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Synergic effect of metakaolin and groundnut shell ash on the behavior of fly ash-based self-compacting geopolymer concrete

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ABSTRACT

The sustainable self-compacting geopolymer concrete (SCGC) production is an eco-efficient concrete with a lower carbon footprint than conventional concrete. This experimental work was performed on the fly ash based SCGC mixtures which blended metakaolin and groundnut shell ash individually and combined them into 5–20% with an increment of 5% as replacement of fly ash in the mixtures. The main theme of this research work is to determine the fresh properties in terms of filling ability (slump flow, V-Funnel and T50 flow) and passing ability (J-Ring and L-box) tests and hardened properties in terms of compressive, splitting tensile and flexural strengths, and water permeability of the SCGC mixture. However, a total of 260 concrete specimens were made and tested at 28 days. The outcomes of this research work revealed that the addition of metakaolin and groundnut shell ash separate and combined as partial replacement of fly ash in the SCGC mixtures that causes a reduction in the workability, while the hardened properties of SCGC are significantly enhanced by using metakaolin and groundnut shell ash individually and combined up to 10% by the weight of fly ash. Moreover, the compressive, splitting tensile and flexural strengths of SCGC were measured as 56.42 MPa, 4.68 MPa and 5.12 MPa for the mix contained 5% of groundnut shell ash and metakaolin together at 28 days, respectively. Furthermore, the water penetration depth declined as the extent of metakaolin and groundnut shell ash as replacement of fly ash separate and combined rises in the mixtures.

1. Introduction

Concrete is one of the essential resources which is extensively served in the construction industry all over the world. However, the usage of concrete around the globe is increasing day by day, so the use of Portland cement (PC) is also increased which is not an environmentally friendly constituent. It is recognized that the manufacturing of PC is produced a high quantity of carbon dioxide emissions as well as other greenhouse gases which degrade the atmosphere. Besides, 1.60 tons of raw materials [1] and about 6.50 million British thermal unit (BTU) of energy are needed for the making of one ton of PC and during its production, one ton of carbon dioxide is discharged into the environment, which destroys the atmosphere [2]. Hence, in order to protect the worldwide atmosphere from the influence of PC production, new opportunities must be found and explored to develop further ecologically friendly materials which possess the pozzolanic property and these types of materials can be utilized as replacements for PC in concrete [2–5]. To tackle the problem of global warming, the world has made tremendous efforts to decrease the use of PC. These include the disposal of waste by-products by recycling these waste materials and the development of alternative binders for PC [6–8].The use of industrial/agricultural waste by-products like wheat straw ash (WSA) [9], coconut shell ash [10], ground granulated blast furnace slag (GGBFS) [11], wheat straw ash (WSA) [12], eggshell ash [13], metakaolin (MK), corn cob ash (CCA), millet husk ash (MHA) [14,15], açaí natural fibre [16], palm oil fuel ash [17], rice straw and cotton stalk [18], glass fiber [19], ceramic wastes [20], plastic waste [21], seashell [22], rubber [23] and other pozzolanic materials can assist in decreasing the requirement for

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PC in concrete, hence reduce the carbon dioxide discharges [2,24,25]. The addition of fly ash (FA) to concrete can significantly improve many of the properties of fresh and hardened concrete. In addition to economic benefits, FA can also bring many environmental benefits. Since the use of FA replaces the use of cement, it can reduce greenhouse gas emissions, reduce energy consumption, protect precious natural resources, and thus reduce the pressure on the environment [26,27–29]. However, the groundnut shell ash (GSA) is served as a replacement for PC in the concrete mixture. However, the groundnut shell is produced in huge quantities as agricultural waste in many parts of earth planate in the globe. These groundnut shells are dumped improperly in the environment and pose a threat to beauty and safety. Therefore, the possibility of GSA is obtained from the burning of agricultural wastes such as groundnut shells under a controlled temperature arrangement and grinding them into smaller particles that have cementitious properties and can be used in concrete as supplementary cement material [30]. Groundnut shells are agricultural waste obtained after the removal of groundnut seeds or peanuts from the pods. Peanut production in 2014 was approximately 42.31 million tons globally and is expected to gradually increase per year. The groundnut shells constitute about 25–40% of the groundnut plant. For each ton of shell, 2.5% of ash is produced [31]. Moreover, the MK is obtained from kaolin clay, which is burnt under controlled temperature ranges between 650 and 800 °C. Though, the MK is a natural pozzolanic material and it can be used in concrete. Besides, the utilization of MK in concrete which provides greater strength development of interfacial transition zone as compared to the other constituents [32]. Ahmed et al., [33] stated that the compressive and flexural strength of concrete is improved while the using 15% of MK in concrete.

In this regard, geopolymer concrete (GC) is one of the revolutionary developments associated with new materials, leading to inexpensive and environmentally friendly materials as alternatives to PC [3,34]. GC is an aluminosilicate-based inorganic polymer concrete that can be synthesized from geological materials or by-products rich in silicon and aluminium and having a strong alkaline solution [35]. Generally, a combination of sodium silicate and sodium hydroxide is taken as the alkaline activator. Sodium hydroxide (98–99% purity) and sodium silicate solution (Na2O = 14.26%, SiO2 = 29.43%, water = 56.31%) by weight [3,35]. However, the use of geopolymer technology is not only considerably decreases CO_2 releases in the cement industry, but also allows the use of industrial waste by-products of aluminosilicate compositions to produce value-added building materials [3,36–38]. Geopolymers have excellent physical, chemical and mechanical properties which depend on the choice of raw materials and processing conditions. According to available data, in comparison with PC, geopolymers can achieve higher compressive strength and high early strength gain (in most cases, 70% of ultimate compressive strength is achieved within the first 4 h) [39]. Other recording characteristics of geopolymers include low manufacturing costs, excellent durability including chemical resistance, low permeability, high surface hardness and excellent fire resistance, high acid and sulfate resistance, low shrinkage, does not depend on the reaction of alkaline aggregates, due to the high residual pH and low diffusion rate of chlorides [40–43]. Internal protection of steel bars, thermal stability and good resistance to freeze–thaw cycles. These unique characteristics make geopolymer materials a strong candidate for replacing PC [44–47]. Earlier, most of the research focused on the synthesis of geopolymers from MK [47–49]. However, FA is rich in silica and alumina and its use in the production of geopolymers is an important strategy for making concrete more environmentally friendly [3,50]. In fact, concrete depends on complete compaction especially for large and complex structures. Despite a good mix, insufficient compaction of fresh concrete can significantly reduce its final performance. One of the solutions for the achievement of durable concrete structures independent of the quality of construction work is the employment of Self-Compacting Concrete (SCC) [51].

