. In contrast, the self-compacted geopolymer mixes that were activated with a neutral grade single activator solution Ms 2.92 initial setting times ranging from 480 to 920 minutes. For the  $M_1F_{50}G_{50}R_0$  to  $M_6F_{50}G_{25}R_{25}$  mixes. The ultimate setting times for these mixes varied from 980 to 1520 minutes, respectively. It is worth mentioning that the utilization of fly ash, grain a prolonged final setting time was observed in the self-compacted geopolymer mix when activated with a solution of sodium silicate of neutral grade. When activated using a traditional alkaline solution composed of sodium silicate and sodium hydroxide the ultimate setting time value is usually 20 minutes ( $Na_2SiO_3$ ). It is noticeable that in the case of fly ash as well as RHA, GGBFS reacts with the solution more strongly. Compared to fly ash and RHA, the setting properties of the condition of GGBFS liquid demonstrate a faster rate. Therefore, it can be said that when it comes to creating self-compacted geopolymer materials with a high degree of initial strength, GGBFS demonstrates better binding qualities than fly ash, RHA and GGBFS in the formulation of self-compacted geopolymer mixing, when activated with liquid sodium silicate of neutral grade, resulted in an extended final setting time. When activated through a conventional alkaline mixture including a mixture of sodium hydroxide (sodium hydroxide and sodium silicate ( $Na_2SiO_3$ )), the ultimate setting time value is typically 20 minutes. It is evident that GGBFS exhibits a higher reactivity with the solution compared to fly ash and RHA. The setting characteristics of GGBFS in the existence of liquid exhibit a faster rate in comparison to fly ash and RHA. Hence, it can be concluded that GGBFS exhibits superior binding properties compared to fly ash and RHA in the context of producing self-compacted geopolymer substances characterized by a high level of initial strength. In the case of geopolymer mixes activated with a single activator solution of Ms 1.99, the partial replacement of GGBS with RHA by 5% resulted in an extension of the initial set-up period from 360 to 420 minutes, as well as an increase in the ultimate setting time from 705 to 810 minutes. In contrast, the self-compacted geopolymer mixes that were activated with a neutral grade single activator solution of Ms 2.92 exhibited an increase in the initial setting time from 480 to 590 minutes, as well as an increase in the final setting time from 980 to 1100 minutes. A longer setting time was found for the mixture activated with a neutral grade single activator solution. Hence, it may be inferred

that a suitable blend of fly ash, GGBFS, and RHA, synthesized using a single activator solution with a high silica modulus, may be recommended to achieve a desired setting time characteristic. The introduction of GGBFS partially replaced with RHA at a concentration of 10% resulted in an increase in the initial setting time from 420 to 500 minutes, as well as an increase in the ultimate setting time from 810 to 900 minutes. In contrast, the self-compacted geopolymer mixes that were activated with a single activator solution of Ms 2.92 exhibited an initial setting time ranging from 590 to 650 minutes, while the final setting time increased from 1100 to 1250 minutes. A longer setting time was found for the mixture activated with a neutral grade single activator solution. Hence, it may be inferred that a suitable blend of fly ash, GGBFS, and RHA, synthesized using a single activator solution with a high silica modulus, may be recommended to achieve a desirable setting time characteristic.

The setting times of self-compacted Geopolymer paste were assessed using the methodology outlined in IS: 4031-1988 (part 5). The binder combinations consisted of fly ash, GGBS, and RHA, with 500 grams of mass overall. The content of liquid was determined and the value of 0.85P is used to indicate the normal consistency value of P the specific self-compacted geopolymer mix. In the case of self-compacted geopolymer mixes activated with a single activator solution of Ms. 1.99, the geopolymer paste's consistency  $M_1F_{50}G_{50}R_0$  was determined to be 38%. The liquid content utilized for estimating the initial and final timings was calculated to be 0.85 P, which corresponds to 32.3% of the paste's consistency. Similarly, for the geopolymer paste  $M_6F_{50}G_{25}R_{25}$ , which had a consistency of 45%, the amount of solution used was also 0.85 P, resulting in a liquid content of 38.25%. In a similar way, the consistency of this geopolymer paste was examined when self-compacted geopolymer mixtures were activated using single activator concentrations of Ms 2.92.  $M_1F_{50}G_{50}R_0$  was found to be 40%. Consequently, the liquid quantity employed to determine the initial setting time (IST) and final setting time (FST) was calculated as 0.85 P (0.85 multiplied by 40 equals 34%). Conversely, for the paste  $M_6F_{50}G_{25}R_{25}$ , which exhibited a consistency of 49%, the amount of solution utilized was also 0.85 P (0.85 multiplied by 49 equals 41.65%). The potential cause for the extended setting time seen in the self-compacted geopolymer paste  $M_6F_{50}G_{25}R_{25}$  could be attributed to variations in the chemical composition of the fly ash, GGBS, and RHA.



