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Workability and Compressive Strength of Self-Compacting Geopolymer Concrete Blended with Industrial and Agricultural Waste

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Abstract

Objectives: To investigate the effect of replacement of Rice Husk Ash (RHA) on the workability and compressive strength of Self Compacting Geopolymer Concrete (SCGC) blended with Ground Granulated-Blast Furnace Slag (GGBFS) for sustainable environment. **Methods:** GGBFS as an industrial waste and RHA as an agricultural waste were used as an aluminosilicate source materials for the development of SCGC. Use of RHA is popular for their considerable effects on the mechanical as well as microstructural properties of cement based binders as well as geopolymer binders. The SCGC mixes were prepared by replacing GGBFS with RHA at various proportions of 5%, 15% and 25%. The fresh properties of SCGC have assessed through "Slump Flow, V- funnel, L-Box and J-Ring test methods as per EFNARC" guidelines. **Findings:** Partial replacement of RHA decreases the workability. Replacement of RHA in SCGC beyond 5% reduces the compressive strength, yet the target strength (30MPa) of all mixes were achieved. SEM analysis with EDXS spectra shows the dense microstructure of optimum mix with 5% RHA replacement. The 28 days strength of 42.6 MPa for 5% RHA, 39.31MPa for 15% RHA and 31.59 MPa for 25% RHA were achieved at ambient temperature, which is 110%, 94% and 56% higher than control mix strength (MF-100% FA) at ambient temperature. **Novelty:** SCGC is a new concrete which fulfill the properties of both Geopolymer (GPC) and Self Compacting Concrete (SCC). Most of the investigations in SCGC have been performed using Fly Ash, Metakeoline, and GGBFS as a binder. In this experimental study, GGBFS as an industrial waste and RHA as an agricultural waste are used as source material to develop the SCGC.

Keywords: Sodium Silicate; Sodium Hydroxide; Fresh Concrete; Rice Husk Ash; Microstructure; Self Compacting Geopolymer Concrete

1 Introduction

Due to the rapid growth of the construction industry and the need for cementitious building materials in challenging conditions, such as long spans, high strength, and high-rise buildings, there is an increased demand for cement. However, the production of cement is a significant contributor to greenhouse gas emissions, making the cement industry the second-largest producer of greenhouse gases. The use of Ordinary Portland Cement (OPC) has led to a substantial amount of CO_2 emissions and ecological imbalance due to the depletion of natural resources. It is estimated that OPC production accounts for approximately 8-10% of global greenhouse gas emission[(1)]. To address this issue and promote environmental sustainability, it is crucial to explore the utilization of industrial and agricultural waste materials as an alternative in concrete production, thereby conserving resources and mitigating waste disposal problems[(2)].

One approach to develop sustainable concrete is through the use of Geopolymer Concrete (GPC), which offers economic and eco-friendly benefits while maintaining similar mechanical properties to OPC concrete. The term "geopolymer" was introduced by Davidovits in 1978 to describe a new material formed through the polymerization reaction between source materials and an alkaline liquid containing silicon (Si) and aluminum (Al), resulting in an amorphous microstructure[(3)]. Various industrial and agricultural waste materials, such as Ground Granulated Blast Furnace Slag (GGBFS), Fly Ash (FA), Rice Husk Ash (RHA), and Metakeoline (MK) have been utilized either individually or in combination as source materials for GPC[(3)].

GGBFS, which is abundantly available worldwide, is a by-product of iron production in blast furnaces. It consists of calcium, magnesium silicates, and aluminosilicates. The use of slag in cement has been extensively studied since 1939 to understand its impact as a cementitious material in concrete production[(4)]. Peiliang Cong and Yaqian Cheng (2021) found that the inclusion of soluble or partly soluble calcium in the form of GGBFS accelerated the setting and hardening of geopolymer pastes. However, they also concluded that replacing FA with GGBFS reduces the workability of Geopolymer Concrete (GPC) due to the rapid reaction of calcium oxide and the angular shape of slag particles[(3)].