SCC is a type of concrete that, by its own weight, can be fully compacted to every corner of the frame. SCC development aims to provide adequate compaction and facilitate concrete placement in congested structures and confined areas [51–53]. Flowability, filling, and passing ability without segregation and/or bleeding are the fundamental properties of SCC. In the concrete industry, self compacting geopolymer concrete (SCGC) is a novel concept. It is a type of advanced concrete that combines the properties of geopolymer concrete and SCC [54]. There were a few studies on SCGC. Further investigation is required to evaluate both the fresh and hardened state performance of SCGC by using different supplementary cementitious materials (SCM) for potential use, as in the case of ordinary SCC. However, SCM and mineral fillers are commonly used to reduce costs, improve workability, and improve hardening properties [55]. However, many researchers [56,57] were performed that the slump flow of SCC mixtures was reduced with an increase in the content of MK in the mixture. This reduction in slump flow is due to the very fine particle size of MK, which is smaller than that of the other ingredients of the SCC mixture. The most related study was conducted by Arun et al. [58] that the slump flow is decreased with a rise in the content of MK in the SCGC mixtures. On the other hand, many investigators [42,46,57] concluded that the incorporation of MK of about 10–20% in geopolymer concrete mixtures made development in mechanical strengths.

Furthermore, most of the studies were performed on the use of SCM in SCC or SCGC mixtures. In addition, many researchers worked on the use of FA and MK as SCM or binder in the production of SCGC. But there is no study explored on the use of GSA and MK as replacements for FA separated and combined in SCGC. Therefore, this experimental study was conducted to bridge the knowledge gap by using GSA and MK as replacements for FA separated and combined in the SCGC mixtures, to investigate the fresh, mechanical and durability properties of SCGC.

2. Experimental program

2.1. Materials

Fly ash (FA) used in this experimental study is classified as Class F and satisfied the requirements of ASTM C 618 [59]. Therefore it can be used as a binding material in self-compacting geopolymer concrete (SCGC) for this experimental work. It was collected from the Plant with prior permission and after collecting FA, it was dried under the atmosphere for 24 h, and then it was sieved through a 75 μm sieve to remove large particles. After sieving, it was used as binding material in SCGCs. However, the metakaolin (MK) was collected and sieved from 75 μm sieve to eliminate the unwanted particles. However, the Blaine air permeability method [60] is used to determine the surface area of the utilized powder materials. The sieved MK was used at 5%, 10%, 15% and 20% as replacements for FA in SCGC mixtures. Moreover, groundnut shells were collected from a field, which is a locally available waste product. After collecting the groundnut shell was burned under a control temperature arrangement of 800 °C for five hours to convert it into ash and then it was left for 24 h to cooldown. The groundnut shell ash (GSA) was sieved through a 75 μm sieve to eliminate the large particles and sieved ash was used of 5%, 10%, 15% and 20% as replacement for FA in SCGC mixtures. The chemical composition of FA, MK and GSA are summarized in Table 1. An alkaline solution performs an essential role in the synthesis of geopolymers used to dissolve silica and alumina and a reaction of polymerization catalyst [61]. In this experiment work, a combination of sodium silicate and sodium hydroxide was taken as the alkaline liquid. Sodium hydroxide (99% purity) and sodium silicate solution (Na2O = 14.26%, SiO2 = 29.43%, water = 56.31%) by weight, was used for this research work. To prepare a sodium hydroxide solution, sodium hydroxide particles are dissolved in tap water to achieve the desired concentration and allowed to cool for about 24 h. Mix the two liquid solutions together to make an alkaline solution. Besides, the superplasticizer (SP) was used to improve the workability to a certain limit which was needed for SCGC. After some trials, the desired dosage

Table 1
Chemical composition of FA, GSA, and MK.

Binding materials	Oxides (%)										Physical property	
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	SO_3	MgO	K_2O	P_2O_5	Others	Specific gravity	Specific surface area (m^2/kg)
FA	54.20	28.30	4.58	8.73	0.62	0.58	1.40	0.75	0.54	0.30	2.32	379
GSA	39.46	24.50	10.24	13.52	1.64	0.53	5.60	2.02	2.0	0.49	2.22	1114
MK	62.18	21.67	3.01	3.22	1.04	2.92	2.08	2.68	0.76	0.44	2.60	18,000

of SP was used in SCGC to obtain the required workability [62]. In this investigation, the Chemrite 530 type of 1.18 specific gravity was used. In addition, the extra tap water was used to achieve the desired fresh properties of SCGC. Furthermore, the crushed stone was used as coarse aggregates having a maximum size of 14 mm and river sand was served as fine aggregates which passed through a sieve of 4 mm in this experimental investigation. The physical properties of aggregates are mentioned in Table 2.

2.2. Mixture design and mixing

This research methodology was done on thirteen mixtures of self-compacting geopolymer concrete (SCGC) in which one mixture was made of FA only as binding material, four mixtures of SCGC including 5–20% of FA replaced with MK as binding material, four mixtures were made of SCGC containing 5–20% of FA replaced with GSA, and the remaining mixtures were prepared with the combined use of MK and GSA as replacement of FA material in SCGC. The alkaline activator-to binder ratio was 0.5 and the alkaline activator was a mix of NaOH solution having a 10 M concentration and ready-made Na_2SiO_3 solution. The total content of alkaline activator was 200 kg/m^3 and the ratio between sodium hydroxide and sodium silicate was designated as 1:2.5. The details of all the mixed proportions of SCGCs were evaluated in this experimental study as mentioned in Table 3. However, the mixing duration and series are significant in the self-compacting geopolymer concrete (SCGC) manufacturing process to obtain a uniform and homogeneous concrete in all SCGCs, followed the procedures recommended by Khayat et al. [63] for the mixing and batching. A dry fine and coarse aggregates, FA, GSA, and Mk, were added to a power-driven revolving pan mixer and homogeneously mixed for 30 s. Consequently, about one-third of the activated solution was poured into the mixer and it was permitted to continue the mixing for 60 s more. Subsequently, SP and extra water [49] with the remaining activation solution were added to the mixer. The concrete was mixed for 3 min, then left to rest for 2 min. Lastly, the mixture was mixed about another 2 min to complete the manufacturing.

After homogeneous freshly mixed concrete was checked for essential workability tests like (slump flow, T_{50} flow, V-funnel, L-box test, and J-Ring Test) which were needed to describe the SCGC.

After testing of the workability of freshly mixed SCGC, it was poured into the steel moulds (cubes, cylinders, and prisms) without compaction, filling all the spaces in the moulds by its self-weight. Moreover, cubes were cast for compressive strength, cylinders were tested for splitting tensile strength, and prism specimens were equipped for flexural strength of SCGC. Besides, the permeability of SCGC was performed on concrete specimens. After casting the specimens of SCGC, without any delay, all the concrete samples along with steel moulds were kept in an oven and cured for two days at 75 °C. At the end of the oven curing period, the samples were separated from the moulds and placed at room temperature for air curing until the day of testing.

Table 2
Physical properties of aggregates.