**Table 4.** SCGP consistency as well as setting times for varying binder quantity

Mix/Proportion of binders	Normal consistency (%)		IST (minutes)		FST (minutes)	
	MS 1.99	MS 2.92	MS 1.99	MS 2.92	MS 1.99	MS 2.92
M <sub>1</sub> F <sub>50</sub> G <sub>50</sub> R <sub>0</sub>	38	40	360	480	705	980
M <sub>2</sub> F <sub>50</sub> G <sub>45</sub> R <sub>5</sub>	39	42	420	590	810	1100
M <sub>3</sub> F <sub>50</sub> G <sub>40</sub> R <sub>10</sub>	42	44	500	650	900	1250
M <sub>4</sub> F <sub>50</sub> G <sub>35</sub> R <sub>15</sub>	43	46	580	740	1050	1370
M <sub>5</sub> F <sub>50</sub> G <sub>30</sub> R <sub>20</sub>	44	48	660	810	1200	1450
M <sub>6</sub> F <sub>50</sub> G <sub>25</sub> R <sub>25</sub>	45	49	750	920	1300	1520

### 3.3. Fresh Properties

The rheological properties are evaluated for SCGPC in the form of T<sub>50</sub> slump, J-ring, V-funnel, slump flow and V<sub>5</sub>minutes- funnel etc., which is presented in Table 5. Substituting RHA with GGBFS at levels ranging from 0% to 25% meets the fresh property criteria outlined by EFNARC guidelines. However, as the RHA content increases from 0% to 25%, there is a decline in rheological properties. RHA exhibits a higher specific surface area compared to fly ash and GGBFS particles. Therefore, it absorbs more water for a uniform mixture of SCGPC mix, which increases the water requirements very high and results in a decline of rheological qualities. As illustrated when a greater quantity of RHA is added, the mixture develops more cohesive and viscous. Resulting in a loss in flowing ability and flexibility of the SCGPC mix. In a study, Patel and Shah looked at the new characteristics of SCGC using RHA at 5%, 15%, and 25% in place of GGBS. They discovered that mix workability dropped when RHA was partially substituted for GGBFS. With a larger specific surface area and smaller particle size than FA and GGBFS, RHA's microporous, irregularly shaped nature raised the water requirement in the SCGC mix, decreasing workability. Higher RHA proportions in SCGC mixes reduced their fluidity and flow ability because RHA, like SF, absorbed more water, making the mixtures denser and more cohesive [26]. Henigal et al. [27] investigated how superplasticizer (SP) dosages affected concrete mixture strength. They tested 3%, 6%, and 7% SP dosages. As SP dosage increased, power increased. To clarify, the mixture with 3% SP had a strength of 40.8 MPa, whereas those with 6% and 7% SP had 16.42% and 20.83% higher powers. Higher SP dosages improved stability, with a 6% SP dosage increasing strength by 16.42% and a 7% SP dosage increasing strength by 20.83%.

