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Parametric studies on the workability and compressive strength properties of geopolymer concrete

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Abstract:
Geopolymer concrete is a booming technology in the construction industry. Much research is occurring in geopolymer concrete, as it emits low carbon dioxide into the atmosphere, is eco-friendly material and is an alternative for cement. This research mainly focuses on the use of fly ash based geopolymer concrete in ambient curing conditions and the use of manufactured sand due to the scarcity of natural sand. Mainly studies have evolved on the workability, setting time and compressive strength by the effect of ground granulated blast furnace slag (GGBFS), manufactured sand (M-sand), alkaline activator solutions to binder ratio and the proportions of sodium silicate to sodium hydroxide (SS/SH) in geopolymer concrete and mortar. The experimental studies were carried out using nine geopolymer concrete mixes and the comparisons were made. The workability of concrete decreases by increasing the percentage of GGBFS, M-sand and the proportions of SS/SH whereas workability of concrete increases when increasing the alkaline liquid to binder ratio. The compressive strength of geopolymer mortar and concrete increases when the percentage of GGBFS and M-sand is increased, and it decreases by increasing the alkaline liquid content. There is no change in strength by decreasing the proportions of SS/SH.

Keywords: compressive strength, geopolymer, GGBFS, M-sand, setting time, workability

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1 Introduction

The production of cement is of prime importance and is second largest contributor to the release of greenhouse gases [1]. The production of cement is increasing by 3% annually [2] and it will be expected to reach around 3.7–4.4 billion tons by 2050 from 2.5 billion tons in 2006. Ordinary Portland cement concrete usually contains about 12% cement and 80% aggregate by mass. Annually in concrete production, the rate of consumption is approximately 10–11 billion tons of sand, gravel and crushed rock globally. To reduce the environmental impact of the concrete industry, cement protection is first step for reducing the greenhouse gas emissions and energy consumption [3].

On the other hand, the cementitious or by product materials such as fly ash, ground granulated blast furnace slag, etc., produce enormous quantities of these materials which are also used in low value applications such as landfills and road sub bases or are simply discarded in ponding or build up stocks. Hence, these by products, can be used as cement substitutes by abolishing the production of more Portland cement in the construction industry. Geopolymer concrete is a new technology to reduce the cement usage in ordinary Portland cement concrete. It is an eco-friendly and greener material, as it does not emit greenhouse gases into the atmosphere during the polymerization process. The by-product materials which are rich in silica and alumina are mainly used as replacement material for cement in geopolymer concrete and the polymerization reaction is mainly activated by alkaline activator solutions [4], [5]. Geopolymers are gaining more attention, due to emission of low CO_2 when compared to Portland cement [6]. Sand mining is a very big issue and it creates a demand for natural sand. Due to the increase in construction activities, the scarcity of natural sand is increasing. To overcome the demand for natural sands, artificial sand called manufactured sand with the desired size and grade are used as a substitute material for natural sand.

Temuujin et al. investigated the acid and alkaline resistance of Class F fly ash based on a geopolymer paste and found that the partial crystallization of non-reacted fly ash particles in geopolymer decreases its solubility

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in acid and alkaline solutions [7]. Azizul Islam et al. reported the use of an optimum level of palm oil fuel ash (POFA) ground granulated blast furnace slag (GGBFS) and low calcium fly ash (FA) with manufactured sand (M-sand) to produce geopolymer mortar [8]. Nath et al. aimed for setting time, compressive strength using GGBFS as a binder and achieved that flow of mortar & slump of concrete decreased with increase of slag. The workability and setting time reduced in the fly ash based Geopolymer mixture when GGBFS increased [9]. Praveen Kumar and Radhakrishna varied the replacement of M-sand with natural sand in cement mortar 1:6 and it be recommended for the river sand [10]. Zhang et al. showed that the addition of additives of short carbon fibers, basalt fibers and styrene-acrylate in metakaolin (MK)/fly ash based geopolymer concrete influenced the bond strength at ambient curing temperatures (or) at elevated temperatures. At ambient conditions, the addition of short carbon fibers did not influence the strength, but improved the bond strength achieved at 100–300°C range [11] . Bashar et al. utilized palm oil fuel ash (POFA), fly ash (FA) and blast furnace slag (BFS) as binders along with manufactured sand (M-sand) and quarry dust with the replacement of conventional mining sand (N-sand) on the compressive strength of geopolymer mortar. POFA-FA-BFS and M-sand as binders and fine aggregates could be an alternative for conventional materials [12]. Omer et al. showed that the relationship between ultrasonic pulse velocity (UPV) and compressive strength was exponential on GGBS based geopolymer mortars [13].