Properties	Fine aggregates (F.A)	Coarse aggregates (C.A)
Size (mm)	4.75	14
Fineness modulus	2.35	–
Water absorption (%)	1.20	0.54
Specific gravity	2.62	2.65
Bulk density (kg/m^3)	1875	1750

2.3. Testing methods

The fresh properties of SCGC were performed with respect to the European Federation of National Associations Representing for Concrete (EFNARC 2005) [64] for SCC mixtures to determine the slump flow diameter, V-Funnel, T_{50} flow time, J-Ring and L-box tests. For the slump flow test, fresh SCGC was added to the slump, after which the slump was raised and the deposit two-direction average was taken. The slump flow time can be determined by calculating the time required to reach the fresh concrete to a diameter of 50 cm and is abbreviated as T50. The V-funnel test involves filling a V shape with fresh concrete and then opening the lower gate of the V shape to let the concrete flow out, while recording the elapsed time, which is well-known as the V-funnel flow time. The L-box test can be performed to determine the ability of fresh SCGC to flow freely through congested reinforcing areas and small spaces. Fresh concrete was poured into a vertical part of the L shape and then allowed to flow horizontally through the vertical smooth reinforcing bars and gaps. The L-box height ratio was determined by dividing the height of concrete at the ends of horizontal section H2/H1 beyond and before the reinforcement bars.

On the other hand, some tests for hardened characteristics were conducted. Compressive strength tests were conducted on 10-cm cubes in accordance with ASTM C39-20 [65]. The splitting tensile strength test was performed on a cylinder of 10 × 20 cm using ASTM C496-17 [66] methods. The flexural strength test of SCGC mixtures on a prism of 10 × 10 × 50 cm was carried out using ASTM C78-17 [67] procedures. Moreover, the permeability of the SCGC mixture was performed on 10-cm cubes of concrete specimens by consuming the BS EN-12390-8 [68] code procedures. These all-concrete specimens were cured and tested at 28 days. Furthermore, the findings on an average of five SCGC specimens have been taken for all hardened testing.

3. Results and discussions

3.1. Fresh properties of SCGC

3.1.1. Slump flow of SCGC

Figure 1 indicates the slump flow diameter result of fresh properties of the SCGC mixture with accumulation of several dosages of MK and GSA as replacement for FA individually and merged into the mixture. It can be noted that the slump flow of all SCGC mixtures was within EFNARC [64] limitations and in the range of 550–750 mm. However, the maximum outcome of slump flow diameter was recorded as 750 mm for the control mix and the lowest slump flow diameter was recorded as 554 mm for the mix that replaced 20% of FA with MK in the mixture of SCGC. Similarly, the slump flow diameter of SCGC decreased as GSA incorporation increased separately or combined with MK. Arun et al. [58] also reported that the decrease in slump flow with increasing MK content was due to MK particles being amorphous and having a large surface area. In addition, Guneyisi and Gesoglu [57] concluded that the increase in MK content enhanced the cohesiveness of the SCC, which in turn decreased slump flow diameter. Generally, the reduction of workability properties of SCGC, specially for slump flow diameter was due to the specific

Table 3
Mix Proportions of self-compacting geopolymer concrete.

Mix ID	Concrete mixture quantity (kg/m^3)						SH		SP kg/m^3	Extra water mass fraction/Wt.%	Oven curing	
	FA	MK	GSA	F.A	C.A	SS	Kg/m^3	Mol/L			Time/days	Temp: /°C
M0	400	0	0	814.1	795	143	57	10	12	15	2	75
MK5	380	20	0	814.1	795	143	57	10	12	15	2	75
MK10	360	40	0	814.1	795	143	57	10	12	15	2	75
MK15	340	60	0	814.1	795	143	57	10	12	15	2	75
MK20	320	80	0	814.1	795	143	57	10	12	15	2	75
GSA5	380	0	20	814.1	795	143	57	10	12	15	2	75
GSA10	360	0	40	814.1	795	143	57	10	12	15	2	75
GSA15	340	0	60	814.1	795	143	57	10	12	15	2	75
GSA20	320	0	80	814.1	795	143	57	10	12	15	2	75
2.5GSA2.5MK	380	10	10	814.1	795	143	57	10	12	15	2	75
5GSA5MK	360	20	20	814.1	795	143	57	10	12	15	2	75
7.5GSA7.5MK	340	30	30	814.1	795	143	57	10	12	15	2	75
10GSA10MK	320	40	40	814.1	795	143	57	10	12	15	2	75

Note: SS = Sodium Silicates, SH = Sodium Hydroxide.

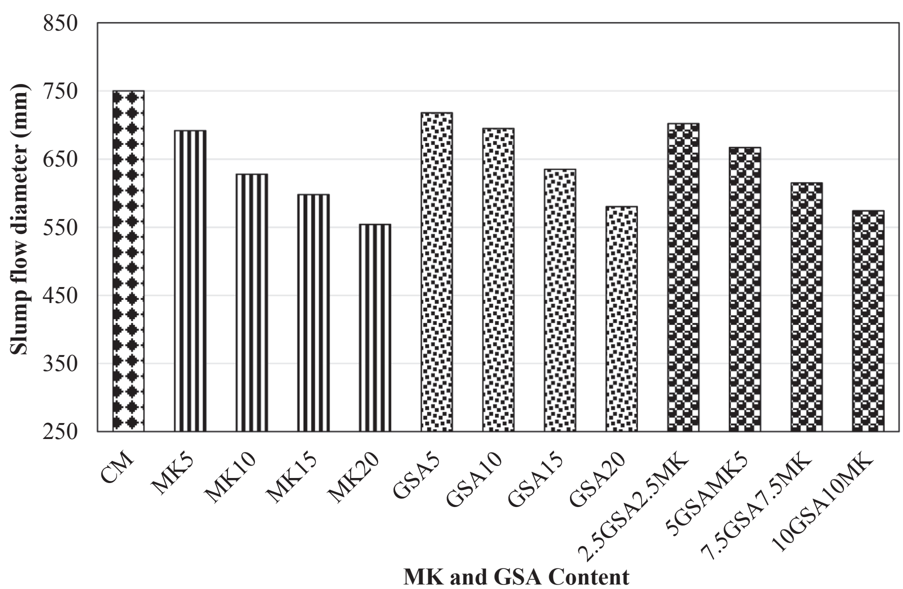

Fig. 1. Slump flow of SCGC mixtures.

surface area of MK and GSA being greater than that of FA, as shown in Table 1 which reduces the slump flow of the SCGC mixture. On the other hand, many researchers [57,58] found that the slump flow diameter of SCGC mixtures was reduced by the increasing MK content in the mixture. This reduction in the slump flow diameter was due to the very fine particle size of MK compared to other ingredients of the SCGC mixture. The most related study was conducted by keerio et al. [56] that the slump flow decreased with a rise in the content of MK in the mixture.