#### 3.3.1. Slump Flow Results

The slump flow results of several SCGPC blends. According to EFNARC recommendations, concrete has adequate filling capability if its slump flow values range from 650 mm to 800 mm. M<sub>1</sub> should be mixed with a single activation solution of Ms 1.99. The slump flow recorded

for M<sub>1</sub> (F<sub>50</sub>G<sub>50</sub>) reference is 718 mm. The mix M<sub>6</sub> (F<sub>50</sub>G<sub>25</sub>R<sub>25</sub>) had a low slump flowing value of 666 mm. The slump flowing value decreased as the RHA increased (from 0% to 25%). M<sub>1</sub> should be mixed with a single activation solution of Ms 2.92. The droop flow recorded for M<sub>1</sub> (F<sub>50</sub>G<sub>50</sub>) in reference is 720 mm. The mix M<sub>6</sub> (F<sub>50</sub>G<sub>25</sub>R<sub>25</sub>) had the lowest slump flow reading of 670 mm. Slump flow values were reduced with all mixes with Ms1.99 single activator solutions, while fresh properties were improved with single activation solutions MS 2.92 for all mixes.

#### 3.3.2. Findings of the T<sub>50</sub> Slump Flow Test

The slump flowing diameter measurements capture the time it takes for the mixture of concrete to spread to a diameter of 500 mm. T<sub>50</sub> cm slumped flow is the name given to this flow time. According to EFNARC criteria, a shorter time indicates high flow ability. The findings of T<sub>50</sub> cm slump time for flow according to the results, different SCGPC mixtures T<sub>50</sub> cm slump flowing hall mixes with Ms1.99 single activation solution achieving greater fresh characteristics with single activation solutions MS 2.92 for all mixes. With using single activator solution of Ms 1.99 the values are 3.5s to 7s. And as per results, various SCGPC mixes T<sub>50</sub> cm slump flow with using single activator solution of Ms 2.92 the values are 3s to 6s. The permissible values as per EFNARC guidelines are between 2sec to 5 sec. Except M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub> reaming all the mixes satisfy the EFNARC criteria. With the increase of the RHA (0% to 25%) the SCGPC mix's flow capability and fluidity are reduced as it becomes more cohesive and viscous.

#### 3.3.3. Results of the J-Ring Test

The J-Ring testing is used to determine the flow and pass ability of a concrete mix. The J-Ring test according to EFNARC (2002), a satisfactory range of off-blocking step is 0-10 mm. According to ocular assessments and record data, all six mixes demonstrated good passing ability. According to EFNARC (2002), the J-Ring readings of several SCGPC mixes were within the permitted range of 0-10 mm. As per results various SCGPC mixes J-Ring test with using single activator solution of Ms 1.99 the values are 5.5mm to 9 mm. And as per results various SCGPC

mixes T J-Ring test with using single activator solution of Ms 2.92 the values are 5 mm to 8 mm. Minimum value of 5mm was recorded with mix of M<sub>2</sub>F<sub>50</sub>G<sub>45</sub>R<sub>5</sub> with using single activator solution of Ms 2.92 and maximum value of J-Ring is 9 mm was recorded with mix of M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub> with using single activator solution of Ms 1.99. As the RHA increase from (0% to 25%) flow ability and passing ability of fresh properties are reduced.

### 3.3.4. V-Funnel Test Results

The stability and flow ability of SCGPC mixes activated by single activator solutions of MS 1.99 and Ms 2.92 were assessed by V-Funnel test. The results of V-Funnel flow time and V- T<sub>5</sub> minutes all the six mixes are achieved as per EFNARC (2002). As per the results the V-Funnel values varies various SCGPC mixes V-Funnel flow with using single activator solution of Ms 1.99 the values are 7.8 sec to 11.6 sec and V-Funnel flow with using single activator solution of Ms 2.92 the values are 7.5 sec to 11 sec. The permissible values as per EFNARC guidelines are between 6 sec to 12 sec. minimum value of 7.8 sec was recorded with mix of M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub> with using single activator solution of Ms 2.92 and maximum value of V-Funnel flow is 11.6 sec was recorded with mix of M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub> with using single activator solution of Ms 1.99. As the RHA increases from (0% to 25%) flow ability fresh properties increased V-Funnel flow. The same behavior is observed for V- Funnel T<sub>5</sub> minutes flow times.