Deb et al. analyzed the workability and strength variation in geopolymer concrete with variable activator content and sodium silicate to sodium hydroxide (SS/SH) ratio. Strength development of slag based geopolymer concrete in ambient curing is similar to OPC and the strength is increased and the workability is decreased when GGBS is increased [14]. Subhash et al. found an effect on the compressive strength of fly ash based geopolymer mortar by varying the sodium hydroxide concentration, oven heating duration and temperature and concluded that the workability and compressive strength increases when the sodium hydroxide concentration is increased. Three days later there is no noticeable change in the compressive strength [15]. Bhowmick and Ghosh studied the parameters of the ratios of SiO_2 to Na_2O, water to fly ash and fly ash to sand on the workability and compressive strength. Total pore volume and size distribution using mercury electron porosimetry (MIP) were also studied on the compressive strength [16]. Vignesh et al. carried out experiments to find the optimum percentage of mechanical properties of geopolymer concrete by varying the glass fibers to the weight of the cement along with M-sand and concluded that 1% glass fiber concentration is the optimum dosage [17]. Patil and Shinde discussed the process of artificial sand and its uses when compared with natural sand using a compressive strength test by varying the percentage of artificial sand for two different grades of mixes [18]. Vijaya and Senthil Selvan studied the compressive strength and durability of different grades of concrete using manufactured sand and concluded that 60% replacement of M-sand with natural sand shows the optimum percentage replacement [19]. Elavenil and Vijaya concluded that M-sand is a substitute material for river sand to reduce the demand for natural sand [20]. Nagajothi and Elavenil showed substitute materials for cement, natural sand and steel in geopolymer concrete [21]. Nagajothi et al. studied the strength of geopolymer concrete using M-sand in oven dried conditions at 60°C [22]. Nagajothi and Elavenil developed an L9 orthogonal array by varying three levels and factors using the Taguchi method [23]. Rohith et al. examined the usage of metakaoline in fly ash based geopolymer concrete and replaced the copper slag in place of natural aggregate as a fine aggregate [24]. Saravanan et al. developed an L16 orthogonal array by varying five factors and four levels using the Taguchi method [25].

This research mainly focused on producing the geopolymer concrete using ground granulated blast furnace slag as a partial replacement for fly ash and manufactured sand for natural sand in ambient curing conditions. The ground granulated blast furnace slag was replaced with calcium fly ash which was activated by alkaline activator solutions. The setting time and workability of geopolymer concrete and mortar were examined.

2 Experimental program materials

Geopolymer concrete and mortar was produced from Class F fly ash [26] collected from a thermal power plant station, North Chennai and locally obtainable ground granulated blast furnace slag was used. The chemical composition for the collected fly ash and GGBFS are given in Table 1.

Table 1: Chemical composition for the collected fly ash and GGBFS.

Sample (%)	Fly ash	GGBFS
SiO_2	63.32	35.05
CaO	2.49	34.64
MgO	0.29	6.34

Al_2O_3	26.76	12.5
Na_2O	0.0004	0.9
K_2O	0.0002	0.6
Fe_2O_3	5.55	0.3
SO_4	0.36	0.38
LOI[a]	0.97	0.26

[a]Loss of ignition.