3.1.2. V-Funnel Test

Figure 2 presents the V-funnel flow time results of fresh properties of SCGC mixtures including MK and GSA as replacements for FA separate and combined in SCGC mixtures. The V-funnel flow time is noted during the performance of the test. Based on the obtained outcomes from the test, the V-funnel flow time lies between 8.5 and 13.40 sec while using various proportions of MK and GSA as replacements for FA separate and combined in the SCGC mixture. It has been observed that the results of V-funnel flow time for all the SCGC mixtures meet the requirements of EFNARC [64]. The minimum V-funnel flow time was noted at 8.50 sec for the control mixture of SCGC without the inclusion of GSA and MK as replacements for FA separate and together. From Fig. 2, it can be observed that the V-funnel flow time of SCGC was increased as the usage of MK and GSA as replacements of FA separately and combined increased, which resulted in a reduction the fluidity of the SCGC mixture. However, the reasons for the reduction in V-funnel flow time were the same reasons recorded for the slump flow diameter. Arun et al. [58] also reported that the increase in V-funnel flow time with increasing MK content was due to MK particles being amorphous and having a large surface area. In addition, Guneyisi and Gesoglu [57] concluded that the increase in MK content enhanced the cohesiveness of the mortars, which in turn increased the time of SCGC flow through the V-funnel. Generally, the reduction in workability properties of SCGC was due to the specific surface area of MK and GSA being greater than that of FA, as shown in Table 1, which increased cohesiveness and then increased the V-shape flow time of SCGC mixtures. On the other hand, many researchers [57,58] found that the V-funnel flow time of SCC mixtures was increased by the increasing MK content in the mixture. This increment in the V-funnel flow time was due to the very fine particle size of MK compared to other ingredients of the SCGC mixture.

3.1.3. T_{50} Flow

Figure 3 presents the T_{50} flow time results of the fresh properties of SCGC mixtures, including the MK and GSA as replacements for FA, separate and combined in the SCGC mixtures. The slump flow time for the SCGC mixture reached 50 cm in diameter and was recorded during the performance test. According to the test outcomes, the slump flow

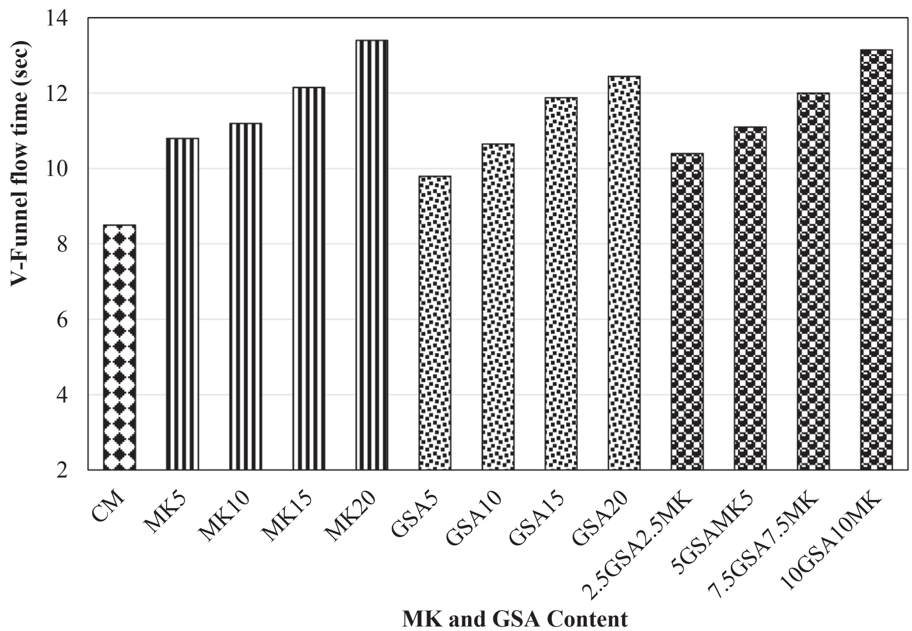

Fig. 2. V-Funnel flow of SCGC mixture.

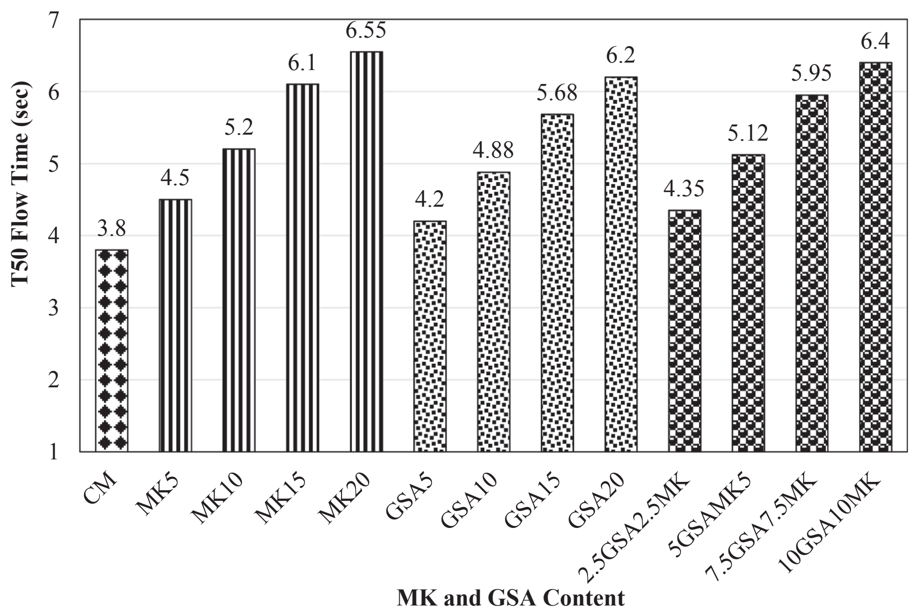

Fig. 3. T_{50} flow of SCGC mixture.

time lies between 3.8 and 6.55 sec while using various proportions of MK and GSA as replacements for FA, separate and combined in the SCGC mixtures. It has been perceived that the slump flow time, except for MK15, MK20, GSA20 and 10GSA10MK, remaining nine mixtures of SCGC are qualified the acceptable values of 2–5 sec as provided in EFNARC [64]. The lowest slump flow time was noted as 3.80 sec for the control mix of SCGC without the inclusion of GSA and MK as replacements for FA separately and together. From Fig. 3, it can be observed that the slump flow time of SCGC was increased while the usage of MK and GSA as replacements for FA increased in the SCGC mixtures. This increment in T_{50} flow time of the SCGC mixture is due to the improving paste volume with MK and GSA as replacements for FA, separate and together. A related kind of research study was explored by Arun et al. [58] who found that the increase in T50 flow time with increasing MK content was due to MK particles being amorphous and having a large surface area. In addition, Guneyisi and Gesoglu [57] concluded that the increase in MK content enhanced the cohesiveness of the mortars, which in turn increased the time of SCGC flow to reach a 50 cm diameter of slump flow. Generally, the reduction in workability properties of SCGC was due to the specific surface area of MK and GSA being greater than that of FA, as shown in Table 1**,** which increased cohesiveness and then increased T50 flow time of SCGC mixtures. On the other hand, many researchers [57,58] were performed that the T50 flow time of SCC mixtures was increased by the increasing MK content in the mixture. This increment in the T50 flow time was due to the very fine particle size of MK compared to other ingredients of the SCGC mixture.

