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RESEARCH ARTICLE

Performance Evaluation of Self-Compacting Geopolymer Concrete with Recycled Brick Aggregate under Varied Curing and Temperature Conditions

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ABSTRACT

In recent days, Self-Compacting Geopolymer Concrete (SCGC) has the potential to revolutionize concrete technology by combining the benefits of both Geopolymer Concrete (GPC) and Self-Compacting Concrete (SCC). The production of SCGC requires proper selection of materials and proportions to achieve a composite concrete with a refined pore structure and low permeability. Additionally, chemical and mineral admixtures play a crucial role in enhancing and refining the pore structure of SCGC, as mineral admixtures reduce the absorbency of the cement matrix further and improve the porosity of the aggregates. In this investigation, the impact of high temperatures on the properties of SCGC was examined. The main focus of this research is to assess the influence of 8 M, 10 M, and 12 M NaOH solutions on the workability, mechanical properties, and durability of Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBS)-based SCGC. The SCGC with 12 M NaOH was selected for partial replacement of normal aggregates with Recycled Brick Aggregate (RBA). In this context, Recycled Brick Aggregate replaced coarse aggregate (CA) in the range of 20% to 100%. The curing temperature was varied from ambient conditions up to 120 °C. Furthermore, the abrasion and impact resistance of the concrete, which are crucial for its durability, were also evaluated. Durability tests including water absorption, acid attack, Rapid Chloride Permeability Test (RCPT), sorptivity, and alkalinity were conducted on the SCGC samples, and the results were analysed.

Keywords: Mineral admixtures, Self-compacting geopolymer concrete, Fly ash, Ground granulated blast furnace slag, Recycled brick aggregate, Durability

1. Introduction

The behavior of Self-Compacting Geopolymer Concrete (SCGC) has been the subject of numerous studies employing diverse types of source materials, including Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), glass powder, metakaolin, Rice Husk Ash (RHA) and Silica Fume (SF), among others. Geopolymer concrete is more environmentally friendly because it has a smaller carbon footprint and uses less Portland cement, which is a major source of CO_2 emissions. Incorporating materials such as fly ash, slag, or recycled aggregates into geopolymer concrete further conserves resources, reduces emissions, and minimizes waste. However, enhancing environmental sustainability does not always lead to better performance. Therefore, it is important to investigate the performance of Self-Compacting

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Geopolymer Concrete (SCGPC) under various operating conditions. This is why the present study focuses on evaluating the performance of SCGPC by analyzing its mechanical properties and durability when modified with different materials.

The present study focused on the development and mechanical properties of SCGC [1] with a blend of FA and GGBS cured at ambient room temperature and varying elevated temperatures with NaOH Molarities (M) ranging from 8 M to 12 M. These studies' findings will be described in subsequent sections. The aim of this study has been demonstrated as follows:

- Develop a mixture proportioning process for the production of FA (Class F) and GGBS based SCGC with 8 M to 12 M of NaOH [2].
- Develop a mix design for SCGC.
- Look at the fresh and mechanical properties of SCGC that has been cured at room temperature with different amounts of NaOH.
- Find out and look into how the hardened properties of SCGC are affected by high temperatures of 40, 60, 80, 100, and 120 ˚C.

The selected SCGC with 12 M has been considered for further investigation by partially replacing the normal aggregates with Recycled Brick Aggregate (RBA). Specifically, in the coarse aggregate (CA) portion, RBA was replaced within the range of 20% to 100%, and the curing temperature was varied from ambient to 120˚C. The most important factor in determining the durability of concrete is the rate of water, gas, and ion penetration, which depends on the microstructure, porosity, and, most importantly, the permeability of the cement paste [3].

In this study, experimental investigations were conducted on SCGC test specimens to determine durability and related properties, including water absorption, acid attack, Rapid Chloride Permeability Test (RCPT), sorptivity, and alkalinity, of the designed M12 grade SCGC trial mixes. For each durability test of the proposed SCGC, a minimum of three specimens were tested, and all tests were conducted following standard SCGC specifications. The following section provides a literature survey related to the proposed SCGC analysis.

1.1. Recent work in SCGC and use of RBA

In a study conducted by Christen et al (2022) explores the incorporation of recycled brick aggregate (RBA) as a sustainable alternative in 3D printable concrete, replacing 64% of natural aggregate. Tested with two RBA types, the highly porous Type 2 was selected for mechanical evaluation. Results indicate that replacing natural aggregate with RBA reduces compressive strength by 25%, interlayer tensile strength by 20%, and directional compressive strength by 14-20%. This research addresses the potential of RBA in construction industry, highlighting its relevance for sustainable construction, particularly in developing countries where brick usage is prevalent [4].

The SCGC literature review performed systematically which is consist of five steps literature collection, review of literature, identification of research gaps, arriving at problem of work, and finally fixing the aim and objectives of present study. Khalil and colleagues (2018) examined the effect of temperature on SCGC with 3 %, 4 %, 5 %, 6 %, and 7 % Superplasticizers (SP) dosages [5]. The behavior of the CS (Compressive Strength) of SCGC at various temperatures was studied using different curing temperatures (60 ˚C, 70 ˚C, 80 ˚C, and 90 ˚C). In the study, Sikaviscocrete-3430 was used as the SP [6]. The fresh properties of SCGC, including the slump flow, T50cm, V-funnel, L-Box, and J-ring tests, were evaluated with varying percentages of SP, and it was determined that the fresh properties and CS of concrete improved with an increase in SP dosage. According to the results, the maximum CS (51.52 MPa) was achieved with an SP dosage of 6 % and an oven temperature of 70 ˚C. However, a decrease in strength was observed when the temperature exceeded 70 ˚C [7]. Based on the findings of this study, the optimal SP dose was 6 %, and the optimal temperature was 70 ˚C. One of the recent studies shows that how adding fibres enhances the mechanical properties of recycled concrete with brick aggregates, addressing its inherent deficiencies. It analyses the impact of brick content and fibres types on concrete strength, highlights current research challenges, and offers future development suggestions. The findings underscore RBA's potential to expand recycled concrete applications, promoting sustainable construction practices and resource efficiency in the industry [8].

In a study aimed at creating a sustainable SCGC by combining GGBS and RHA, GGBS was replaced with varying proportions of RHA (0%, 5%, 15%, and 25%). The mechanical properties of SCGC were investigated at different temperatures, including room temperature, 60˚C, and 70˚C [9]. Additionally, Scanning Electron Microscopy (SEM) analysis was performed to understand the microstructure of SCGC. The results indicated that the optimal RHA replacement at room temperature was 5%, and at 70˚C, it was 15%. SEM analysis revealed that both 5% RHA (at room temperature) and 15% RHA (at 70˚C) exhibited a dense microstructure, which contributed to their high strength [10]. Since strength under one set of conditions does not necessarily equate to

toughness under another, it is customary to include an environmental reference when describing durability. According to American Concrete Institute (ACI) committee with has explained that the Portland cement's durability is defined as its resistance to weathering, chemical attack, abrasion, or any other disintegration process; that is, durable cement will retain its original form, quality, and functionality when exposed to its environmental condition. No material is inherently durable [11]. Their microstructure and properties change over time because of how they interact with their environment. A material has reached the end of its useful life when its properties have changed to the point where continuing to use it is either dangerous or not worth the cost. It has conducted a study to demonstrate the durability of GPC prepared with high Ca-FA and AAS when exposed to a 2 % solution of H_2SO_4 and 5 % Magnesium Sulphate ($MgSO_4$) for up to 45 days. The durability was determined by calculating water absorption and water retention [12].

In order to select the molarity grades a study examined M 30, M 40, M 50, and M 60, and the mixtures were formulated for M of 8 M and 12 M. The AAS used in the study is a mixture of solutions of Na_2SiO_3 and NaOH in a ratio of 2.50 to 3. The test specimens were 150 × 150 × 150 mm cubes and 100 × 200 mm cylinders that had been cured in an oven at 60 °C [13]. i) As the grade of concrete and M of the solution increase, so does the CS of GPC. ii) The ratio of NaOH to Na_2SiO_3 solution also plays a crucial role in determining the GPC or Portland Cement Concrete (PCC) strength [14]. Through analysis, it was found that the ratio of 2.5 was more powerful than the ratio of 3.5. iii) The potency of GPC and PCC decreases gradually as the day of exposure progresses [15]. iv) The reductions in CS observed for GPC and PCC specimens after 15, 30, and 45 days of exposure were 7 %, 15 %, 23 %, 10 %, 15 %, and 40 %, respectively. v) The reductions in STS (Split Tensile Strength) observed for GPC and PCC specimens after 15, 30, and 45 days of exposure were 8 %, 18 %, 25 %, and 15 %, 18 %, 45 %, respectively [16]. vi) The strength goes down because Al_2SiO_5 polymers break down in acidic environments and zeolites form. vii. In acidic environments, the superior performance of Geopolymer is materials compared to ordinary cement concrete may be attributable to the lower Ca content [17] of the source material since GPC does not rely on lime like PCC.