The alkaline activator solutions of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) were used in this research. A concentration of 8 M solution of NaOH (flakes) was prepared using tap water. Sodium silicate solution collected from the local market with the mass ratio of 2.0 was used. The fine aggregate of manufactured sand was used as a substitute material for natural sand for making the geopolymer mortar. The composition of M-sand is given in Table 2. Coarse aggregate with sizes of 20 mm, 12 mm and 8 mm, were used in saturated surface dry conditions for making geopolymer concrete. The material's physical properties are given in Table 3. For maintaining the workability of the concrete and mortar a geopolymer naphthalene based super plasticizer was used. This procedure was adopted for a small quantity of material. For a huge quantity of materials, maintaining the saturated surface dry (SSD) conditions is rather difficult. Hence, the moisture content of the aggregates was taken into account when preparing the alkaline liquid. To draw the grading curves and find the fineness modulus of fine aggregates, a sieve analysis was carried out. The sieve analysis graph is shown in Figure 1 and it reveals that fine aggregates are in zone II and are also given in Table 4.

Table 2: Parameters of manufactured sand.

Sample (%)	M-sand
CaO	6.00
SiO_2	63.86
MgO	0.7
SO_4	0.07
Cl	0.07
Al_2O_3	22.93
Fe_2O_3	4.25
Na_2O	0.00
K_2O	Nil
PH	8.74

Table 3: Materials physical properties.

Description	Flyash	GGBFS	CA[a]	NS[b]	MS[c]
Specific gravity	2.13	2.85	2.73	2.66	2.72
Fineness modulus	–	–	–	3.04	3.15
Water absorption	–	–	0.64	1.13	3.14

[a]Coarse aggregate, [b]natural sand, [c]manufactured sand.

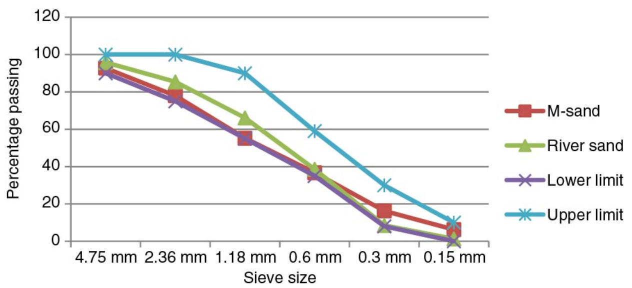

Figure 1: Sieve analysis of two sands.

Table 4: Sieve analysis of two sands.

Sieve size	Passing % of M-sand	Passing % of river sand
4.75 mm	92.75	95.8
2.36 mm	77.95	85.4
1.18 mm	55.2	66.1
0.6 mm	36.75	38.6
0.3 mm	16.25	8.5
0.15 mm	6.25	1.3

3 Mixer proportions of geopolymer concrete and mortar

The mixture proportions of geopolymer concrete and mortar were used to examine the effect of GGBFS, the effect of M-sand, the effect of alkaline liquids, the effect of proportions of sodium silicate to sodium hydroxide.

The mix design was adopted based on previous work and by many trails to achieve G30 geopolymer concrete [23].

In this research GGBFS is G, M-sand is M, alkaline solutions are A and the proportion of sodium silicate to sodium hydroxide is P. Based on the many trials tested, the unit weight of concrete was taken as 2400 kg/m^3. The GGBFS were replaced with fly ash for the overall binder content of 380 kg/m^3. For mix nos 1 (M0), 2 (M50) and 3 (M100), the M-sand was varied at 0%, 50% and 100% as a replacement for natural sand and the GGBFS was kept constant at 20%. Mix no 4 (G0) is fly ash only without the addition of any binder. Mix nos 5 (G10) and 6 (G30) are GGBFS replaced at 10% and 30%, respectively. For all the mix nos 4–6, the fine aggregate of M-sand is the full replacement of natural sand. For all the mixtures from 1 to 6, the alkaline activator solution and proportion of sodium silicate to sodium hydroxide were kept as constant at 45% and 2.5, respectively. For mixtures 7 and 8, the alkaline activator solutions were taken at 40% and 50% and for mix no 9 the proportion of sodium silicate to sodium hydroxide was 1.5. Mix no 10 was considered for the nominal mix of ordinary Portland cement concrete. Additional water was not added for all the mixes and only 1% of superplasticizer (Conplast SP 430,Astra Chemicals, Chennai, India) was added to get the workability of the geopolymer concrete.