3.1.4. *Blocking ratio (L-box test)*

Figure 4 displays the blocking (H2/H1) ratio results of the fresh SCGC mixtures, including varying percentages of MK and GSA as

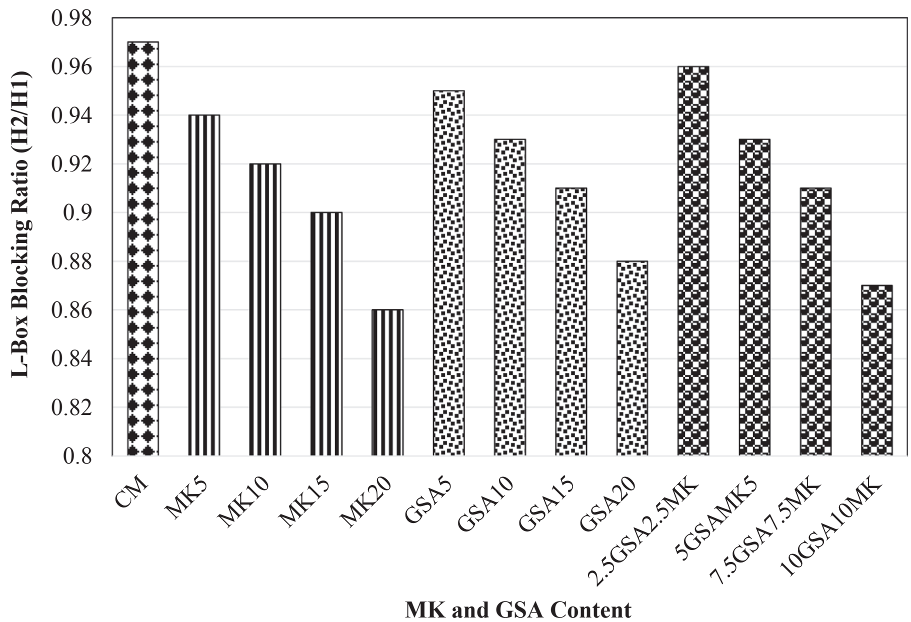

Fig. 4. L-Box blocking ratio of SCGC mixture.

replacements for FA, separately and combined. It has been observed that all mixtures of SCGC passed easily from the L-box and no type of blockage was seen from any of the mixtures of SCGC during the evaluation of the fresh concrete for passing ability. However, the test outcomes show that the L-box height ratio of SCGC mixtures gradually decreased as the dosages of MK and GSA as replacements of FA separately and combined increased in the mixtures. Actually, all the results are within the allowable limitations as specified in EFNARC [64]. A similar kind of research study was conducted by Arun et al. [58] who found that the decrease in the slump flow with increasing MK content was due to MK particles being amorphous and having a large surface area. In addition, Guneyisi and Gesoglu [57] concluded that the increase in MK content, enhanced the cohesiveness of the SCC, which in turn decreased the workability. Generally, the reduction of workability properties of SCGC, specially for L-box height ratio, was due to the increasing cohesiveness of the SCGC mixtures, and the specific surface area of MK and GSA is greater than that of FA, as shown in Table 1. On the other hand, many researchers [57,58] were performed that the H2/H1 ratio of SCGC mixtures was reduced by the increasing MK content in the mixture.

3.1.5. J- Ring test

This test was performed on the fresh mixtures of SCGC including dissimilar percentages of MK and GSA separate and combined as replacements with FA as shown in Fig. 5. However, the J-Ring test was used to evaluate the flow of the SCGC mixture and rests between 0 and 10 mm according to EFNARC [64]. However, the optimum result of J-Ring for the SCGC mixtures was recorded as 9.50 mm for the mix containing 20% of MK as a replacement of FA, and the lowest value was measured as 3.50 mm for the control mix of SCGC. In addition, the workability of SCC decreased while the value of the J-Ring increased and approached 10 mm. Consequently, it has been observed that the J-Ring results of the SCGC mixtures were increased by increasing the quantity of MK and GSA as replacements for FA in the SCGC mixtures. Arun et al.

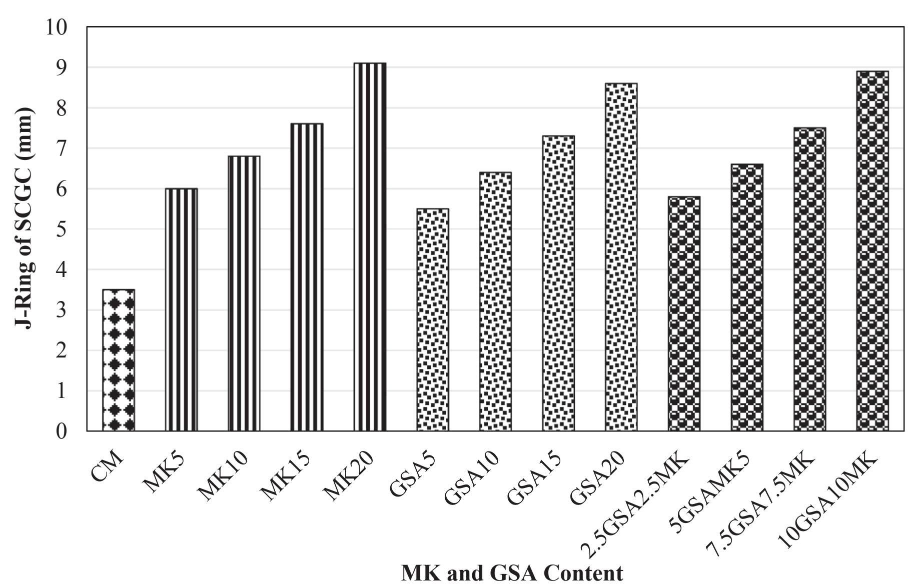

Fig. 5. J-Ring of SCGC mixture.

[58] also reported that the decrease in the workability with increasing MK content was due to MK particles being amorphous and having a large surface area. In addition, Guneyisi and Gesoglu [57] concluded that the increase in MK content enhanced the cohesiveness of the SCC, which in turn decreased the workability of SCC mixtures. Generally, the reasons for the workability reduction of SCGC were illustrated in the slump flow diameter section. The most related study was conducted by Keerio et al. [56] that showed the J-Ring increased with a rise in the content of MK in the mixtures.

3.2. Hardened properties of SCGC

3.2.1. Compressive strength of SCGC

The effect of GSA and MK at different replacement levels with FA separately and combined on the compressive strength of SCGC mixtures at a curing period of 28 days was illustrated graphically in Fig. 6. However, the compressive strength of SCGC mixtures increased with increasing MK content up to 15% then reduced as compared with the control mix which was produced with FA only.