When the specimens were exposed to H_2SO_4 and $MgSO_4$, the GPC and PCC mixtures exhibited negligible weight and strength changes. The range of CS loss for H2SO4 samples exposed to PCC was 10 to 40 %, whereas the range for GPC was 7 to 23 % [18]. The range of CS loss for specimens exposed to $MgSO_4$ was between 5 and 25 % for Porous Portland Cement Concrete (PPCC) and between 3 and 12 % for GPC. The STS loss for samples exposed to H_2SO_4 varied between 15 and 25 % for PCC and between 8 and 45 % for GPC. The STS loss of samples exposed to MgSO4 ranged between 4 and 15 % for PPCC and between 7 and 30 % for GPC [19]. The novelty of this research resides in integrating RBA into geopolymer concrete, examining its impact on the material's properties and performance. This method adds to the field's body of knowledge by looking into a new way to use RBA in eco-friendly building materials. Also, RBA in SCGC analysis is very important for figuring out if using recycled brick aggregates in construction is possible, what the benefits are, and what problems might come up. This supports building practices that are better for the environment and more sustainable. The next section shows the mix design procedure and the analysis of fresh and mechanical properties (Compressive Strength - CS, Split Tensile Strength - STS, Flexural Strength - FS Tests) of proposed SCGC with varying M of NaOH (8 M, 10 M and 12 M) and different curing periods [20].

2. Materials and methods

The constituents need for this research as Fly ash, GGBS, Aggregates, AAS, Superplasticizers. The physical and chemical properties of binding materials as following: FA's physical properties, such as its specific gravity, were measured to be 2.25, while its fineness was measured to be 360 m^2/ kg. GGBS was found to have physical properties of 2.83 and 400 m^2/ kg. Scanning Electron Microscopy (SEM) analysis in GGBS research is important for evaluating its microstructure, composition, and hydration behaviour. All of these things have a direct effect on how well it works as a supplementary cementitious material in concrete and other similar uses. Fig. 1 shows the SEM image for GGBS used in the present study.

In this work, the initial step involves utilizing GGBS and fly ash as raw materials to formulate a new concrete mixture. Different amounts of are in both raw materials. Chemical makeup includes Al_2O_3 (alumina), SiO_2 (silica), CaO (lime), SO_3 (sulfur trioxide), MgO (magnesia), Fe_2O_3 (iron oxide), TiO_2 (titanium oxide), and loss on ignition. Table 1 shows what minerals are in GGBS and fly ash. The chemical composition of FA and GGBS (Class F) as presented in Table 1. According to [5], The AAS to binder (FA and GGBS) ratio was maintained at 0.45 to ensure adequate workability and to optimize the geopolymerization process, the ratio of sodium hydroxide to

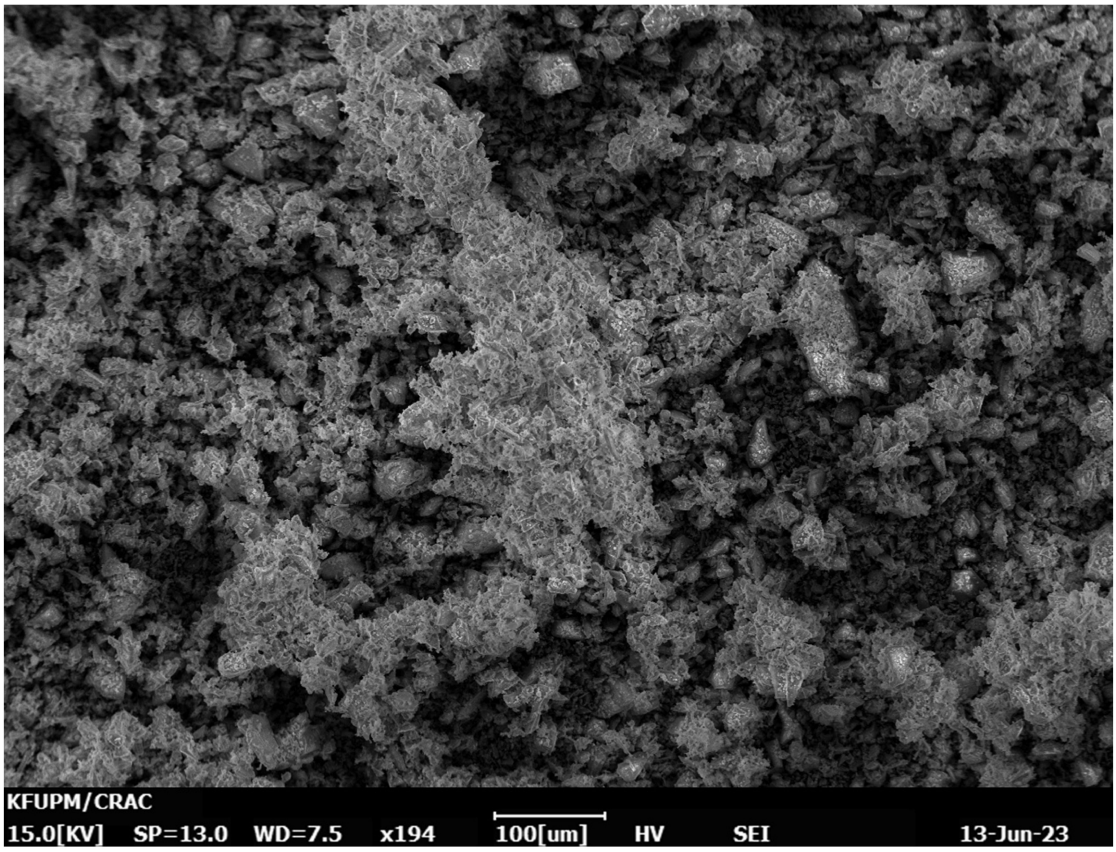

Fig. 1. SEM image of Self-Compacting Geopolymer Concrete (SCGC) at 60% RBA replacement.

Table 1. The chemical composition of FA (Class F) and studied GGBS.

Chemical Composition in %	FA (Class F)	GGBS
(SiO_2) – Silica	65.5	34.20
(Al_2O_3) - Alumina	28.21	16.42
(Fe_2O_3) - Iron Oxide	3.01	1.11
(CaO) - Lime	1.01	37.52
(MgO) - Magnesia	1.01	7.98
(TiO_2) - Titanium Oxide	0.51	-
(SO_3) - Sulphur Trioxide	0.21	1.91
Loss on Ignition	0.30	0.76

sodium silicate was maintained at 2.5 to optimize the geopolymerization reaction, ensuring adequate workability, setting time, and compressive strength. The water-to-geopolymer solids ratio was maintained at 0.33 to achieve a balance between workability and mechanical strength, as supported by previous research. [21]. This ratio ensures proper geopolymerization while minimizing porosity and enhancing durability. The specific gravity of RBA was 2.45 and the impact strength for the RBA is 27.6%, also the crushing value obtained for the RBA is 26.3%. Moreover, the RBA exhibited a water absorption of 19%.

2.1. Mix design of SCGC

Using European Federation of National Associations Representing Concrete (EFNARC) guidelines, mix designs of the SCGC was formulated. Based on EFNARC's recommendations and Hardjito [22] the following ranges were selected for the mixture's elements:

i) The mass proportion of LCFA (Class F) and GGBS for the Geopolymer binders [23] is fixed at 50:50.
ii) The combined proportion of coarse and fine aggregates was typically between 70 and 80 % by mass. In this study, 72.8 % of the mass of concrete can be attributed to the combined aggregate mass [24].
iii) In this combined aggregate, coarse aggregates of 12.5 mm (45 %) and fine aggregate of sand (55 % each) were selected to satisfy the requirements of standard grading curves.
iv) The AAS was administered as a mixture of Na_2SiO_3 ($Na_2O = 13.71$ %, $SiO_2 = 29.41$ %, and $H_2O = 55.9$ % by mass) and NaOH in the form

Table 2. SCGC Mix proportions.