RHA can serve as a pozzolanic material in concrete, similar to silica fume. It is obtained by burning rice husk under controlled temperature and is a waste product from biomass power plants. RHA poses challenges for disposal and contributes to environmental issues due to its low bulk density, large dry volume, and rough and abrasive surfaces that hinder natural degradation. However, RHA contains amorphous silica and carbon that can be utilized in industrial and technical applications. The primary element in RHA is amorphous silicon oxide (92-98%), with trace amounts of CaO, MgO, K_2O, Al_2O_3, Fe_2O_3, and Na_2O. With its mesoporous structure, RHA functions as an internal water "curing agent" and a pozzolanic admixture in Ultra-High Performance Concrete (UHPC), making it an excellent source material in GPC[(5)]. Hossain et al. (2021) extensively reviewed the utilization of RHA for sustainable geopolymer and concluded that it can be used (up to 15%) in GPC without compromising essential properties. They also recommended that incorporating RHA in GPC enhances mechanical and long term properties, reduces production costs, and mitigates adverse environmental effects[(6)]. Rattapon et al. (2022) developed geopolymer hollow blocks using RHA and FA activated by NaOH and found that RHA can replace up to 50% of FA, achieving a compressive strength of 4.1 MPa at 28 days[(7)]. Anhad S. Gill and Rafat Siddique (2018) observed approximately a 46% reduction in porosity and a 45% reduction in water absorption when MK (Metakeoline) and RHA were added to produce Self-Compacting Concrete (SCC)[(8)].

As per EFNARC (2005), SCC offers advantages such as "good quality of concrete, easy pouring of concrete in congested reinforcement, reduced construction time, good compaction and homogeneous concrete as well as increased bond strength". As there is no vibration, it reduces noise levels which facilitate a safe working environment with reduced overall cost of construction[(9)]. SCGC is a new concrete which fulfills the properties of both GPC and SCC. Sari et al. (2021) concluded effectiveness of 10% RHA replacement in FA based SCGC[(10)]. N. Vishnu (2021) assessed the workability and mechanical properties of ambient cured SCGC blended with FA, GGBFS, Wollastonite, Graphene oxide[(11)]. Nishanth and Dr. Patil (2022) studied fresh and mechanical properties of SCGC Using 60% GGBFS, 35% FA and 5% alccofine[(12)]. Khaleel (2022) studied the influence of molarity of Sodium Hydroxide (NaOH) on fresh properties of slag based SCGC containing recycled aggregate[(13)]. M. Thakur and S. Bawa (2022) had carried out extensive review of properties of SCGC. This study reviewed the effect of various parameters such as source materials, NaOH molarity, water to binder ratio, curing temperature, fibers and superplasticizer on the fresh properties and mechanical properties of SCGC[(14)].

After studying the existing literature on GPC and SCGC following are the research gaps: (i) most of the investigations of SCGC have been performed using FA, MK, silica fume and GGBFS as a source material. (ii) Temperature curing is carried out in almost every experimental study. Ambient curing is preferable in cast-in-citu constructions and in hot region. (iii) Very few studies exist on microstructural properties of SCGC. It is indeed to study the microstructure of SCGC developed using different source materials, fibres and other additives to understand the modification of properties and long term behaviour. The source materials play very vital role in development of GPC and SCGC. The development of SCGC with combination of GGBFS and RHA needs to be discovered. In this experimental study, GGBFS as an industrial waste and RHA as an agricultural waste were used as source materials to develop the SCGC.

2 Methodology

In the absence of standard code for the mix design of SCGC, the EFNARC (2005) [9] guidelines were utilized for the mix design of SCGC. Multiple test methods were employed to assess the various workability aspects, including filling ability, passing ability, and resistance to segregation, to ensure that the desired workability criteria were met as per EFNARC. Water to geopolymer solid ratio of 0.43 was maintained for all mixes. SCC mixes results in low yield stress and high viscosity, which required a high dosage of superplasticizer to achieve the required deformability. The new generation polycarboxylic ether-based master Glenium sky 8784 superplasticizer was used at a dosage of 6% by mass of binder, along with 25% water content, to achieve the necessary workability as per EFNARC [9].

The alkaline activator liquid used in this study was a mixture of sodium hydroxide and sodium silicate. Sodium silicate of Grade A53, containing 55.52% water, 29.75% SiO_2, and 14.73% Na_2O was used. The molarity of sodium hydroxide was fixed at 12M, corresponding to 480 g of NaOH solids per liter of water. The mass of NaOH solids used was calculated as 361 g/kg of NaOH solution with a concentration of 12 molar. The exothermic reaction that occurs during mixing of the two liquids generates significant heat, necessitating cooling of the liquid for at least one hour before adding it to the dry mixture. Different cooling period was applied in previous literature for alkaline activator to add in the dry mix. To support the results of compressive strength, Scanning Electron Microscopy Analysis was employed to examine the microstructure of the specimens.