The unit weight of the geopolymer mortar was kept at 2200 kg/m^3 [9]. In the fly ash based geopolymer mortar, the binder was taken as one third of the total mixture. The remaining parameters such as alkaline solutions, slag contents were considered as was used in the geopolymer concrete mixes. To compare with the M30 grade of concrete, 53 grades of ordinary Portland cement were used in this research. The mix combinations of the geopolymer concrete and mortar are given in Table 5.

Table 5: Details of mix proportions of geopolymer concrete and mortar (kg/m^3).

Mix no.	Designation	Concrete mixture quantity (kg/m^3)							Mortar mixture quantity (kg/m^3)					
		CA[a]	NS[b]	MS[c]	Fly ash	GGBFS	SS[d]	SH[e]	NS[b]	MS[c]	Fly ash	GGBFS	SS[d]	SH[e]
1	G20/M0/ A45/P2.5	1178	0	660	304	76	122	49	1141.5	0.0	584	146	234.6	93.9
2	G20/M50/ A45/P2.5	1178	330	330	304	76	122	49	570.8	570.8	584	146	234.6	93.9
3	G20/M100/ A45/P2.5	1178	0	660	304	76	122	49	0.0	1141.5	584	146	234.6	93.9
4	G0/M100/ A45/P2.5	1178	0	660	380	0	122	49	0.0	1141.5	730	0	234.6	93.9
5	G10/M100/ A45/P2.5	1178	0	660	342	38	122	49	0.0	1141.5	657	73	234.6	93.9
6	G30/M100/ A45/P2.5	1178	0	660	266	114	122	49	0.0	1141.5	511	219	234.6	93.9
7	G20/M100/ A40/P2.5	1178	0	660	315	79	113	45	0.0	1141.5	584	146	208.6	83.4
8	G20/M100/ A50/P2.5	1178	0	660	294	74	131	53	0.0	1141.5	584	146	260.7	104
9	G20/M100/ A45/P1.5	1178	0	660	304	76	103	69	0.0	1141.5	584	146	197.1	131

10	C/M100	1178	0	660	380 (cement)	171 (water)	0.0	1141.5	730 (cement)	328.5 (water)

G, % of GGBFS; M, % manufactured sand; A, % of alkaline activator solutions; P, proportions of SS to SH.
[a]Coarse aggregate, [b]natural sand, [c]manufactured sand, [d]sodium silicate, [e]sodium hydroxide.

4 Preparation of specimens

The activator solutions were prepared by mixing sodium silicate and sodium hydroxide solutions for half an hour before mixing the concrete or mortar. The aggregates in SSD conditions were dry mixed with the binders and the solutions were added in the mixes. The mixing was continual for 4–6 min for proper mixing. The geopolymer concrete was casted in the standard mold (150 mm × 150 mm × 150 mm size) and compacted on a vibrating table. In the same way, the geopolymer mortars were casted in the mold size (50 mm × 50 mm × 50 mm) and the specimens of concrete and mortar were demolded after 24 h and kept at an ambient temperature. Before being poured into the mold the slump values were observed by a slump cone and the setting times of the geopolymer concrete mortars were observed using a Vicat apparatus. The compressive strength of specimens was examined using a universal testing machine (UTM) machine at 7 days and 28 days for the geopolymer concrete and mortar for ambient curing and OPC concrete for water curing. The geopolymer concretes at the time of mixing and casting are shown in Figure 2.

Figure 2: Geopolymer concrete at the time of mixing and casting.

5 Results and discussion

To study the effects such as workability, setting time and compressive strength for geopolymer concrete and geopolymer mortar at ambient temperature, 10 mixtures were casted and there were compared with a conventional concrete and mortar.

5.1 Workability of concrete

To find the workability of concrete, a slump test is mainly used as it is a basic property. No additional water was added. Only a superplasticizer was added to get the required workability of the geopolymer concrete. Geopolymer concrete mixes with different slump values are represented graphically in Figure 3.