Required Materials	Mass (kg/m^3)		
	8 M	10 M	12 M
Coarse Aggregate	786.24	786.24	786.24
Fine Aggregate (sand)	960.96	960.96	960.96
LCFA (class F)	225.1	225.1	225.1
GGBS	225.1	225.1	225.1
Na_2SiO_3 (solution)	144.275	144.275	144.275
NaOH (solution)	18.01	23.08	27.15
Alkaline Solution / (FA + GGBS) (by mass)	0.45	0.45	0.45
Na_2SiO_3 / NaOH	2.5	2.5	2.5
Water/Geopolymer Solids (by Mass)	0.33	0.33	0.33
SP	9	9	9

of pellets with a purity of between 97 % and 98 %.

v) The mass ratio of Na_2SiO_3 to NaOH solution was typically between 0.4 and 2.5. In this study, the value was set at 2.5.

vi) Various molarities of NaOH solution were utilized in the production of AAS, including 8 M, 10 M, and 12 M [25].

vii) The AAS to binders (FA and GGBS) ratio was maintained at 0.45.

viii) The water to Geopolymer solids ratio was taken to be 0.33.

ix) To achieve the desired workability characteristics of SCGC, a binder dosage of 2 % SP (Polycarboxylic Ether – PCE based) by mass was used as per the past study [26].

2.1.1. SCGC mix design procedure for 10 M

The details about the preparation of design mix is elaborated here:

The Step 1: Take density of SCGC = 2400 kg/m^3.

Step 2: Mass of aggregate equals 72.82 % of the mas of concrete = (72.8 × 2400/100) = 1747.2 kg/m^3, CA = 0.45 × 1747.2 = 786.24 kg/ m^3, Fine aggregate = 0.55 × 1747.45 = 960.96 kg/ m^3.

Step 3: Mass of binders and the alkaline solution = 2400 - 1747.2 = 652.8 kg/m^3.

Step 4: Alkaline liquid to binder's ratio by mass = 0.45. Therefore, the mass of binders (FA + GGBS) = 652.8 / (1 + 0.45) = 450.21 kg/m^3.

Step 5: FA and GGBS are fixed at a 50:50 mass ratio, i.e., FA content = 225.1 kg/m^3, GGBS content = 225.1 kg/m^3, Total binder content= 450.2 kg/m^3.

Step 6: Mass of alkaline solution = 0.45 × 450.2 = 202.59 kg/ m^3.

Step 7: Ratio of Na_2SiO_3 to NaOH solution = 2.5.

Step 8: Mass of NaOH solution = 202.59 / (1 + 2.5) = 57.71 kg/ m^3.

In 1 liter of water, 40 grams of NaOH pellets are dissolved to create a 1 molar NaOH solution. Thus, for 1 molar, 40 g pellets or 1000 ml of water are required. For 8 molar: 8 × 40 g of pellets, 1000 g or 1000 ml of water. % of NaOH solids (pellets) in NaOH Solution = 40 %. In NaOH solution, solids = 0.4 × 57.71 = 23.08 kg/m^3, Weight of water in NaOH solution = 60 % of 57.71 = 0.60 × 57.71 = 34.63 kg/m^3 [5].

Step 9: Water content in Na_2SiO_3 solution = 55.9 %, Mass of Na_2SiO_3 solution = 2.5 × 57.71 = 144.275 kg/m^3.

Step 10: SP = 2 % of mass of binder = 0.02 × 450.2 = 9 lit/m^3.

The preceding section described the SCGC procedure for 8 M, 10 M, and 12 M mix proportions. However, the detailed proportions of the SCGC mixture are listed in Table 2. This work describes the results obtained from fresh properties such as slump flow, T50cm slump flow, V-funnel tests, L-box tests and hardened properties such as CS (Compressive Strength), STS (Split Tensile Strength) and FS (Flexural Strength) of SCGC, following the mix proportion. 8 M, 10 M, and 12 M concentrations of NaOH were used to evaluate the fresh properties. The hardened mechanical properties of SCGC were estimated using different concentrations of NaOH and curing temperatures ranging from room temperature to 800 ˚C.

2.2. Properties of fresh SCGC

The three primary characteristics of SCC: filling efficiency, passage ability and segregation resistances are used to gauge the new qualities of SCGC mixtures. To describe an SCC mix, many test methods have been provided by the European guidelines EFNARC-2002.

The fresh properties like average slump flow, T_{50}cm slump flow, V-funnel and L-box tests of SCGC with varying molarities as represented in Table 3. From that, it is noticed that the slump flow value of SCGC mixes (8 M, 10 M and 12 M) were ranges between

Table 3. Properties of Fresh SCGC.

Mix No.	Molarity (M)	Slump Flow (mm)	T_{50}cm Slump Flow (sec)	V-Funnel (sec)	L-Box Ratio (h_2/h_1)
SCGC1	8	685	3.5	9.50	0.95
SCGC2	10	690	3.7	10.5	0.93
SCGC3	12	698	4.3	11.9	0.90
SCGC Acceptance Criteria as per EFNARC					
Minimum		650	2	6	0.8
Maximum		800	5	12	1

665 mm (8 M) to 687 mm (12 M), and these values are within the range of SCGC acceptance criteria. Whereas, the T50cm slump flow, V-funnel and L-box ratio results varies from 3.5 sec (8 M) to 4.3 sec (12 M), 9.50 sec (8 M) to 11.9 sec (12 M) and 0.95 (8 M) to 0.90 (12 M) respectively. From the obtained results, it is observed that the all mixes have met the SCGC acceptance criteria given by EFNARC-2002. From the results it is also noticed that the mix SCGC1 with 8 M of NaOH has excellent fresh properties having high range of slump flow value with the low range of T50cm and V-funnel time as compared to other two mixes. The mix SCGC1 also have high value of L-box ratio with 8 M of NaOH.

Finally, it is concluded that the observed results indicate the increase in molarity of NaOH decreases the fresh properties of SCGC. This is due to fact that the increase in molarity from 8 M to 12 M enhances the viscosity of the SCGC mix and thus the fresh properties of concrete were reduced. From past research, it is also revealed that the similar type of phenomena was shown with increase of NaOH to decrease the fresh properties of SCGC.

2.3. Hardened properties of SCGC

At the age of 7, 28 and 56 days, the mechanical properties of SCGC such as CS, STS and FS has conducted and verified the results. For each given set of parameters at each selected age, the respective average strengths of three specimens are used to depict the strength development. The differences in strength production with molarity, age and composition of the binder are presented, facilitating the discussions. The fresh and hardened state properties tests are shown in Fig. 2.

2.3.1. CS test of SCGC

The CS of SCGC mixes were estimated with varying M of NaOH (8 M, 10 M and 12 M) and different curing periods of 7 days, 28 days and 56 days respectively. After completion of curing period, the cube specimens were kept at an elevated temperature (Ambient, 40, 60, 80, 100 and 120 ˚C) for 2 hours and then tested. Selection of 2 hours hot curing is based on previous study stated that “The 2 hours of hot curing may be sufficient to achieve initial setting and some early strength in geopolymer concrete. Afterward, the concrete can continue to gain strength at ambient temperature until it reaches its full strength” [27]. It can be observed that the CS of SCGC mixtures cured for 7 days, 28 days and 56 days at temperatures ranging from Ambient, 40 ˚C to 120 ˚C showed a decrease in performance. However, the increase in molarity from 8 M to 12 M increases the CS of SCGC throughout the entire curing period. The maximum strength was attained at ambient temperature such as 52.46 MPa (12 M) after 56 days, while the minimum strength was at 120 ˚C like 15.06 MPa (8 M) after only seven days. It should be noted that the significant decrease in CS is primarily attributable to the continuous moisture loss from the cube specimens with an increase in temperature, which resulted in the formation of voids and weakened the SCGC. At an elevated temperature of 120 ˚C, the average pore size of the concrete increased, regardless of its age, resulting in the greatest strength loss.

2.3.2. STS test of SCGC

The STS of SCGC mixes were estimated with varying M of NaOH (8 M, 10 M and 12 M) and different curing periods. After completion of curing period, the cylindrical specimens were kept at an elevated temperature (Ambient -120 ˚C) for 2 hours and then tested. From the observation, the maximum strength attained at ambient temperature and minimum strength values attained at 120 ˚C. After 7 days of ambient curing, SCGC mix (8 M) exhibited a STS value of 3.35 MPa, whereas after 28 days of ambient curing it was 4.15 MPa and after 56 days of ambient curing it was 4.42 MPa. After 7 days of ambient curing, SCGC mix (10 M) exhibited a STS value of 3.46 MPa, whereas after 28 days of ambient curing it was 4.29 MPa and after 56 days of ambient curing it was 4.58 MPa. After 7 days of ambient curing, SCGC mix (12 M) exhibited an STS value of 3.57 MPa, whereas after 28 days of ambient curing it was 4.42 MPa and after 56 days of ambient curing it was 4.67 MPa.