The compressive strength of SCGC was recorded by 54.78 MPa, 56.62 MPa and 53.20 MPa at 5%, 10% and 15% of FA replaced with MK was greater than the control mixture, respectively. The compressive strength of the SCGC mixture contained 20% of MK as a replacement of FA was lower than the control mix. Clearly, it has been seen that the addition of 5%-15% MK as a replacement for FA in SCGC is provides the maximum compressive strength of SCGC, and further addition of MK as FA replacement material in SCGC reduces the strength of the SCGC mixture. Similarly, the optimum compressive strength of SCGC is determined by 53.50 MPa, 55.86 MPa and 52.64 MPa at 5%, 10% and 15% of FA replaced with GSA, respectively, and the lowest strength is noted by 48.25 MPa at 20% of FA replaced with GSA at 28 days. The test findings show that the compressive strength of the SCGC mixture is enhanced by the use of GSA as a replacement for FA up to a maximum of 15% in the mixture of SCGC, and then it starts to decline. Moreover, the maximum compressive strength is gotten by 54.30 MPa, 56.42 MPa and 52.98 MPa at 2.5GSA2.5MK, 5GSA5MK and 7.5GSA7.5MK, respectively, and the smallest strength is found by 49 MPa at 10GSA10MK as a replacement for FA in the SCGC mixture. It has been observed that the compressive strength of SCGC is improved by consuming the GSA and MK up to 15% as a combined material, replaced with FA in the SCGC mixture. This increment in compressive strength of the SCGC mixture is associated with the very fine particle size of MK and GSA as compared to FA, which causes the pore size refinement and dense particle packing to produce a denser concrete mix. On the other hand, many researchers have reported that the increase in compressive strength may be due to the active pozzolanic reaction of MK, and that the silica content of MK particles promotes the formation of C-S-H, a gel responsible for strength development [69]. The primary factors affecting the strength of MK SCC are (i) the filling effect, (ii) the dilution effect, and (iii) MK's pozzolanic response to CH [69–71]. Additionally, the compressive strength of SCC was estimated to be reduced by more than 15% when MK was used [72]. The same effect of MK on compressive strength obtained from this study was concluded by many investigators [42,46,56–58].

3.2.2. Splitting tensile strength of SCGC

Figure 7 indicates the split tensile strength results of the SCGC mixture including GSA and MK as replacements for FA, individually and together in the mixture were checked at 28 days. However, the maximum split tensile strength of SCGC is recorded by 4.75 MPa and 4.63 MPa at 10% of FA replaced with MK and GSA and the lowest strength is found by 4.18 MPa and 4.0 MPa at 20% of FA replaced with MK and GSA at 28 days, respectively. It has been seen that the addition of 5–15% MK and GSA as replacement for FA in SCGC provides the maximum split tensile strength of SCGC and further addition of MK and GSA as FA replacement materials in SCGC reduces the strength of the SCGC mixture. Similarly, the maximum split tensile strength is gained by 4.68 MPa at 5GSA5MK and the smallest strength is found by 4.12 MPa at 10GSA10MK as a replacement for FA in the SCGC mixture at 28 days, respectively. It has been observed that the splitting tensile strength of SCGC is improved when GSA and MK are used in SCGC up to 15% as the combined material is replaced with FA. The improvement in the split tensile strength of the SCGC mixture is owing to the specific surface area of MK and GSA as compared to FA, which makes SCGC denser than that of a SCGC mixture made without the addition of MK and GSA. On the other hand, many researchers have reported that the increase in splitting tensile strength may be due to the active pozzolanic reaction of MK, and that the silica content of MK particles promotes the formation of C-S-H, a gel responsible for strength development [69]. Also, for the same reasons explained previously in the compressive strength result part of this study. The same effect of MK on splitting tensile strength obtained from this study was achieved by many researchers [56–58].

Furthermore, Fig. 8 depicts the relationship between splitting tensile strength and compressive strength of SCGC blended with MK and GSA as a replacement for FA in the mixtures of SCGC at 28 days. It has been

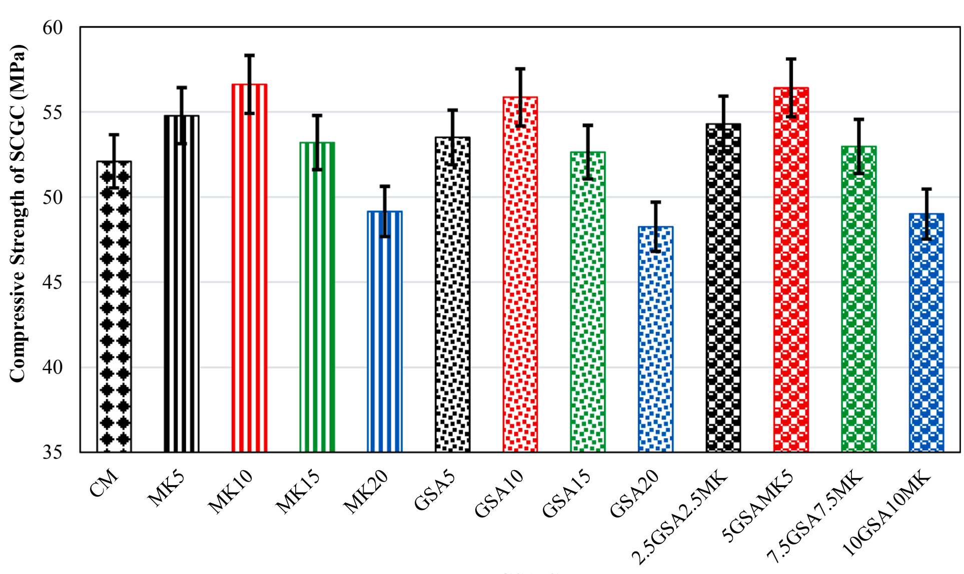

Fig. 6. Compressive strength of SCGC mixture.

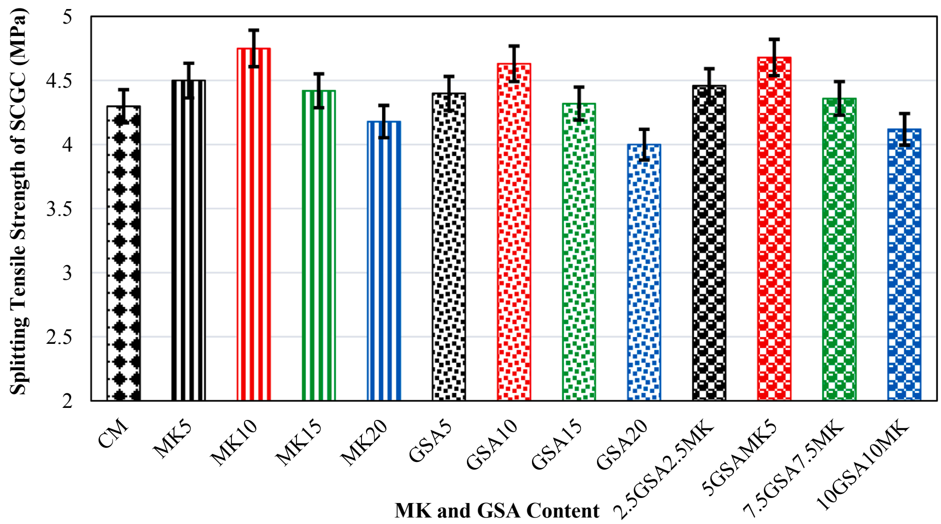

Fig. 7. Splitting tensile strength of SCGC mixture.