2.1 Materials

FA, GGBFS and RHA were locally available in Ahmedabad. Table 1 shows the mineralogical composition of FA, GGBFS and RHA tested at Divine Metallurgical Services Pvt. Ltd, Ahmedabad. Natural sand with specific gravity of 2.6 and fineness modulus of 2.75 confirming Zone II as per IS 383(1970) was used as fine aggregate [15]. Locally available 14 mm crushed aggregates with the specific gravity of 2.87 were used. A mixture of sodium silicate and sodium hydroxide was used for geopolymerization of source materials. Sodium hydroxide in the form of flakes (98 % purity) and sodium silicate were obtained from the local manufacturer. To achieve flowability and fulfill the workability criteria of fresh SCGC as per EFNARC [9], second-generation polycarboxylic ether based superplasticizer, Master Glenium Sky 8784 purchased from BASF with relative density 1.10 was used.

Table 1. Chemical compositions of Fly Ash, RHA and GGBFS

Sample (%)	**SiO_2**	**Al_2O_3**	**CaO**	**Na_2O**	**Fe_2O_3**	**MgO**	**SO_3**	**K_2O**	**LOI**
FA	51.72	34.70	1.40	1.35	6.00	1.35	0.04	0.25	0.45
GGBFS	34.01	14.32	39.7	0.70	0.50	9.00	0.35	0.80	0.05
RHA	92.30	0.40	0.70	0.70	0.45	0.85	0.04	0.85	3.15

2.1.1 Proportions

The mix design of the SCGC mixes was calculated as per the EFNARC (2005) [9] guidelines for the SCC. The target strength of SCGC was fixed as 30 MPa. Five mixes, one control mix with 100 % FA and four mixes with GGBFS as a prime binder with different proportions of RHA (0%, 5%, 15% and 25%) were prepared. The total binder was fixed at 500 kg/m^3. The water to powder ratio by mass for all the mixes was maintained at 0.25. The 12 M sodium hydroxide was used with 2.5 ratio of sodium silicate to sodium hydroxide. To achieve the self compatibility as per EFNARC, extra water of 25% and superplasticizer of 6% dosage by mass of the binder were added. The proportions of various mixes are given in Table 2.

2.2 Mixing, Casting and Curing

Coarse aggregates and fine aggregates in dry state were mixed in mixture machine for 3.0 min. After that FA, GGBFS, RHA were mixed in finely powder form. After dry mixing, a liquid mixture of superplasticizer, alkaline solution and extra water was added in dry mix. Wet mixing is done for about 3 min for homogeneous concrete mix. The fresh properties of SCGC were assessed by performing the workability tests as per the EFNARC (2005) [9]. Immediately after workability tests, thoroughly mixed fresh concrete was poured into cube moulds by its own weight without compaction. For each mix, nine cubes of 150 mm were casted [16]. After casting, without delay, the moulds were placed at ambient conditions for 24 hours. After demoulding, the

Table 2. Details of Mix Proportion

Mix Type	Fly Ash	GGBFS	RHA	Coarse Aggregate	Fine Aggregate	NaOH		Na-silicate	Extra water	SP
	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Molarity	Kg/m^3	Kg/m^3	%
MF (Fly Ash-100%)	500	00	00	785	1100	65	12	163	25	6
M1 (GGBFS-100%)	00	500	00	785	1100	65	12	163	25	6
M2 (RHA-5%)	00	475	25	785	1100	65	12	163	25	6
M3 (RHA-15%)	00	425	75	785	1100	65	12	163	25	6
M4 (RHA-25%)	00	375	125	785	1100	65	12	163	25	6

specimens were kept at room temperature for the air curing up to date of testing.

2.3 Testing Procedure

2.3.1 Fresh Properties

The three properties of SCC, filling ability, passing ability, and resistance to segregation should be satisfied by concrete mix to be considered as SCGC. To assess the characteristics of workability, more than one test method required. The "filling and passing ability" of the mixes can be assessed by performing Slump flow test, V- Funnel test, L-Box test, J- Ring test methods. Resistance to segregation can be assessed by L-Box and V- funnel test as well as through visual observation. In present experimental study, "Slump flow test, Slump flow at 50 cm, V-funnel test, V-funnel at $T_{5\ min}$, L-Box and J-Ring" tests were performed to assess the fresh properties of SCGC mixes as per EFNARC (2005)[9].

2.3.2 Compressive Strength Test

Cube specimens of size 150 mm[17] were casted and an average of three specimens was calculated as compressive strength of SCGC mix as per IS 516 (1959)[18] at 3, 7 and 28 days. The specimens were tested using a digital compressive testing machine (2000-kN) at a rate of 5.2 kN/s up to the failure of the specimen.