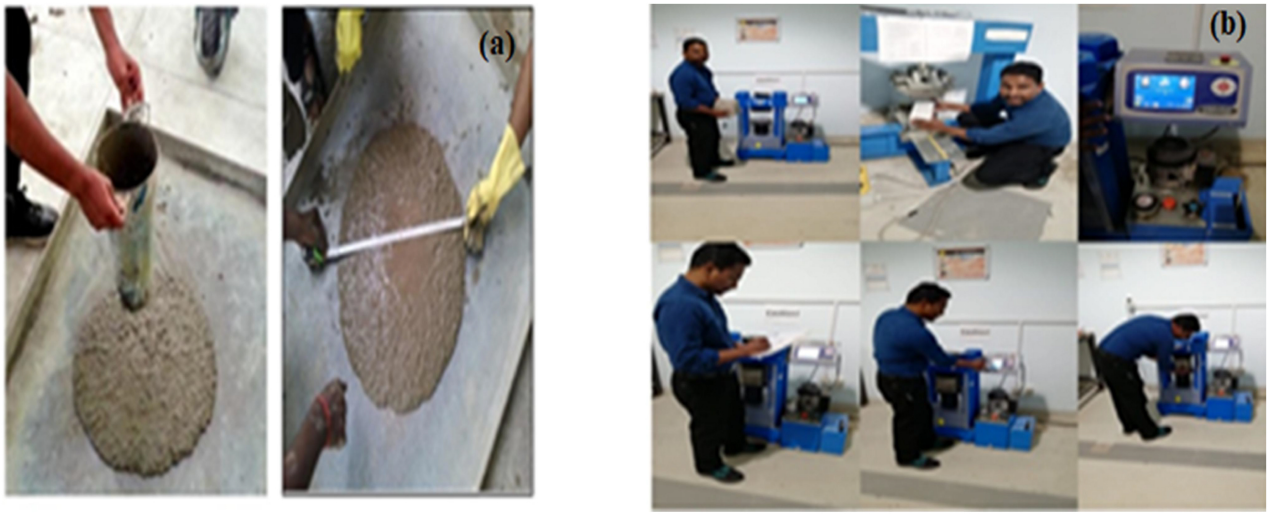

Fig. 2. Determination of a) fresh and b) hardened concrete properties in the laboratory.

According to the findings, following a 7-day curing period, all mixes showed a considerable reduction in STS when the temperature was raised from ambient to 120 ˚C. A similar pattern was also noted at 28 and 56 days. It is important to highlight that the development of surface cracks and a rise in average pore size in the concrete are the primary causes of the notable decline in STS. It can be observed that the STS of SCGC mixtures cured for 7 days at temperatures showed a decrease in performance. At 28 and 56 days of curing, they also exhibited a similar trend, a decrease in STS results with an increase in temperature. From the results it is concluded that there was continuous moisture loss from the concrete specimens due to increase of temperature from Ambient to 120 ˚C which produce voids and resulting in the strength degradation of concrete.

From the results it is concluded that there was continuous moisture loss from the concrete specimens due to increase of temperature from ambient, 40 ˚C to 120 ˚C which produce voids and resulting in the strength degradation of concrete. Thus, the variation has happened when the different temperature (Ambient to 120 ˚C) curing at 7-, 28- and 56-days CS, STS and FS of SCGC. All the resultant values of fresh and hardened properties of SCGC have explained briefly in the above section. The Fig. 3 shows the Graphical analysis of CS, STS and FS of SCGC with different days.

2.3.3. FS test of SCGC

The FS of SCGC mixes were estimated with varying M of NaOH (8 M, 10 M and 12 M) and different curing periods. After completion of curing period, the prism specimens were kept at an elevated temperature (Ambient to 120 ˚C) for 2 hours and then tested. From the observation, the maximum strength attained at ambient temperature and minimum strength values attained at 120 ˚C. After 7 days of ambient curing, SCGC mix (8 M) exhibited a FS value of 3.74 MPa, whereas after 28 days of ambient curing it was 4.56 MPa and after 56 days of ambient curing it was 4.83 MPa. After 7 days of ambient curing, SCGC mix (10 M) exhibited a FS value of 3.85 MPa, whereas after 28 days of ambient curing it was 4.68 MPa and after 56 days of ambient curing it was 5.02 MPa. After 7 days of ambient curing, SCGC mix (12 M) exhibited a FS value of 3.97 MPa, whereas after 28 days of ambient curing it was 4.82 MPa and after 56 days of ambient curing it was 5.08 MPa. Table 4 shows the CS, STS and FS of SCGC with different molarities (8 M, 10 M, 12 M).

According to the data, following a 7-day curing period, the temperature was raised from ambient to 120 ˚C, which significantly reduced FS in all mixes. A similar pattern was also noted at 28 and 56 days. Note that the main causes of the notable decline in FS are the development of surface fractures in the concrete and a rise in the average pore size. The graphical representation for the obtained results has designed for all 7, 28 and 56 days with different M (8 M, 10 M, and 12 M). It can be observed that the FS of SCGC mixtures cured for 7 days at temperatures ranging from Ambient to 120 ˚C showed a decrease in performance. At 28 and 56 days of curing, they also exhibited a similar trend, a decrease in FS results with an increase in temperature. The increase of curing temperature in SCGC can decrease strength due to rapid moisture loss, microcracking, and thermal shrinkage.

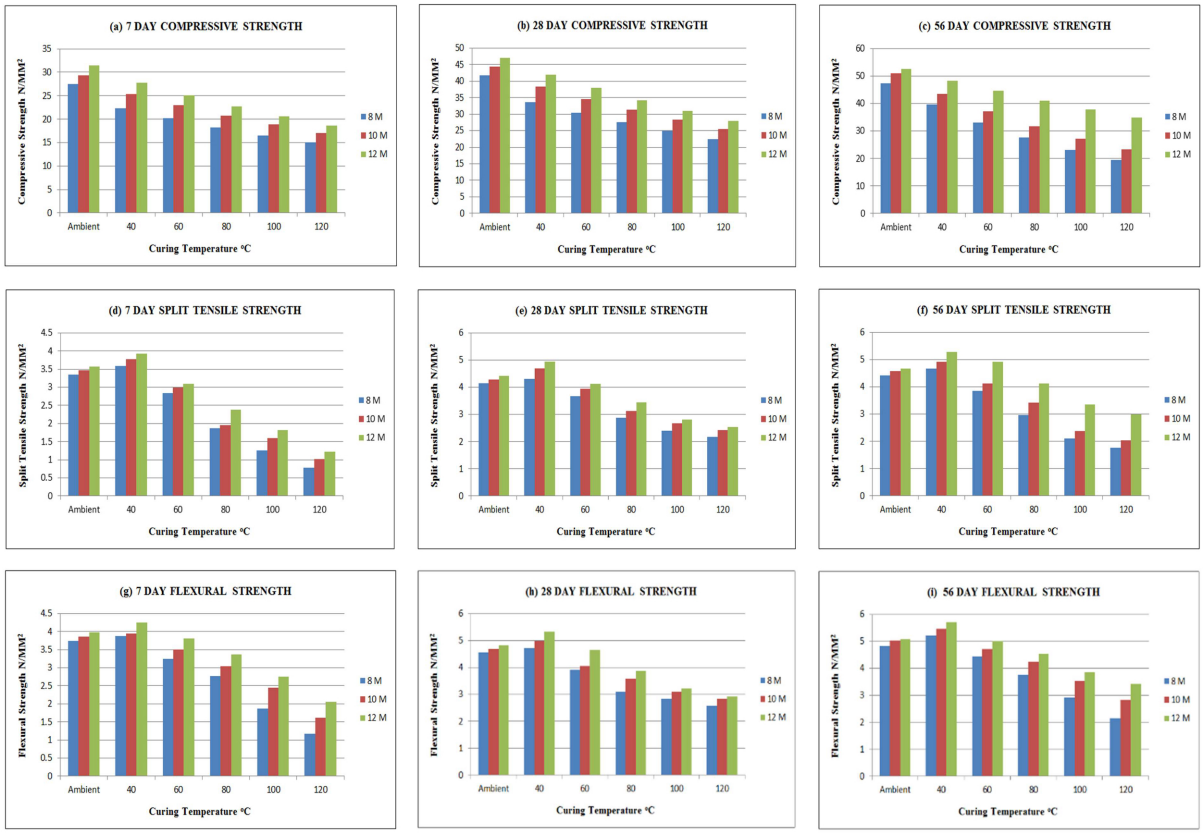

Fig. 3. (a) Graphical analysis of 7 day CS, (b) 28 day CS, (c) 56 day CS, (d) 7 day STS, (e) 28 day STS, (f) 56 day STS, (g) 7 day FS, (h) 28 day FS, (i) 56 day FS of SCGC.

Table 4. CS, STS and FS of SCGC with different Molarities.