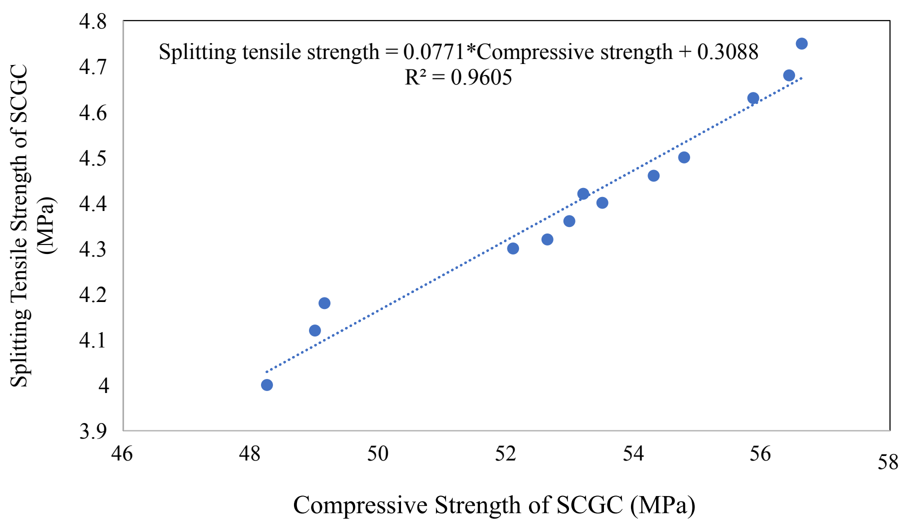

Fig. 8. Relationship between tensile and compressive strength of SCGC mixture.

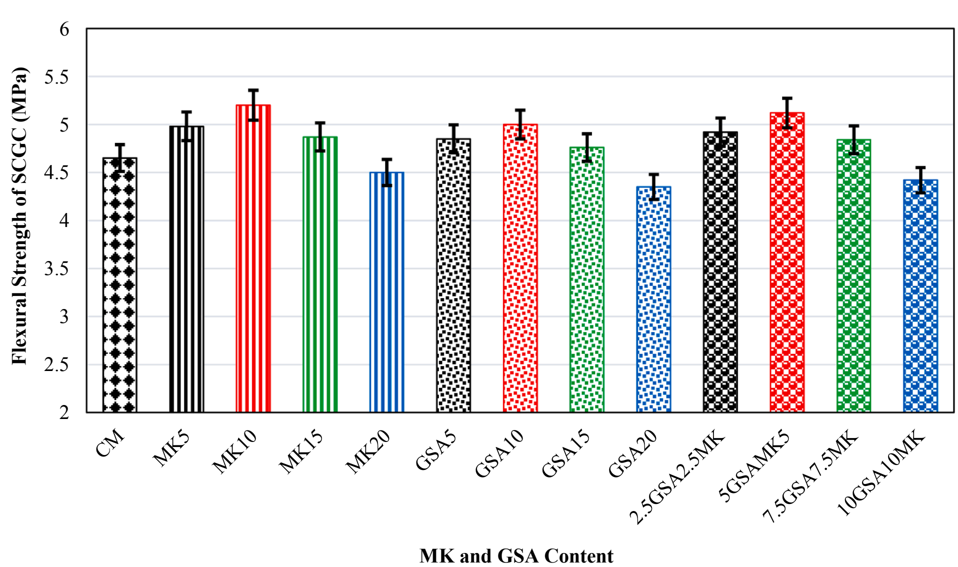

Fig. 9. Flexural strength of SCGC mixture.

acknowledged that there is a great linear relationship of $R^2 = 0.96$ between compressive and tensile strength of SCGC. So, the equation given in Fig. 8 will be helpful to predict either the tensile strength or compressive strength if one of the values is available.

3.2.3. Flexural strength of SCGC

Figure 9 indicates the flexural strength results of the SCGC mixture including GSA and MK as replacements for FA separate and combined in the mixture. However, the highest flexural strength of SCGC is documented by 5.20 MPa at 10% of FA replaced with MK, and the lowest flexural strength of SCGC mixture is attained by 4.50 MPa at 20% of FA replaced with MK in the mixture after 28 days, respectively. It has been seen that the addition of 5–15% MK as replacement for FA in SCGC provides the best flexural strength of SCGC, and further addition of MK as FA replacement material in SCGC reduces the strength of the SCGC mixture. Similarly, the better flexural strength of SCGC is calculated by 5.0 MPa at 10% of FA replaced with GSA, and the lowest strength is observed by 4.35 MPa at 20% of FA replaced with GSA at 28 days, respectively. The test results show that the flexural strength of the SCGC mixture is enhanced while utilizing GSA as a replacement for FA up to 15% in the mixture of SCGC and then it starts to decrease. Moreover, the maximum flexural strength is achieved by 5.12 MPa at 5GSA5MK and the smallest strength is obtained by 4.42 MPa at 10GSA10MK as a replacement for FA in the SCGC mixture at 28 days, respectively. It has been observed that the flexural strength of SCGC is improved while consuming GSA and MK up to 15% as the combined material is replaced with FA in the SCGC mixture. The improvement in flexural strength of the SCGC mixture is due to the very fine particle size of MK and GSA than that of FA which fill the pores by production of more C-S-H due to the active pozzolanic reaction of MK, and the silica content of MK particles [69]. These finer particles remove the micro-cracks of concrete and produce a much denser concrete structure that results in an improvement in the hardened properties of concrete. Also, for the same reasons explained previously in the compressive strength result part of this study. The same effect of MK on flexural strength obtained from this study was achieved by many researchers [42,56–58].

In addition, Fig. 10 illustrates the correlation between flexural strength and compressive strength of the SCGC mixture, including MK and GSA as replacements for FA separate and combined in the mixtures at 28 days. It can be seen from Fig. 10 that there is a good linear correlation between these properties. It has been approved that there is a great linear relationship of $R^2 = 0.97$ between compressive and flexural strength of SCGC. So, the equation given in Fig. 10 will be helpful to predict either the flexural strength or compressive strength of SCGC mixture if one of the values is available.

3.2.4. Water penetration depth of SCGC

Figure 11 displays the water penetration depth of SCGC is determined on the SCGC mixture made specimens with the accumulation of MK and GSA as replacements for FA separate and combined in the mixture. The water penetration depth of SCGC measured by 19.04%, 33.33%, 51.20% and 60.95% at 5%, 10%, 15% and 20% of FA replaced with MK is greater as compared to the control mixture of SCGC without the addition of MK. It can be seen that the permeability of the SCGC mixture declines as the quantity of MK as a replacement for FA increases in the SCGC. This aspect is associated with Keerio et al. [56] that the permeability of concrete is reduced while using MK up to 15% as a replacement for PC in concrete at 28 days. Similar observation were explored by Bheel et al., [11]. Besides, the water penetration depth of SCGC is recorded by 12.85%, 26.67%, 42.86% and 51.43% at 5%, 10%, 15% and 20% of FA replaced with GSA is greater as compared to the control mixture of SCGC without addition of GSA. The water penetration depth of the SCGC mixture has declined as the extent of GSA as a replacement for FA has increased in the SCGC. A comparable kind of study was achieved by many researchers [56,57] where the water penetration depth of SCGC is decreased as the content of MK rises in concrete. Moreover, the water penetration depth of the SCGC mixture was estimated as 18 mm, 15 mm, 11.40 mm, and 9.88 mm at 2.5GSA2.5MK, 5GSA5MK, 7.5GSA7.5MK and 10GSA10MK as replacement for FA, which is lower than that of the control mixture of SCGC without inclusion of GSA and MK at 28 days, respectively. From Fig. 11, the test result shows that the water penetration depth of the SCGC mixture has plummeted while the extent of MK and GSA combined as a replacement for FA in the mixture of SCGC. This decrement in water penetration depth of SCGC is owing to the fineness of MK and GSA, which fill the pores by producing more C-S-H due to the active pozzolanic reaction of MK, and that the silica content of MK particles [68] then reduces the penetration depth of water.