2.3.3 Scanning Electron Microscopy Analysis

The detail study and analysis of microstructure, phase composition was carried out using Scanning Electron Microscopy (SEM) with EDXS on ZEISS ULTRA-55. The specimens were dried at oven temperature of 200^0C and sputtered with "AuPd alloy" using "LEICA EMACE 200" sputter coater.

3 Results and Discussion

3. 1 Fresh properties

The results of fresh properties of SCGC mixes with different percentages of RHA are as shown in Figures 1, 2, 3, 4, 5 and 6. Workability of the mixes reduces with the increase in RHA percentage. The specific surface area of RHA used in SCGC was obtained $22.5m^2/g$. The mean particle size of RHA is 12.5 mm. Due to higher specific surface area; it required higher water content in fresh GPC leads in the loss of workability. Just like silica fume, due to its higher surface area of RHA, absorbed the excessive water in the SCGC mix; less water is available for lubrication of mix. The similar outcome was reported in normal GPC[19,20]. Mixes with higher percentage of RHA were observed more cohesive and viscous and hence reduction in "flowability and fluidity" of mixes were recorded with higher percentage of RHA. Similar results were reported by Hossain SS et. al (2021)[6].

3.1.1 Results of Slump Flow Test

Slump Flow test is performed to evaluate filling ability of fresh SCGC. As per Figure 1, the slump flow value of all SCGC mixes is within the EFNARC[9] permissible limit (650-800 mm).

The control mix MF (100% Fly Ash) achieved maximum slump flow value of 720 mm. Figure 1 shows the slump flow (690 mm) of mix M2 with 5% RHA. Due to very fine "particle size and the increased surface area" of RHA ultimately increases the water requirement[6] of the mixes results in decrease in slump flow value with compared to100% FA mix M1.

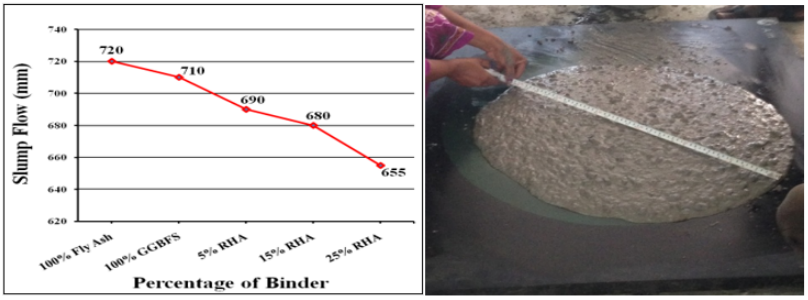

Fig 1. Effect of RHA on slump flow

3.1.2 Results of T50cm Slump Flow Test

The time required for SCGC to reach 50 cm diameter during the slump flow test is called as "T_{50cm} slump flow time". This test indicates the relative viscosity and a relative estimation of the unconfined flow rate of the SCGC mix. A lower the T_{50cm} time, better is the flow ability. Figure 2 shows the results T_{50cm} slump flow test. As per results, except for the mix M4, all other mixes flow time is within the EFNARC[9,21] range (2-5 sec).

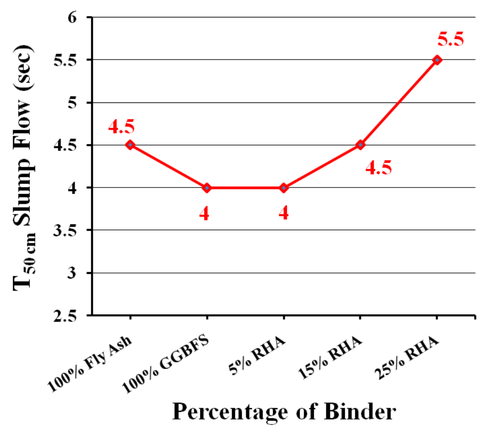

Fig 2. Effect of RHA on T_{50cm} Slump Flow

3.1.3 Results of V- Funnel Test

This test basically assesses the filling ability of SCGC as well as determines the flow of concrete through a tapering section without segregation and blocking[21]. Figure 3 shows the results of the V-funnel flow time.