### 3.4. Hardened Properties

Based on Davidovits [28], the use of heat is critical in the process of curing and the chemical response of the paste. Endothermic condensation occurs during the geopolymerization process. The observed association between temperatures and strength may be attributed to the increased hardened of the SCGC mixture due to the increased rate of the polymerization process. According to the study of P. Nath, et al. [29], increasing the curing temperature between 60 and 90 degrees Celsius accelerates the speed of response, which leads to an increase in the compressive strength. Nonetheless, it has been demonstrated that the compressive value of SCGC decreases at 70 °C. This is because, as previously noted by Memon, et al [30], the majority of the polymerization of condensation process has already transpired at this temperature. The rate of formation of calcium silicate hydrate, or C-S-H, gel and geopolymer gel is enhanced at high temperatures because of the quick dissolving of the calcium (Ca), silica (Si), and aluminum (Al) monomer from the source materials. The mixes displayed poorer toughened qualities at room temperature when compared to the specimen cured at temperature of 70- and 60-degree C, owing to the slow dissolve rate of the aluminum and silicon monomers [31-33].

The alkali activator, hydroxide ion (OH<sup>-</sup>), enhances the ability to react of ground-granulated slag from blast

furnaces (GGBFS). The aforementioned mechanism facilitates the disintegration of chemical bonds present in the Ca-O, Si-O, and Al-O structures, leading to the creation of dissolved species including Ca<sub>2</sub>, [H<sub>2</sub>SiO<sub>4</sub>]<sub>2</sub>, [H<sub>3</sub>SiO<sub>4</sub>]<sup>-</sup>, or [Al(OH)<sub>4</sub>]<sup>-</sup>. The chemical reaction produces calcium-silicate-hydrate (C-S-H) and calcium aluminum silica hydrate (C-A-S-H) [36], as well as the formation of sodium alumina silicate hydrate (N-A-S-H) gel, leading to a denser microstructure [9, 37]. GGBFS has an increased content of calcium dioxide (CaO) along with greater levels of alumina and silica when compared to Fly Ash (FA).

The primary constituents of FA consist mostly of crystal alumina and silica phases, whereas GGBFS has a greater level of amorphousness, which enhances its reactivity [13]. The incorporation of calcium oxide (CaO) inside GGBFS accelerates the process by which geopolymer paste gains strength, resulting in enhanced strength at early stages of development. The accelerated progress in achieving high initial strength in combinations including Ground Granulated Blast Furnace Slag (GGBFS) can be ascribed to the prompt reaction of a larger amount of calcium present in GGBFS. The combination of ground granulated blast furnace slag, or GGBFS with water results in an exothermic reaction involving calcium oxide (CaO), which produces heat. This heat promotes the onset of geopolymerization in the mixture, even at ambient temperature. Based on the research conducted by Memon, F.A. et al. [30], it has been determined that a geopolymer paste incorporating 50% GGBFS demonstrates increased density and decreased porosity in comparison to the paste solely composed of 100% GGBFS. This attribute has a significant role in augmenting the strength of geopolymer compositions. The inclusion of Ground Granulated Blast Furnace Slag (GGBFS) in the mixture yielded an elevation in calcium compound levels and facilitated the development of a more prominent Calcium-Silicate-Hydrate (C-S-H) gel [34]. The phenomenon of geopolymerization, which encompasses the utilization of GGBFS leads to the creation of composite material consisting of calcium-silicate-hydrate (C-S-H) gel. This gel is formed through the chemical reaction between CaO and alumino-silicate gel, which is generated by the dissolution of SiO<sub>2</sub>. The formation of a geopolymer, specifically the C-A-S-H hydrate, was successfully accomplished by combining two separate geopolymeric gels [35].

The presence of C-A-S-H in the gel results in a solidification and initial strengthening of the SCGC material, which is primarily composed of GGBFS. The effectiveness of RHA in improving the mechanical characteristics of both traditional concrete as well as geopolymer-based concrete has been proven [36]. The use of Rice Husk Ash (RHA) in geopolymer concrete results in changes to the physical properties and reaction process, resulting in modifications to the geopolymer matrix.