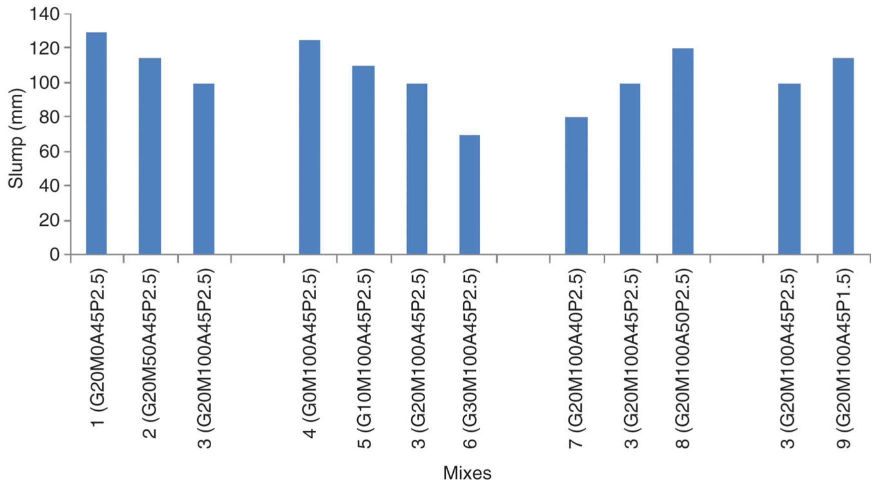

Figure 3: Comparison of slump for geopolymer concrete.

From Figure 3, mix no.1 which has 20% GGBFS and is completely made from natural sand (0% M-sand) shows a greater slump value when compared with mix nos 2 and 3 which have 20% GGBFS and 50% M-sand and 20% GGBFS and 100% M-sand, respectively. It also shows that when the percentage of M-sand increases in the replacement of natural sand the slump value decreases. To achieve the workability of the geopolymer concrete, a superplasticizer was added during the mixing of the concrete.

While comparing the mix numbers of 4 (G0M100), 5 (G10M100), 3 (G20M100) and 6 (G30M100), which have a GGBFS of 0%, 10%, 20% and 30%, respectively, and full replacement of M-sand with natural sand, the slump value of mix no 6 (G20M100) shows more workability than the other mixes. It reveals that the workability of the geopolymer concrete decreases when the GGBFS content is increased in the mixes. At the same time the workability of the geopolymer concrete increases only in the fly ash used without any percentage of GGBFS.

By varying the alkaline activator solutions to the binder ratio in the mixes of 7 (A40), 3 (A45) and 8 (A50), the slump value is more for the mix of 8 (A50) than the other two mixes. Poor workability of the geopolymer concrete was achieved when AAS to binder ratio decreased. For that it needs extra water and more superplasticizer. It shows that as the ratio of AAS to binder increases, the slump value also increases.

By lowering the proportions of sodium silicate to sodium hydroxide in the mix of 9 (P1.5) when compared with mix no 3 (P2.5), the slump value increases. It shows that when the ratio of sodium silicate to sodium hydroxide is decreased, the workability of geopolymer concrete is increased. Except for the first two mixes, the M-sand is fully replaced with the natural sand.

5.2 Effect of GGBFS

Mix numbers of 5 (G10M100), 3 (G20M100) and 6 (G30M100) were taken to examine the effect of GGBFS by replacing the percentage of GGBFS with the fly ash at 10%, 20% and 30% and the results were compared with the control mix of 4 (G0M100) geopolymer concrete which is a geopolymer concrete based on fly ash alone. Figure 4 shows the effect of GGBFS on setting time, and the development of compressive strength in geopolymer concrete and mortar.