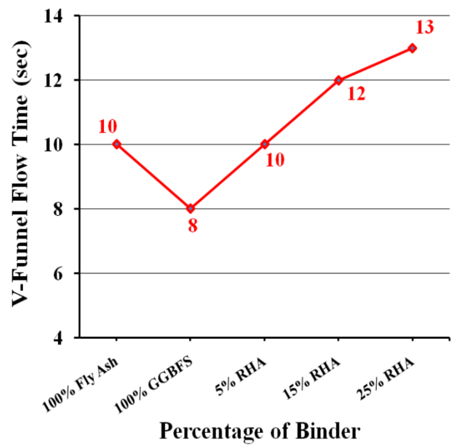

Fig 3. Effect of RHA on V-Funnel Flow

As per the results, the flow time varies between 8 and 13 sec. Except for mix M4, all other mixes satisfy the EFNARC[9] requirements. The maximum time of 13 sec was recorded for the mix M4 with 25% RHA. The minimum flow time of 8 sec was recorded for the mix M1 (100% GGBFS). With the percentage increase in the RHA, the fluidity of concrete decreases due to fine particle size and higher specific surface area results in the more water demand which increases the V- Funnel flow time[6,22]. As shown in Figure 4, the percentage increase in RHA leads to the increase in $T_{5\ min}$ time.

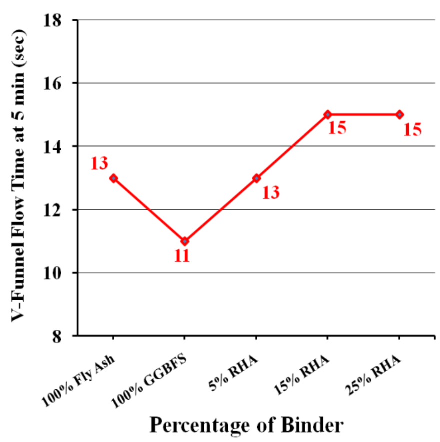

Fig 4. Effect of RHA on V-funnel at $T_{5\ min}$

3.1.4 Results of L- Box Test

The filling and passing ability are measured by performing this test. Lack of stability in the form of segregation can be assessed by visual observation. The blocking ratio closer to unity is considered as good flowability and passing ability of the concrete[21]. The permissible limit of blocking ratio is between 0.8 and 1.0 as per EFNARC[9] guidelines. The uniformly distributed coarse aggregates on the concrete surfaces up to the end of the horizontal section as well as in all directions are considered as possessing good segregation resistance[23]. The blocking ratio results are as shown inFigure 5. All SCGC mixes were easily passed through the bars of L-Box without any blockage. The blocking ratio varies from 0.8 to 0.95 for various mixes. With the percentage increase in RHA, the L-Box ratio reduces. In mix M4 it was observed that paste first reached to the end of the horizontal section of the L-box due to minor blocking of aggregates at the bar section, though the ratio was found within the limit of EFNARC (2005)[9]. The best result of ratio was observed in mix M1 and M2.

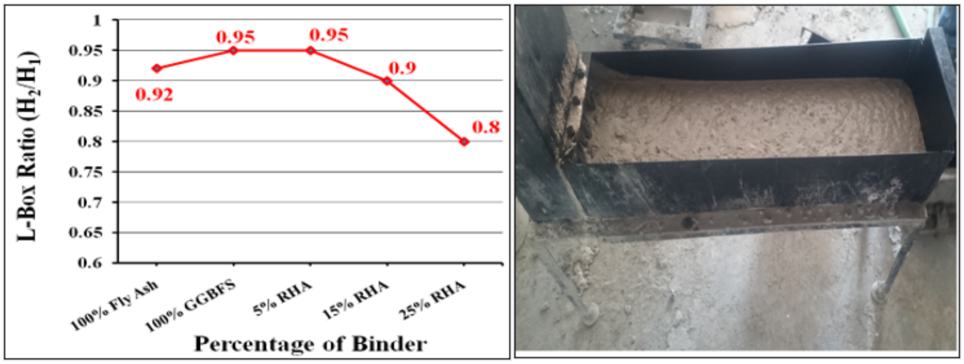

Fig 5. Effect of RHA on L-Box Ratio

3.1.5 Results of J-Ring Test

The test measures the passing ability of SCGC as per EFNARC[9] guidelines. The J-Ring consists of vertical bars through which fresh concrete is allowed to flow uniformly in all directions horizontally. The difference of the height of concrete at the central position and an average of the four height measurement at outer side of the J-Ring is known as the blocking step. The blocking step value very close to zero indicates passing and filling ability. As per EFNARC[9], permissible limit of blocking step is from 0 to10 mm. As per the results of J-Ring test shown in Figure 6, all SCGC mixes are within the permissible limit of EFNARC[9]. The blocking step values varied between 6 to 9 mm. Lowest blocking step value of 6 mm is observed for mix M1 and mix MF. Highest blocking step of 9 mm was obtained for mix M4 with 25% RHA due to more stiffness of the mix which restricts the passing ability of mix[21].