		Hardened Properties								
		CS Values (N/mm^2)			STS Values (N/mm^2)			FS Values (N/mm^2)		
Age (days)	T (°C)	8 M	10 M	12 M	8 M	10 M	12 M	8 M	10 M	12 M
7	Ambien	27.55 ± 1.5	29.28 ± 1.6	31.5 ± 1.7	3.35 ± 0.1	3.46 ± 0.2	3.57 ± 0.1	3.74 ± 0.3	3.85 ± 0.2	3.97 ± 0.1
	40	22.29 ± 1.7	25.34 ± 1.5	27.74 ± 1.8	3.59 ± 0.3	3.78 ± 0.2	3.93 ± 0.1	3.88 ± 0.2	3.95 ± 0.1	4.25 ± 0.1
	60	20.19 ± 1.5	22.95 ± 1.8	25.09 ± 1.5	2.84 ± 0.1	2.99 ± 0.1	3.10 ± 0.3	3.25 ± 0.1	3.50 ± 0.1	3.80 ± 0.2
	80	18.27 ± 1.5	20.76 ± 1.5	22.71 ± 1.6	1.87 ± 0.3	1.95 ± 0.1	2.37 ± 0.1	2.77 ± 0.3	3.04 ± 0.1	3.37 ± 0.1
	100	16.57 ± 1.8	18.83 ± 1.7	20.56 ± 1.5	1.25 ± 0.1	1.59 ± 0.1	1.82 ± 0.2	1.86 ± 0.1	2.45 ± 0.3	2.75 ± 0.3
	120	15.06 ± 1.6	17.05 ± 1.5	18.61 ± 1.7	0.78 ± 0.2	1.01 ± 0.3	1.23 ± 0.1	1.17 ± 0.2	1.62 ± 0.1	2.05 ± 0.1
28	Ambient	41.68 ± 1.7	44.35 ± 1.6	47.03 ± 1.6	4.15 ± 0.1	4.29 ± 0.1	4.42 ± 0.1	4.56 ± 0.1	4.68 ± 0.2	4.82 ± 0.3
	40	33.59 ± 1.6	38.33 ± 1.5	41.98 ± 1.6	4.31 ± 0.4	4.69 ± 0.2	4.93 ± 0.3	4.72 ± 0.3	4.98 ± 0.1	5.33 ± 0.1
	60	30.36 ± 1.8	34.61 ± 1.6	37.90 ± 1.8	3.68 ± 0.1	3.95 ± 0.1	4.12 ± 0.1	3.91 ± 0.1	4.05 ± 0.4	4.64 ± 0.2
	80	27.47 ± 1.6	31.27 ± 1.8	34.26 ± 1.6	2.88 ± 0.3	3.13 ± 0.3	3.45 ± 0.1	3.11 ± 0.2	3.58 ± 0.1	3.88 ± 0.2
	100	24.82 ± 1.6	28.27 ± 1.6	30.94 ± 1.8	2.41 ± 0.1	2.68 ± 0.2	2.81 ± 0.2	2.82 ± 0.1	3.11 ± 0.3	3.21 ± 0.1
	120	22.47 ± 1.7	25.56 ± 1.7	27.97 ± 1.6	2.17 ± 0.1	2.43 ± 0.1	2.53 ± 0.2	2.58 ± 0.2	2.82 ± 0.3	2.93 ± 0.2
56	Ambient	47.41 ± 1.6	50.88 ± 1.6	52.46 ± 1.6	4.42 ± 0.2	4.58 ± 0.1	4.67 ± 0.1	4.83 ± 0.2	5.02 ± 0.1	5.08 ± 0.1
	40	39.56 ± 1.6	43.45 ± 1.6	48.36 ± 1.7	4.67 ± 0.1	4.91 ± 0.2	5.28 ± 0.1	5.21 ± 0.1	5.47 ± 0.2	5.70 ± 0.1
	60	33.05 ± 1.7	37.12 ± 1.7	44.58 ± 1.7	3.86 ± 0.2	4.13 ± 0.1	4.91 ± 0.3	4.45 ± 0.3	4.72 ± 0.1	5.01 ± 0.2
	80	27.64 ± 1.7	31.75 ± 1.7	41.11 ± 1.6	2.96 ± 0.1	3.42 ± 0.2	4.13 ± 0.2	3.75 ± 0.3	4.23 ± 0.2	4.52 ± 0.2
	100	23.15 ± 1.6	27.15 ± 1.6	37.94 ± 1.5	2.11 ± 0.1	2.38 ± 0.1	3.36 ± 0.1	2.92 ± 0.1	3.53 ± 0.1	3.86 ± 0.1
	120	19.43 ± 1.5	23.27 ± 1.8	34.98 ± 1.6	1.77 ± 0.3	2.04 ± 0.3	2.98 ± 0.2	2.16 ± 0.2	2.83 ± 0.2	3.42 ± 0.1

*Results with confidence intervel of 95%.

3. Results and discussion

3.1. Investigation of strength with RBA modified SCGC

The test results of mechanical behavior have clearly explained the 12 M (NaOH) with SCGC has provided good strength properties. Hence the selected SCGC with 12 M has considered for the further investigation by partial replacement of normal aggregates with Recycled Brick Aggregate (RBA). Regarding which, in the coarse aggregate amount, replaced the RBA with the range of 20 to 100 % and the curing temperature in the range of ambient to 120 ˚C. After curing, the CS, STS and FS of SCGC have found and corresponding results have been noted in the tabular form and plotted in the graph.

3.1.1. RBA strength results at 7-day curing

At earliest, SCGC strength results has taken with 7 days curing with different stages varying from 20 to 100 % at different temperatures (Ambient to 120 ˚C). From the obtained results of strength analysis, it has been noted that for the ambient degree temperature with 7-day curing, when the replaced CA percentage increased leads to decrease in the strength values (CS, STS and FS) of modified 12 M modified SCGC.

For example, 20 % partially replacement has provided the CS as 28.45 MPa, STS as 3.45 MPa and FS as 3.87 MPa where as 100 % partially replacement of CA has given the CS as 15.5 MPa, STS as 2.5 MPa and FS as 2.92 MPa in 7 day, ambient ˚C. Like this, the strength results have taken with 28 days and 58 days curing with different stages varying from 20 to 100 % at different temperatures. The Table 5 has given the results of CS, STS and FS with 7 day with curing temperature (Ambient to 120 ˚C) of RBA - 12 M modified SCGC. The Fig. 4 has shown the variation results of CS, STS and FS with 7-day, (Ambient to 120 ˚C) temperature of 12 M modified SCGC.

3.1.2. RBA strength results at 28-day curing

In this section, the 28-day curing strength results have been examined at different temperatures, ranging from ambient to 120 ˚C. Therefore, the SCGC strength results were obtained after 28 days of curing, with different stages varying from 20% to 100% at various temperatures (Ambient to 120 ˚C). The Table 6 has given the results of CS, STS and FS with 28 day, (Ambient to 120 ˚C) of RBA - 12 M modified SCGC. From the obtained results of strength analysis, it has noted for the ambient degree temperature with 28 day curing when the replaced CA percentage increased which leaded to decrease the strength values (CS, STS and FS) of modified 12 M modified SCGC. For example, 20 % partially replacement has provided the CS as 44.21 MPa, STS as 4.35 MPa and FS as 4.77 MPa where as 100 % partially replacement of CA has given the CS as 32.45 MPa, STS as 3.25 MPa and FS as 3.67 MPa in 28 day, ambient ˚C. Then, the 12 M grade SCGC with RBA strength analysis with 28 day, 40 ˚C has examined and so on. The Fig. 5 has shown the variation results of CS, STS and FS with 28 day, (Ambient to120˚C) temperature of 12 M modified SCGC. Furthermore, the SEM imaging (Fig. 1) reveals that 60% RBA got 2 hours of hot curing at 40˚C have a dense microstructure and hence higher strength.

Table 5. Strength analysis of 7 day, 12 M (Ambient to 120 °C) with RBA modified SCGC.