The use of reactive hydrous alumina (RHA), which contains a high concentration of SiO<sub>2</sub>, can be employed to

adjust and maintain the SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio in the source material. Geopolymer with a greater silica to alumina ratio exhibit enhanced flexibility. In their study, in a study conducted by Songpiriyakij et al. [36], it was observed that the geopolymer paste exhibited a shift from being brittle to an elastic condition whenever the SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> mole ratio reached 15.9. However, this transformation was accompanied by a decrease in compressive strength. According to the findings of Chindaprasirt et al. [37], the utilization of rice husk ash (RHA) with a smaller particle size resulted in enhanced reactivity, leading to a higher degree of geopolymerization. The presence of free water in the geopolymer matrix leads to the formation of voids. The fine particles have the capability to occupy the empty spaces, while the porous nature of RHA particles improves the pore configuration and enhances the weight of the geopolymer matrices. Consequently, the mechanical characteristics of SCGC are improved [38,39]. The utilization of recycling high-alumina (RHA) of geopolymer composites led to a significant enhancement in compressive strength, accompanied by a significant reduction in pore width of up to 55% [40].

3.4.1. Compressive Strength

Table 6 displays the compressive strength values of self-compacted geopolymer concrete with varying mix

proportions during a span of 3 days, 7 days, and 28 days. In this study, the fly ash content remains constant at 50% throughout all mixtures, but the range of rice husk ash (RHA) replacement with ground granulated blast furnace slag (GGBFS) varies from 0% to 25%. These proportions are then activated using two distinct types of single activated solutions. The compressive strength of self-compacted geopolymer concrete mixes, which were activated using a single activator solution with a Ms 1.99, exhibited varying values for different mix compositions. For a range of mix compositions, namely M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub> to M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub>, the compressive strength after three days ranged from 22.49 to 18.4 Mpa. Similarly, after seven days, the compressive strength ranged from 32.13 to 26.8 Mpa. Finally, after 28 days, the compressive strength varied from 44.2 to 38 Mpa. In a similar manner, the compressive strength of Self-compacted geopolymer concrete blends activated with a single activator solution of Ms 2.92 can be observed. The compressive strength values for mixes M<sub>1</sub>F<sub>50</sub>G<sub>50</sub>R<sub>0</sub> to M<sub>6</sub>F<sub>50</sub>G<sub>25</sub>R<sub>25</sub> range from 27.37 to 26.8 MPa after three days, 35.12 to 28.8 MPa after seven days, and 51.2 to 46.5 MPa after 28 days. The present study observed that the maximum compressive strength was obtained with 5% of RHA proportion when compared to other mixes [41].

Table 5. Workability of various mixtures

Mix proportions	SLUMP FLOW		T <sub>50</sub> SLUMP FLOW		V- FUNNEL		V-FUNNEL T5 MIN TIME		J- RING	
	MS 1.99	MS 2.92	MS 1.99	MS 2.92	MS 1.99	MS 2.92	MS 1.99	MS 2.92	MS 1.99	MS 2.92
M <sub>1</sub> F <sub>50</sub> G <sub>50</sub> R <sub>0</sub>	701	705	4	3.5	8.5	8	12	11	6	5.6
M <sub>2</sub> F <sub>50</sub> G <sub>45</sub> R <sub>5</sub>	691	695	3.5	3	10	9.7	11	10.8	5.5	5
M <sub>3</sub> F <sub>50</sub> G <sub>40</sub> R <sub>10</sub>	680	685	3.8	3.2	11	10.5	11.5	11.2	6	5.4
M <sub>4</sub> F <sub>50</sub> G <sub>35</sub> R <sub>15</sub>	670	674	4.5	4	11.6	11	12.5	12.1	7	6
M <sub>5</sub> F <sub>50</sub> G <sub>30</sub> R <sub>20</sub>	668	670	5	4.8	12	11.8	14.1	13.5	8	7
M <sub>6</sub> F <sub>50</sub> G <sub>25</sub> R <sub>25</sub>	655	658	5.8	5.3	15	14.5	16	15.3	9	8