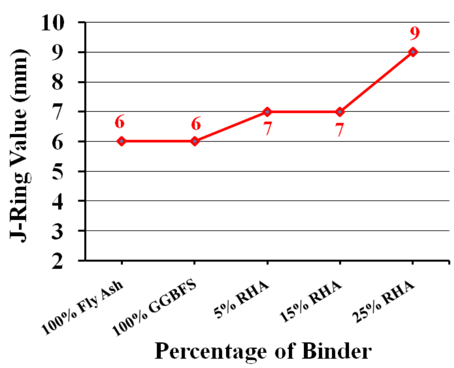

Fig 6. Effect of RHA on J-Ring value

3.2 Results of Compressive Strength Test

It is proved that RHA enhanced the mechanical properties of normal concrete as well as GPC[20,21]. The inclusion of RHA in concrete significantly changes the matrix of geopolymer. The SiO_2 rich RHA can be used to get better geopolymerization process. The fine RHA particles and cellular porous surface fills the voids formed due to evaporation of free water in the geopolymer matrix. The denser pore structure produced due to this particle packing enhances the microstructure of geopolymer matrix and hence improves the final mechanical properties. Similar results were obtained by Saloni, Parveen et al.[24] in normal GPC blended with RHA and OPC and by G. Liang et al.[25] in GPC blended with RHA and MK. Figure 7 shows the results of compressive strength of the SCGC at 3, 7 and 28 days. The effect of RHA on the compressive strength of the SCGC at ambient temperature is discussed. SCGC with 100% FA was kept as control mix and the strength of mixes with RHA were compared with strength of 100% FA mix.

The compressive strength of SCGC mixes (0%, 5%, 15% and 25% RHA) is higher than the control mix MF (100% FA) at 3, 7 and 28 days of curing. The demoulding of specimens of MF mix with 100 % FA was not possible even at 3 days of curing due to slow geopolymerization of high silica content at ambient temperature. FA as a sole binder reacted very slowly and develops very poor strength at ambient temperature cuing [21,26]. The mix did not set in the one day and hence considerable strength was not attained after 3 days to be demoulded. The mix M1 with 100% GGBFS was observed to achieve gain of strength of 6.59%, 11.16% and 18.96% from 3 days to 7 days, 7 days to 28 days and 3 days to 28 days respectively. In GGBFS based mix heat is generated due to exothermic reaction of CaO which accelerates the geopolymerization and hence higher strength development at 3 days [23,27]. About 80% strength of 28 days was achieved within 3 days in 100% GGBFS mix.