Temperature (˚C)	Partially RBA as CA (%)	Mechanical Property		
		CS (MPa)	STS (MPa)	FS (MPa)
Ambient	20	28.45 ± 1.5	3.45 ± 0.2	3.87 ± 0.1
	40	25.2 ± 1.8	3.25 ± 0.3	3.67 ± 0.2
	60	21.3 ± 1.5	3.1 ± 0.2	3.52 ± 0.1
	80	18.1 ± 1.6	2.8 ± 0.2	3.22 ± 0.2
	100	15.5 ± 1.8	2.5 ± 0.1	2.92 ± 0.2
40	20	25.45 ± 1.5	2.81 ± 0.3	3.22 ± 0.3
	40	22.3 ± 1.7	2.7 ± 0.3	3.11 ± 0.1
	60	20.1 ± 1.5	2.51 ± 0.2	2.92 ± 0.1
	80	16.5 ± 1.6	2.22 ± 0.2	2.63 ± 0.2
	100	14.3 ± 1.5	2.05 ± 0.1	2.46 ± 0.3
60	20	23.25 ± 1.6	2.31 ± 0.2	2.73 ± 0.2
	40	21.1 ± 1.6	2.16 ± 0.2	2.58 ± 0.3
	60	17.7 ± 1.5	2.01 ± 0.1	2.43 ± 0.2
	80	14.2 ± 1.5	1.9 ± 0.2	2.32 ± 0.2
	100	12.1 ± 1.4	1.75 ± 0.1	2.17 ± 0.2
80	20	21.4 ± 1.5	1.91 ± 0.1	2.33 ± 0.2
	40	19.5 ± 1.7	1.86 ± 0.2	2.28 ± 0.2
	60	16.53 ± 1.5	1.51 ± 0.3	1.93 ± 0.2
	80	13.41 ± 1.8	1.35 ± 0.2	1.77 ± 0.3
	100	11.5 ± 1.8	1.2 ± 0.2	1.62 ± 0.2
100	20	19.2 ± 1.6	1.53 ± 0.1	1.94 ± 0.1
	40	16.9 ± 1.5	1.42 ± 0.2	1.83 ± 0.2
	60	13.61 ± 1.5	1.33 ± 0.1	1.74 ± 0.2
	80	11.42 ± 1.7	1.21 ± 0.2	1.62 ± 0.1
	100	9.51 ± 1.5	1.01 ± 0.3	1.42 ± 0.1
120	20	17.1 ± 1.7	1.23 ± 0.1	1.64 ± 0.2
	40	14.7 ± 1.5	1.15 ± 0.1	1.56 ± 0.2
	60	11.21 ± 1.6	1.1 ± 0.1	1.51 ± 0.1
	80	10.31 ± 1.6	0.93 ± 0.2	1.34 ± 0.2
	100	8.5 ± 1.5	0.85 ± 0.3	1.26 ± 0.1

*Results with confidence intervel of 95%.

3.2. Durability test results

3.2.1. Water absorption test

On 150 mm cubes, the water absorption ethics of several mixtures were determined in accordance with American Society for Testing and Materials (ASTM) C 642. Cubes measuring 150 mm cubed were taken as specimens (made according to the convenience of the mold sizes). During water absorption test,

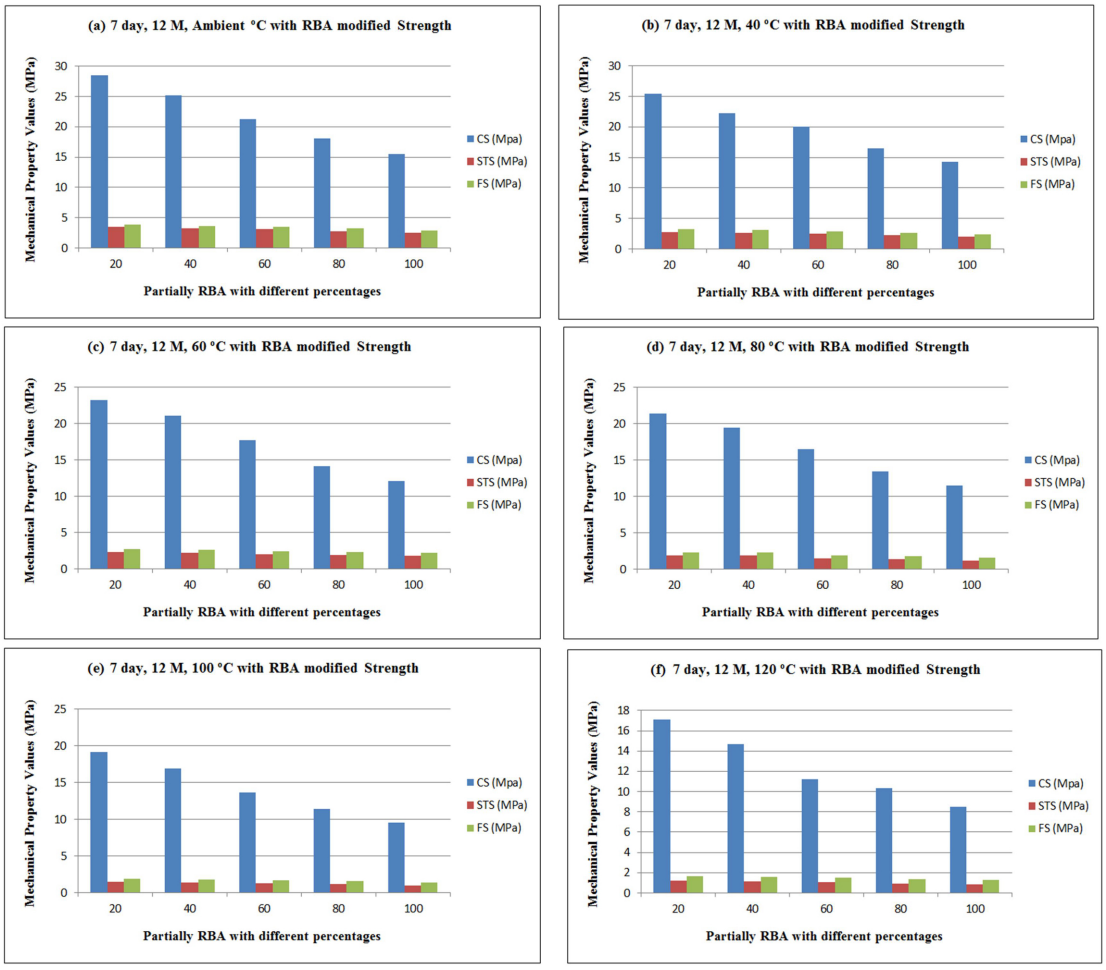

Fig. 4. Graphical presentation of 7 Day, 12 M (a) Ambient °C, (b) 40 °C, (c) 60°C, (d) 80 °C, (e) 100 °C, (f) 120 °C with RBA modified SCGC.

the 18 number of samples was collected. After 28 days, the samples were detached from the preserving tank and dried in an oven heated to 105 °C. The dehydrating procedure was continuous until the change between two consecutive extents was within an acceptable range. After the oven-dried specimens reached room temperature, they were weighed (W_d). After submerging the specimens in potable water for 24 hours, 48 hours, and 28 days, the saturated weight (W_s) was determined after wiping the surface with a clean cloth. Designate the final surface-dry mass after immersion B. Using these weights, Eq. (1) was used to calculate the Saturated Water Absorption (SWA).

$$SWA = {}^{W_S}/_{W_d} \times 100 \quad (1)$$

Where, W_s - Weight of fully saturated specimens in kg, and W_d - Weight of oven dried specimens in kg.

The water absorption rates of the SCGC specimens are presented in Table 7. According to the data, the addition of recycled aggregates to SCGC substantially increased water absorption rates. According to the results, the water absorption of SCGC samples is 5.20 %. When aggregate has added to the SCGC, the water absorption rate is increased slightly, up to 6.14 % for aggregate 100, in accordance with the increased pattern. As the curing temperature increases, the voids between the RBA molecules also increase, which leads to higher water absorption. Therefore, 100 % replaced aggregates were used in RBA specimens, resulting in a high water absorption rate.

3.2.2. Acid attack test

The acid attack test is widely used to determine the durability of concrete because the severity of the conditions imposed on the concrete allows to determine the results in a shorter amount of time than other tests. The level of work may vary, but they ultimately decompose the concrete. Aggregates containing calcareous material and the binding phase of concrete rich in Ca, C, and S are more vulnerable to acid and chemical attack. This occurs when