4. Conclusion

The basic aim of this study was to determine the utilization of MK and GSA as replacements for FA separate and together in the SCGC mixture and their influence on the fresh and mechanical properties of the SCGC mixture. From this research study, the following key points are developed:

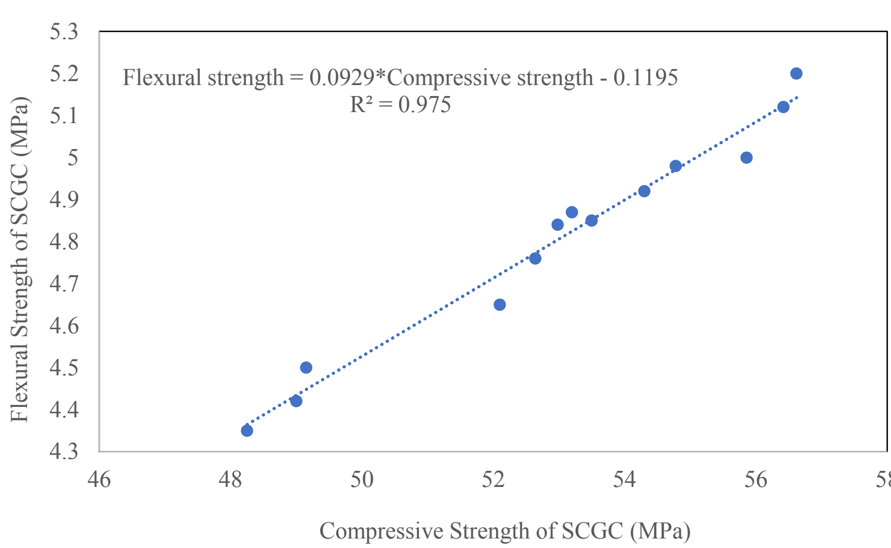

Fig. 10. Relationship between flexural and compressive strength of SCGC mixture.

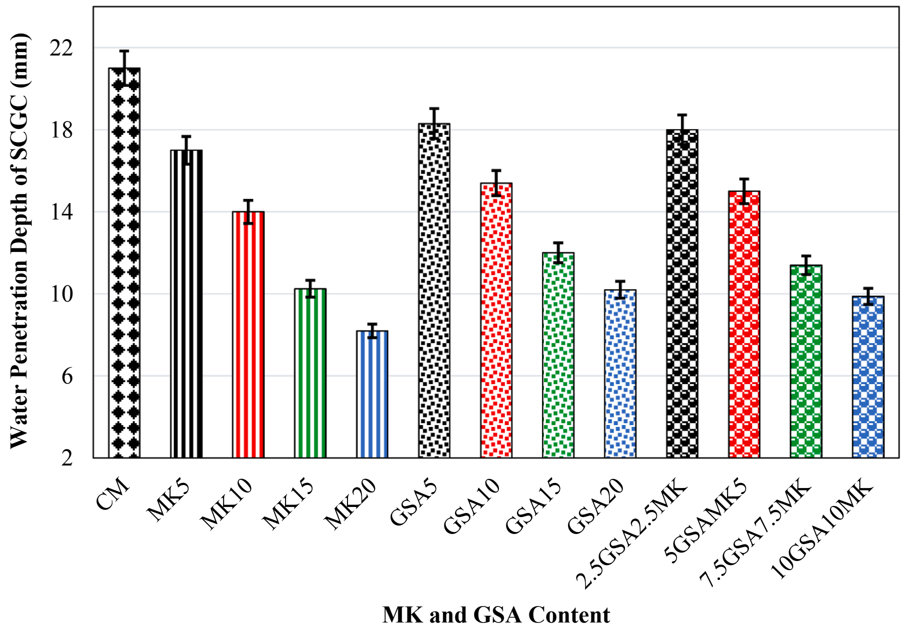

Fig. 11. Water penetration depth of SCGC mixture.

- The slump flow of all mixtures of SCGC is reduced while the use of MK and GSA as replacements for FA content increases in the SCGC mixture. This reduction in slump flow is due to the very fine particle size of MK and GSA, which are smaller than that of FA.
- The V-funnel flow and slump flow time of all SCGC mixtures were increased as the extent of MK and GSA as FA replacements separate and combined, resulting in a decrease in the fluidity of the SCGC mixture.
- All mixtures of SCGC passed easily from the L-box and no blockage was seen from all mixtures of SCGC during the evaluation of the fresh concrete for passing ability. The test outcomes show that the blocking ratio of the SCGC mixture gradually decreases as the dosages of MK and GSA as replacements for FA separate and combine increases in the mixture.
- The J-ring of all mixtures of SCGC was increased as the dosages of GSA and MK as replacements for FA rose individually or combined in the SCGC mixtures.
- The peak compressive strength of the SCGC mixture was recorded as 56.62 MPa at 10% of MK, and the lowest compressive strength was noted as 48.25 MPa at 20% of GSA as a replacement for FA in the SCGC mixture at 28 days. The compressive strength of SCGC was improved by up to 15% while consuming GSA and MK as combined or individual materials replaced with FA in SCGC mixtures.
- The maximum split tensile strength of SCGC was recorded as 4.75 MPa at 10% of MK and the lowest strength was found as 4.0 MPa at 20% of GSA as a replacement for FA in the SCGC at 28 days. It has been observed that the splitting tensile strength of SCGC was improved while GSA and MK were used in SCGC up to 15% as combined or separate materials replaced with FA.
- The optimum flexural strength of the SCGC mixture was recorded as 5.20 MPa at 10% of MK and the lowest flexural strength was noted as 4.35 MPa at 20% of GSA as a replacement for FA in the SCGC mixture at 28 days. It has been observed that the flexural strength of SCGC is improved while consuming the GSA and MK up to 15% as combined or separate material replaced with FA in the SCGC mixtures.
- The water penetration depth of SCGC mixtures dropped while the extent of MK and GSA were separated and combined as replacements for FA in the mixtures of SCGC and it is important for durability improvement.
- From experimental investigations, it was concluded that the use of MK and GSA up to 10–15% separate and combined in the SCGC mixture provides optimum results for structural applications.
- A strong linear relationship was observed between the results of flexural and splitting tensile strengths with compressive strength which achieved a high value in terms of R^2 equal to 0.97 and 0.96, respectively.

CRediT authorship contribution statement

Naraindas Bheel: Investigation, Methodology, Validation, Writing – review & editing. **Paul Awoyera:** Validation, Resources, Data curation, Writing – review & editing. **T. Tafsirojjaman:** Validation, Resources, Data curation, Writing – review & editing. **Nadhim Hamah Sor:** Conceptualization, Formal analysis, Validation, Data curation, Writing – original draft, Writing – review & editing. **Samiullah sohu:** Validation, Writing – review & 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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