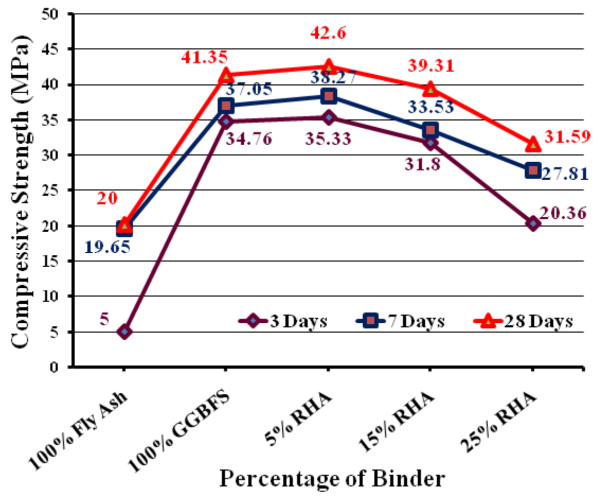

Fig 7. Effect of RHA on Compressive Strength

Higher compressive strength was achieved after 28 days of curing due to improved geopolymerization of SCGC mixes with RHA. The mixes MF, M1, M2, M3, and M4 were attained 304.75%, 18.94%, 20.55%, 23.64%, and 55.15% higher compressive strength at 28 days with respect to 3 days compressive strength respectively. The mix M4 achieved very less strength at the age of 3 days, and it observed a significant increase of strength of 36.59% at 7 days and 55.16% increase at 28 days with respect to 3 days due to slow geopolymerization of higher silica content at ambient temperature [6,28]. When the RHA is added, it supplements the active SiO_2, favorable to form the "siloxo bridges" (-Si-O-Si-O-) during the process of geopolymerization. The biogenic reactive nano silica in the fine RHA particles boosts the dissolution of aluminosilicates ingredients and accelerates the geopolymer polycondensation reaction sequence. These bridge chains bond the particles firmly and resulted in a dense and compact matrix structure [6]. The high specific surface area of RHA improves the "ductility of final geopolymer products" is responsible for higher strength. Similar findings were reported for normal GPC blended with ultra fine slag and RHA as well as in GPC blended with FA and RHA [29,30]. As per results, up to 5% RHA, compressive strength increases but in mixes M3 and M4 with 15% and 25% RHA leads to decrease in compressive strength. It is due to increase in the unreactive silica of higher RHA mix, which further increases the ratio of SiO_2/Al_2O_3 and hence results in negative impact on the compressive strength of geopolymer. It further produces weaker and less ductile geopolymer gel. High volume of RHA is known for geopolymer with lower compressive strength and more brittle due to the larger solid particle and lower specific gravity of RHA [31]. It was delayed reaction of Si and Al ions due to higher amount of SiO_2 which finally results in lower compressive strength [6,29]. The other reason of reduction in strength is difference in degree of solubility between GGBFS and RHA. It decreases the rate of dissolution and polycondensation of aluminosilicates compounds. The reduction in strength also correlates with the conclusion derived by Yaseri et al. (2019) [32] for normal GPC. He concluded that excessive RHA creates pore channel due to the existence of micro-pores in RHA. Initially, pore channel accelerates the ions transfer efficiency that enhances the strength of geopolymer matrix. After long time, dry hollow holes created due to evaporation of free water from the capillary pore. It propagates the micro-cracks and decreases the compressive strength during the load application. All cited researches were obtained for normal GPC due to replacement of RHA with FA, MK, and GGBFS etc. In this study, improvements in properties were reported in SCGC by replacement of RHA with GGBFS. The target strength of 30 MPa was achieved by mixes with higher percentage of RHA. The 28 days strength of 42.6 MPa for 5% RHA, 39.31 MPa for 15% RHA and 31.59 MPa for 25% RHA were achieved at ambient temperature, which is 110%, 94% and 56% higher than control mix strength (MF-100% FA-20 MPa) at ambient temperature.

3.3 Results of Scanning Electron Microscopic Analysis with EDX Spectra

The SEM micrograph of mix MF with 100% FA at ambient temperature is as shown in Figure 8 (a). FA is rich in SiO_2 content and geopolymerization of it requires heat curing. At lower temperature, it is difficult to break down the Si and Al monomers from the surface of FA and hence the dissolution of Si and Al monomers are very slow at ambient temperature. It results in the delayed reaction process and formed poor quality of aluminosilicates gel with wider cracks and large sized pores as shown in Figure 8 (a). The microstructure of mix MF is loose due to nonhomogeneous distribution of gel which lowers the compressive strength of it[31]. The point 1 shows the prism-shaped crystal-like particles distributed in the matrix (point 1). Figure 8 (b) shows the EDXS spectrum of point 1. It shows the existence of O, Si and higher amount of Na elements which confirm that the prism particles are a form of Na_2SiO_3 which is in fact unwanted in geopolymer matrix. It shows that Na_2Sio_3 did not participate in the geopolymerization and hinders the development of strength[28,33].

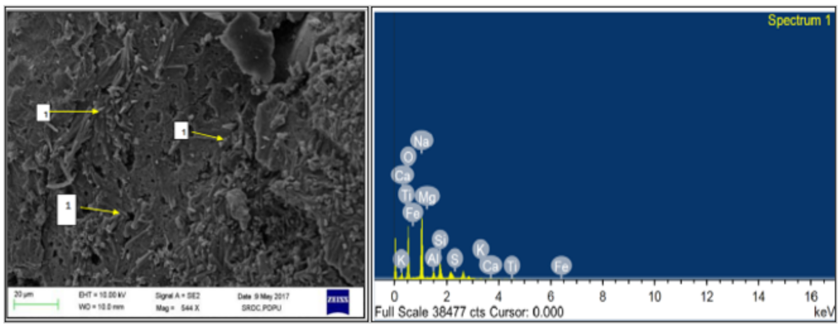

Fig 8. SEM micrographs and EDXS analysis of Mix MF at ambient temperature

The SEM micrograph of the mix M2 with 5% RHA is as shown in Figure 9 (a). It shows the homogeneous distribution of geopolymeric gel as well as C-S-H gel. The heat produced due to reaction process of CaO eventually helps to starts the geopolymerization of SiO_2 present in GGBFS and RHA[33]. The fine particle size of RHA filled out the pores formed in gel produced due to polymerization of GGBFS. As the RHA is finer than GGBFS, it developed dense particle packing with pore size refinement resulting in dense microstructure. The microstructure is very dense with minor cracks and hence higher is the compressive strength. The Figure 9 (b) shows the EDXS spectrum of mix M2 with 5% RHA. It shows the remarkable amount of Si, Al, O and Ca elements with less amount of Na; confirm the better formation of the gel[27]. At ambient temperature combination of GGBFS and RHA develops the dense microstructure with good quality of geopolymer gel.