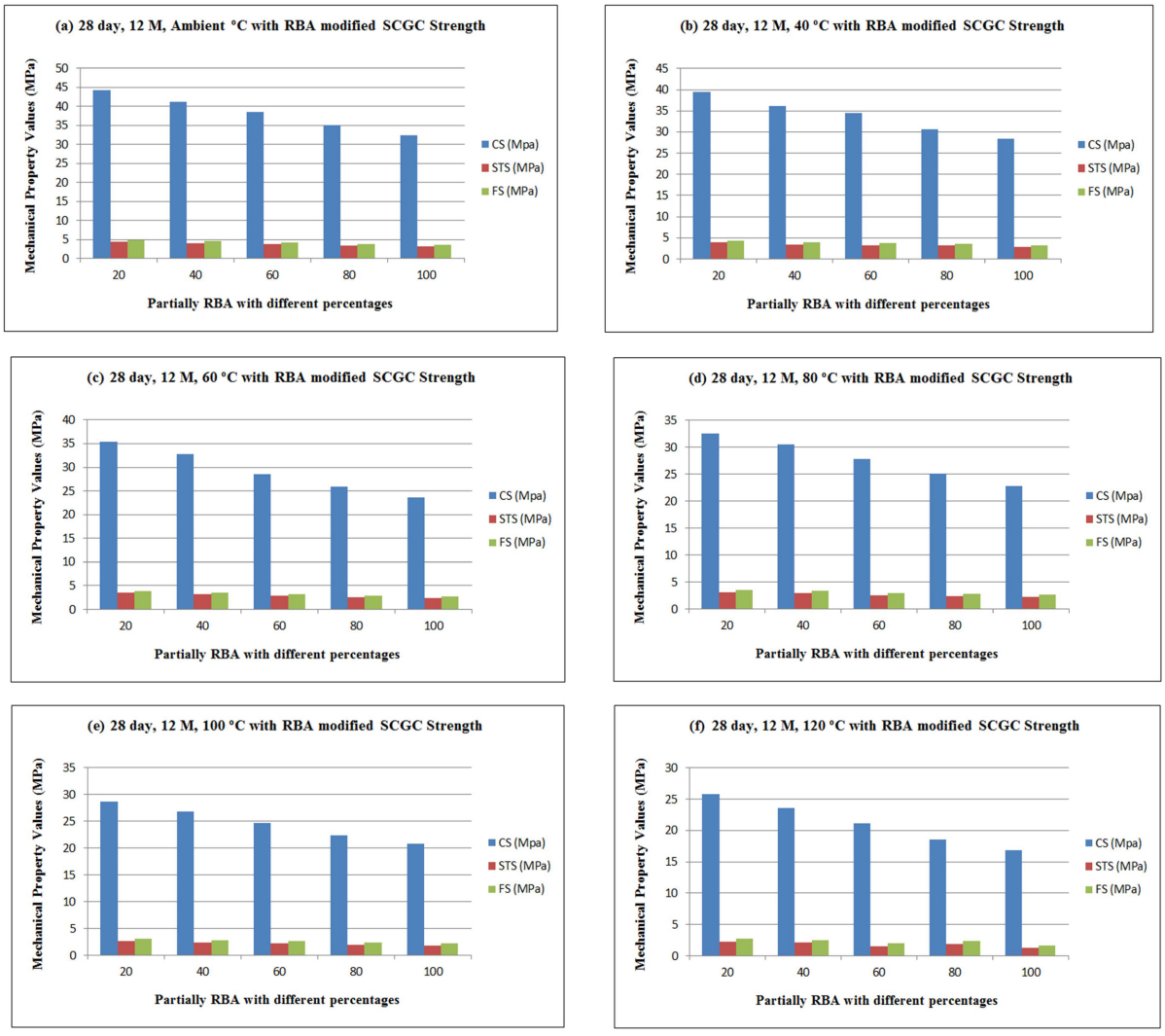

Fig. 5. Graphical presentation of 28 Day, 12 M (a) Ambient °C, (b) 40 °C, (c) 60°C, (d) 80 °C, (e) 100 °C, (f) 120 °C with RBA modified SCGC.

concrete is produced with aggregates and a matrix phase that is weakly bonded. The experimental study was conducted on 150 mm × 150 mm × 150 mm SCGC cube specimens that were immersed in a 5 % H_2SO_4 solution for 7, 28, and 56 days. Consequently, 18 specimens were prepared for the 28-day tests alone. When immersed in a chemical solution for 7, 28, and 56 days, the corrosion of a sample can be measured by determining the weight loss and the reduction in compressive strength of the specimen.

3.2.3. Rapid chloride permeability test (RCPT)

The particular test has been designed as a rapid test capable of measuring the rate of chloride transport into concrete. This RCPT test was conducted in accordance with ASTM C 1202-94. For the test, 50 mm thick and 100 mm diameter SCGC concrete discs were casted. By cutting annular steel pipes to the desired length, moulds were created. After 24 hours, the disc samples were detached from the mould and preserved at 70 °C for eight hours.

After curing, the chloride permeability of the specimens was evaluated. Before testing, all of the 18 samples were completely dehydrated and the 60 V RCPT test was performed on the concrete specimens. The examination of Acid Immersion and RCPT specimen tests is depicted in Fig. 6. It can be observed that the samples were completely immersed in the acid solution, followed by drying, and then permeability measurements were performed. Two specimen halves were sealed in an 80 mm diameter Polyvinyl Chloride (PVC) container. For which, container with one side was occupied with 3 % NaCl solution and linked to the cathode terminal of the supply power, while the container with next side was occupied with 0.3 N NaOH solution and linked to the anode



Fig. 6. Acid immersion and RCPT specimen tests in the laboratory.

Table 6. Strength analysis of 28 Day, 12 M (Ambient to 120 °C) with RBA modified SCGC.

Temperature (°C)	Partially RBA as Coarse Aggregate (%)	Mechanical Property		
		CS (MPa)	STS (MPa)	FS (MPa)
Ambient	20	44.21 ± 1.6	4.35 ± 0.1	4.77 ± 0.1
	40	41.23 ± 1.5	4.1 ± 0.1	4.52 ± 0.2
	60	38.5 ± 1.5	3.75 ± 0.2	4.17 ± 0.2
	80	35.15 ± 1.7	3.41 ± 0.1	3.83 ± 0.1
	100	32.45 ± 1.5	3.25 ± 0.3	3.67 ± 0.3
40	20	39.51 ± 1.6	3.89 ± 0.1	4.31 ± 0.1
	40	36.15 ± 1.5	3.5 ± 0.1	3.92 ± 0.2
	60	34.5 ± 1.6	3.3 ± 0.2	3.72 ± 0.1
	80	30.56 ± 1.5	3.15 ± 0.1	3.57 ± 0.2
	100	28.35 ± 1.5	2.85 ± 0.1	3.27 ± 0.1
60	20	35.42 ± 1.7	3.45 ± 0.2	3.86 ± 0.3
	40	32.8 ± 1.8	3.15 ± 0.3	3.56 ± 0.1
	60	28.53 ± 1.5	2.86 ± 0.1	3.27 ± 0.2
	80	25.9 ± 1.4	2.5 ± 0.1	2.91 ± 0.1
	100	23.67 ± 1.5	2.38 ± 0.1	2.79 ± 0.2
80	20	32.6 ± 1.6	3.12 ± 0.3	3.55 ± 0.1
	40	30.5 ± 1.5	2.96 ± 0.1	3.39 ± 0.2
	60	27.89 ± 1.7	2.52 ± 0.2	2.95 ± 0.3
	80	25.18 ± 1.5	2.34 ± 0.1	2.77 ± 0.2
	100	22.8 ± 1.5	2.25 ± 0.1	2.68 ± 0.1
100	20	28.67 ± 1.7	2.65 ± 0.3	3.09 ± 0.1
	40	26.8 ± 1.5	2.42 ± 0.2	2.86 ± 0.2
	60	24.75 ± 1.5	2.26 ± 0.1	2.7 ± 0.1
	80	22.42 ± 1.6	1.95 ± 0.1	2.39 ± 0.1
	100	20.76 ± 1.6	1.84 ± 0.1	2.28 ± 0.1
120	20	25.87 ± 1.5	2.32 ± 0.2	2.74 ± 0.2
	40	23.65 ± 1.5	2.15 ± 0.1	2.57 ± 0.1
	60	21.2 ± 1.7	1.56 ± 0.2	1.98 ± 0.3
	80	18.54 ± 1.7	1.95 ± 0.3	2.37 ± 0.3
	100	16.9 ± 1.5	1.24 ± 0.1	1.66 ± 0.3

*Results with confidence intervel of 95%.

terminal. For six hours, the current was noted at each 30 minutes. The Cl permeability was computed using the whole current in coulombs that passed after six hours, the outcomes based obtained using amount of time taken and current. The RCPT experiment was conducted on concrete specimens, and Table 8 provides a summary of the RCPT test results. The average transferred charge for SCGC is 3,820 coulombs. The RCPT concentrations then ranged between 3875 ± 6 and 4,250 ± 4 coulombs when aggregate SCGC was substituted. The SCGCAR100 advanced with coulomb values of 4250 ± 4, which is the highest value compared to other SCGC aggregates.

3.2.4. Sorptivity test

Sorptivity, which determines the rate of water's dispersion into concrete pores via vessel pressure, has been cited as a crucial durability factor for concrete. The test method is relatively straightforward and facilitates rapid diagnosis. The coefficient of sorptivity is indispensable for predicting the service life of concrete structures and enhancing their performance. This test examined the rate of water absorption by calculating the weight gain of a concrete specimen as a role of time for up to eight days. The water absorption for first six hour was used to define the initial absorption also called as sorptivity of SCGC, while the rate of water absorption from beginning to 8 days was used to define the secondary absorption. The initial rate of absorption was high (up to 24 hours), but it decreased after this period and became nearly stable within seven days. The testing procedure was conducted in accordance with ASTM Standard C 1585, but specimen sizes varied slightly. The 150 mm cube specimens (made according to the convenience of mould sizes) were kept at 110°C in an oven. A total of 18 specimens (three of each type of concrete) were collected. The side surfaces of the samples were then layered with epoxy paint so that water could only enter the SCGC through the lowest surface.