Table 6. Results of compressive strength of various concrete mixtures

Mix ID	3 DAYS		7 DAYS		28 DAYS	
	MS1.99	MS2.92	MS1.99	MS2.92	MS1.99	MS2.92
M <sub>1</sub> F <sub>50</sub> G <sub>50</sub> R <sub>0</sub>	22.4	27.3	32.1	35.12	44.2	51.2
M <sub>2</sub> F <sub>50</sub> G <sub>45</sub> R <sub>5</sub>	26.5	29.2	36.5	37.9	47.4	55.6
M <sub>3</sub> F <sub>50</sub> G <sub>40</sub> R <sub>10</sub>	25.3	27.6	34.4	36.6	45.5	53.5
M <sub>4</sub> F <sub>50</sub> G <sub>35</sub> R <sub>15</sub>	22.6	25.4	31.8	34.4	41.3	51.8
M <sub>5</sub> F <sub>50</sub> G <sub>30</sub> R <sub>20</sub>	20.65	23.3	28.9	32.3	39.6	48.4
M <sub>6</sub> F <sub>50</sub> G <sub>25</sub> R <sub>25</sub>	18.4	26.8	26.8	32.1	38	46.5

The objective of this study was to investigate the compressive strength of self-compacting geopolymer concrete mixes that were formulated using a blend of 50% fly ash and 50% ground granulated blast furnace slag (GGBFS). Additionally, the study aimed to examine the effects of replacing rice husk ash (RHA) with GGBFS at various percentages (0%, 5%, 10%, 15%, 20%, and 25%) on the compressive strength of the concrete mixes. The compressive strength of self-compacting geopolymer concrete (SCGPC) exhibits a reduction as the amount of rice husk ash (RHA) increases. The compressive strength of all mixtures, except for those containing 5% and 10% RHA, exhibits a decrease when subjected to ambient curing. An increase in compressive strength was seen when Ground Granulated Blast Furnace Slag (GGBS) based Self-Compacting Geopolymer Concrete (SCGC) was mixed with Rice Husk Ash (RHA) at different amounts (5%, 15%, 25%). With 5% RHA replacement, the strength reached its maximum of 41.35 MPa during ambient curing. It is worth mentioning that thermal curing, as opposed to ambient curing, can significantly boost the strength of RHA-based SCGC at larger degrees of replacement [42].

#### 4. Conclusions

The experimental findings indicate the feasibility of producing a self-compacting geopolymer concrete (SCGPC) with suitable rheological characteristics and ambient temperature compressive strengths. This is achieved by including fly ash (flay), ground granulated blast furnace slag (GGBFS), and rice husk ash (RHA), while using single activator solutions. The primary findings of this investigation are essentially outlined as follows.

1. To improve the initial and final setting periods of fly ashes-based self-compacting geopolymer concrete, a neutral grading of single activator solution activated fly ash, ground-granulated slag from blast furnaces (GGBFS), and rice husk ash (RHA) have been found to be highly effective. Furthermore, no reducers or retarders were applied during the place of work preparations to extend the setting period.
2. The activation of fly ash, ground granulated blast furnace slag (GGBFS), and rice husk ash (RHA) using neutral sodium silicate has been found to yield the most useful results regarding rheological parameters to produce self-compacting geopolymer concrete, as per the requirements given by EFNARC.
3. The addition of varying percentages (0%, 5%, 10%, 15%, 20%, 25%) of RHA in the binder of self-compacted geopolymer concrete results in an increase in both the setting time and fresh properties. However, when RHA percentages of 15%, 20%, and 25% are used, the setting time increases simultaneously with the fulfillment of fresh properties, according to the EFNARC guideline. In

comparison, the fresh properties are slightly reduced when other percentages of RHA are utilized. The decrease in volume can be attributed to the greater quantity of paste along with the elevated water demands of the porous nature of RHA.

4. The compressive strength of SCGPC was shown to improve by up to 10% when replacing RHA with neutral sodium silicate, as compared to the control mix, across all ages of SCGPC. However, when the RHA replacement reached 15%, 20%, and 25%, the compressive strength of SCGPC decreased during ambient temperature curing.

#### Credit Authorship Contribution Statement

**Thatikonda Naresh:** Conceptualization, Methodology, Data collecting.

**Mainak Mallik:** Supervision, Writing - review & editing and Visualization.

**S. Venkateswara Rao:** original draft and Investigation.

**Sri Rama Chand Madduru:** Validation, Writing - review and editing.

**Sunil Nandipati:** Writing - review and editing

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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