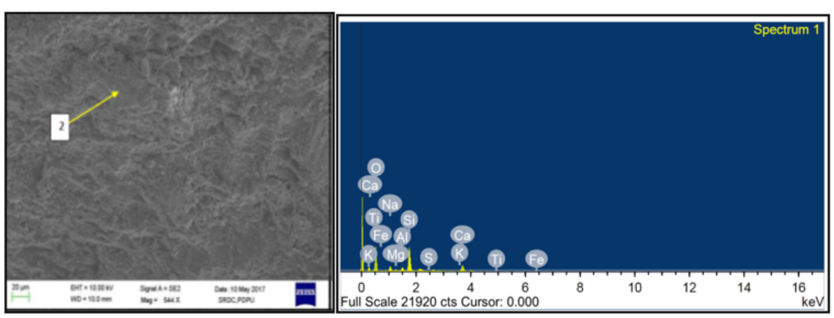

Fig 9. SEM micrographs and EDXS analysis of Mix M2 at ambient temperature

4 Conclusion

This study investigated the fresh properties and compressive strength of sustainable cementless Self Compacted Geopolymer Concrete (SCGC) blended with Rice Husk Ash (RHA) and Ground Granulated-Blast Furnace Slag (GGBFS) at ambient temperature. This aspect has not been extensively explored in previous literature. Workability of the fresh mixes as per EFNARC guidelines and development of compressive strength was determined and compared with control mix blended by

100% FA. Further the results of compressive strength were validated by SEM analysis and EDXS spectra. The conclusions of this experimental study are as under:

- The study found that it is indeed feasible to develop low-cost SCGC by incorporating RHA and GGBFS at ambient temperature. This approach addresses the issue of disposal of RHA and GGBFS, thereby reducing land pollution. Additionally, SCGC, being cement-free, reduces CO_2 emissions associated with cement production, leading to a reduction in air pollution.
- The fresh properties of all the SCGC mixes were within the acceptable limits specified by EFNARC guidelines. However, an observation was made that as the percentage of RHA increased, there was a reduction in flowability and fluidity of the SCGC mixes. The highest slump flow value of 720 mm was obtained with mix MF with 100% FA. As the percentage of RHA increased, the slump flow value decreased, reaching 655 mm for mix4 with 25% RHA. The blocking ratio also decreased from 0.8 for mix4 to 0.95 for mix1, indicating a reduction in flowability with increased RHA content. This can be attributed to the higher water requirement and greater volume of paste associated with the porous structure of RHA.
- The study revealed that the mix with 100% FA failed to achieve the desired strength at 3, 7, and 28 days due to improper geopolymerization process without heat. However, with 5% replacement of RHA, the compressive strength of SCGC improved compared to the strength of 100% GGBFS at all ages. Beyond 5% RHA replacement, a reduction in compressive strength was observed. Notably, the 28-day strengths of 42.6 MPa, 39.31 MPa, and 31.59 MPa were achieved for mixes with 5%, 15%, and 25% RHA, respectively. These values were 110%, 94%, and 56% higher than the compressive strength of the control mix (MF-100% FA-20 MPa).
- The findings of the study were further validated through SEM micrograph analysis and EDXS spectrum analysis. Mix M2 with 5% RHA demonstrated a dense microstructure with a uniform distribution of gel, in contrast to mix1 with 100% FA.

Thus, the study highlights the feasibility of developing low-cost SCGC blended with RHA and GGBFS, which can achieve substantial strength at ambient temperature. The use of RHA and GGBFS helps to address disposal issues, reduces land and air pollution, and presents a promising alternative to conventional cement-based concrete.

5 Limitations of present study/future work

As a self compacted concrete, SCGC should have significant workability. With higher percentage of RHA (25%), flowability of mix reduces. Very limited research is available on durability and microstructure study of SCGC. Both are very important property of concrete. It is need to be studied to understand the long term behaviour and modification in microstructure. Hence, the future work should be to achieve higher workability for self compactability and to assess the long term durability properties.

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