The samples were submerged in the water-filled container and supported by rods submerged

Table 7. Water absorption test results for SCGC.

Specimen ID	Weight of the Concrete Cube		Water Absorption		Density (kg/m^3)	
	Dry	Wet	Gram	Percentage	Dry	Wet
SCGC	8.162 ± 0.2	8.588 ± 0.2	422 ± 0.2	5.20 ± 0.2	2419.90 ± 0.2	2545.68 ± 0.2
SCGCAR20	8.282 ± 0.15	8.761 ± 0.15	475 ± 0.15	5.75 ± 0.15	2427.95 ± 0.15	2564.28 ± 0.15
SCGCAR40	8.303 ± 0.2	8.818 ± 0.2	501 ± 0.2	6.05 ± 0.2	2459.42 ± 0.2	2572.34 ± 0.2
SCGCAR60	8.391 ± 0.15	8.911 ± 0.15	512 ± 0.15	6.10 ± 0.15	2468.20 ± 0.15	2584.22 ± 0.15
SCGCAR80	8.460 ± 0.2	8.940 ± 0.2	517 ± 0.2	6.12 ± 0.2	2470.25 ± 0.2	2586.35 ± 0.2
SCGCAR100	8.548 ± 0.1	8.999 ± 0.1	520 ± 0.1	6.14 ± 0.1	2472.32 ± 0.1	2588.35 ± 0.1

*Results with confidence intervel of 95%.

Table 8. Rapid chloride permeability test results.

Specimen ID	Duration (minutes)	Charge Passed (Coulomb)	Permeability Level
SCGC	30	3820 ± 4	Adequate
SCGCAR20	30	3875 ± 6	Adequate
SCGCAR40	30	3902 ± 5	Adequate
SCGCAR60	30	3982 ± 6	Adequate
SCGCAR80	30	4125 ± 5	High
SCGCAR100	30	4250 ± 4	High

*Results with confidence intervel of 95%.

Table 9. Results of sorptivity test.

Specimen ID	Sorptivity	
	7 Days	28 Days
SCGC	0.078 ± 0.01	0.062 ± 0.01
SCGCAR20	0.090 ± 0.02	0.070 ± 0.02
SCGCAR40	0.116 ± 0.01	0.098 ± 0.01
SCGCAR60	0.138 ± 0.02	0.119 ± 0.02
SCGCAR80	0.170 ± 0.01	0.137 ± 0.01
SCGCAR100	0.188 ± 0.01	0.155 ± 0.01

*Results with confidence intervel of 95%.

approximately 10 mm from the bottom. Using a weighing balance, the amount of water absorbed in squares of time up to 361 minutes was determined. The specimen's surface water was smeared with cotton plaster, and every weighing action was accomplished within 30 seconds. This was plotted as the period of initial sorption. Utilizing the same methodology, secondary sorption was measured between 1 and 8 days. The increasing capacity of water that has entered per unit of exposed external area as a function of the quadrangular source of the time lapsed. Water sorptivity testing is used to determine how much water moves through concrete samples via capillary action. The amount of water absorbed by the sample's bottom surface was used to calculate its sorptivity. The results of various SCGC water sorptivity tests conducted over 7 and 28 days are shown in Table 9. The sorptivity of SCGC without aggregate samples was discovered to be high.

3.2.5. Alkalinity test

The M12 grade of SCGCC trial mixes on cube specimens were evaluated for CS after 28 days of water curing. Using a hammer and a ball mill, the fragments of the tested samples were shattered into lesser pieces and then ground into a powder. Each powder specimen (approximately 20 grams) was melted in 100 ml of condensed water. Additional of the allowed lime in hydrated cement paste was melted in water by allowing the water to stand for at least 72 hours and agitating it frequently.

Table 10. Results of alkalinity test.

Specimen ID	Alkalinity Results (28 Days)	
	(pH level of Solution)	Corrosion Possibility
SCGC	13.85 ± 0.05	low
SCGCAR20	13.72 ± 0.07	low
SCGCAR40	13.58 ± 0.06	low
SCGCAR60	13.32 ± 0.05	low
SCGCAR80	13.14 ± 0.08	low
SCGCAR100	12.98 ± 0.06	low

*Results with confidence intervel of 95%.

The pH of the required water was measured with a pH meter (913-Metrohm). When the pH value is less than 11, indicates a high corrosion risk. SCGC's pH value is an accurate indicator of its chemical properties. The concrete's tenacity is primarily determined by its pH. After curing dried specimens for 28 days in a 105 °C, 24-hour furnace, one way to determine if concrete is deteriorating is to measure its saltiness and pH level. The specimens are then crushed after being cooled to room temperature. To make mortar, cracked concrete is first ground into a fine powder. The ten grams of material are extracted and dissolved in fifty millilitres of sterile water, which is stirred vigorously to create uniform solutions. The pH of the liquid is then determined by inserting a pH meter into the formulation liquid. The alkalinity test results are listed in Table 10.

Higher molarity increases strength in SCGC because it provides more hydroxide ions, which enhance the dissolution and reaction of aluminosilicate materials, resulting in a denser and stronger binding matrix. The SCGC concrete made with RBA typically exhibits lower durability, with increased risks of shrinkage, freeze-thaw damage, and chemical attack compared to concrete made with natural aggregates. In RCPT

results, concrete with more than 80% RBA lets more chloride ions through, which means it doesn't resist chloride penetration very well. This shows that the concrete isn't strong enough for harsh conditions because it has so much RBA in it. RBA < 80%, the concrete is performing better than the reference, so it is considered "adequate" or "acceptable" in terms of durability.

4. Conclusion

Geopolymer concrete is known for being environmentally friendly because it uses less Portland cement, a major source of CO_2 emissions, resulting in a smaller carbon footprint. Incorporating industrial by-products such as fly ash, slag, or recycled aggregates in geopolymer concrete helps conserve resources and reduces waste. However, these sustainability benefits can sometimes compromise the material's performance. Therefore, performance analysis was conducted (including mechanical properties and durability) of the geopolymer concrete in SCGC. The production of SCGC needs the proper selection and materials proportion in order to yield a composite concrete by its fine pore construction and low permeability. In this investigation, the impact of high temperatures on the properties of SCGC has examined the influence of 8 M, 10 M, and 12 M NaOH on the workability, mechanical properties (CS,STS and FS), and durability properties of FA and GGBS based SCGC. The selected SCGC with 12 M has considered for the further investigation by partial replacement of normal aggregates with RBA. Regarding which, in the CA amount, replaced the RBA with the range of 20 to 100 % and the curing temperature in the range of ambient to 120 ˚C. The resultant values have been noted in tabular and graphical form. The abrasion resistance and impact resistance of concrete are also crucial to its durability.

This paper describes the experimental investigations conducted on SCGC test specimens to determine the durability and related properties, including water absorption, acid attack, RCPT, sorptivity, and alkalinity, of the designed 12 M grade SCGC trial mixes. For every test, minimum three samples were tested and all tests have conducted according to the SCGC specifications. The resultant values have been graphed for easy comprehension. Hardened property analysis revealed that the 12 M SCGC mix attained a compressive strength of 52.46 MPa, a split tensile strength of 4.67 MPa, and a flexural strength of 5.08 MPa at 56 days. The durability test showed that the 12 M SCGC mix absorbed 6% water, and the rapid chloride permeability test showed that it had a permeability level of 3820 Coulombs. However, replacement of RBA from 80% shows a higher permeability which suggest an optimum RBA replacement of 60%. Based on the analysis results, it is concluded that using recycled brick aggregates in construction helps the environment and solves problems with waste management. This research is very relevant to current environmental goals. RBA in SCGC is commonly utilized in industrial contexts, including precast elements, flooring, pavements, non-structural components, and repairs. It provides both environmental and economic advantages while ensuring satisfactory performance for appropriate applications.

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Conflicts of interest

There are no conflicts of interest regarding the publication of this paper.

Author contribution

Thavasumony Dhasan was involved in Conceptualization, writing the original manuscript, visualization, and laboratory analysis. **Raid S. Alrashidi** involved in investigation, reviewed and editing. **Muhammad Saleem** supervised the work, formal analysis, and validation. **Joonaith C. Veedu** Data Curation, formal analysis, and validation. **Shahnawaz Alam** formal analysis, reviewed and editing.

Data availability

The authors confirm that the data used in this paper is available and can be provided on request.

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