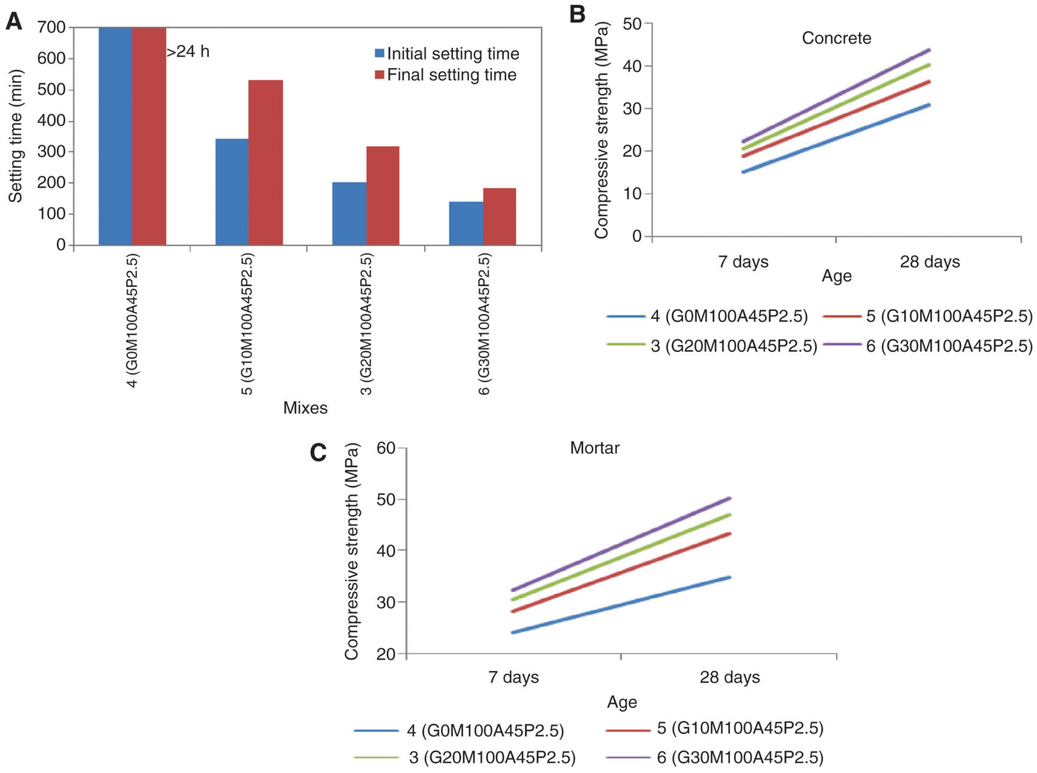

Figure 4: Effect of GGBFS on the setting time (A), compressive strength of geopolymer concrete and mortar (B) and (C).

Figure 4(A) gives a picture of the influence of GGBFS on the setting time of a geopolymer concrete and the experimental test were carried out under ambient curing conditions. It shows that the geopolymer pastes having fly ash alone take a long time to set under ambient curing temperatures. The mix no 4 (G0M100) which was designed with fly ash alone in the binder of geopolymer concrete takes more than 24 h to set. When increasing the percentage of GGBFS in the fly ash based geopolymer pastes, the initial and final setting time of the pastes are decreased.

The initial setting time is decreased from 205 min and 141 min for Mix no 3 (G20M100) and Mix no 6 (G30M100) when compared with mix no 5 (G10M100) which has 10% GGBFS and shows an initial setting time of 345 mins.

The difference between the initial setting time and final setting is reduced when the percentage of GGBFS is increased. The main role of GGBFS is to accelerate the setting time of the geopolymer concrete under ambient curing conditions.

The development of compressive strength for a geopolymer concrete is shown in Figure 4(B). By comparing the mixes of 4 (G0M100), 5 (G10M100), 3 (G20M100) and 6 (G30M100) the compressive strength of the geopolymer concrete increases when the percentage of GGBFS in the concrete mixes is increased. By 28 days, the compressive strength of geopolymer concrete having 10%, 20% and 30% of GGBFS in the binder shows higher strength around 17%, 31% and 41%, respectively, compared with a fly ash only based geopolymer concrete. A replacement of 10% of GGBFS by itself gives a better compressive strength than fly ash alone. Figure 4(C) shows the development of the compressive strength of a geopolymer mortar. It shows that the compressive strength of a geopolymer mortar is greater than the geopolymer concrete. By 28 days, the compressive of mortar increases about 23%, 34% and 43% in the replacement of GGBFS at 10%, 20% and 30%, respectively, compared with a fly ash only geopolymer mortar.

5.2 Effect of manufactured sand

Mix numbers of 1 (G20M0), 2 (G20M50) and 3 (G20M100) were taken to examine the effect of manufactured sand by replacing the percentage of M-sand with natural sand at 0%, 50% and 100%, in geopolymer concrete under ambient curing conditions and the results were compared. Figure 5 gives that the effect of M-sand on the setting time, and the development of compressive strength in the geopolymer concrete and mortar.

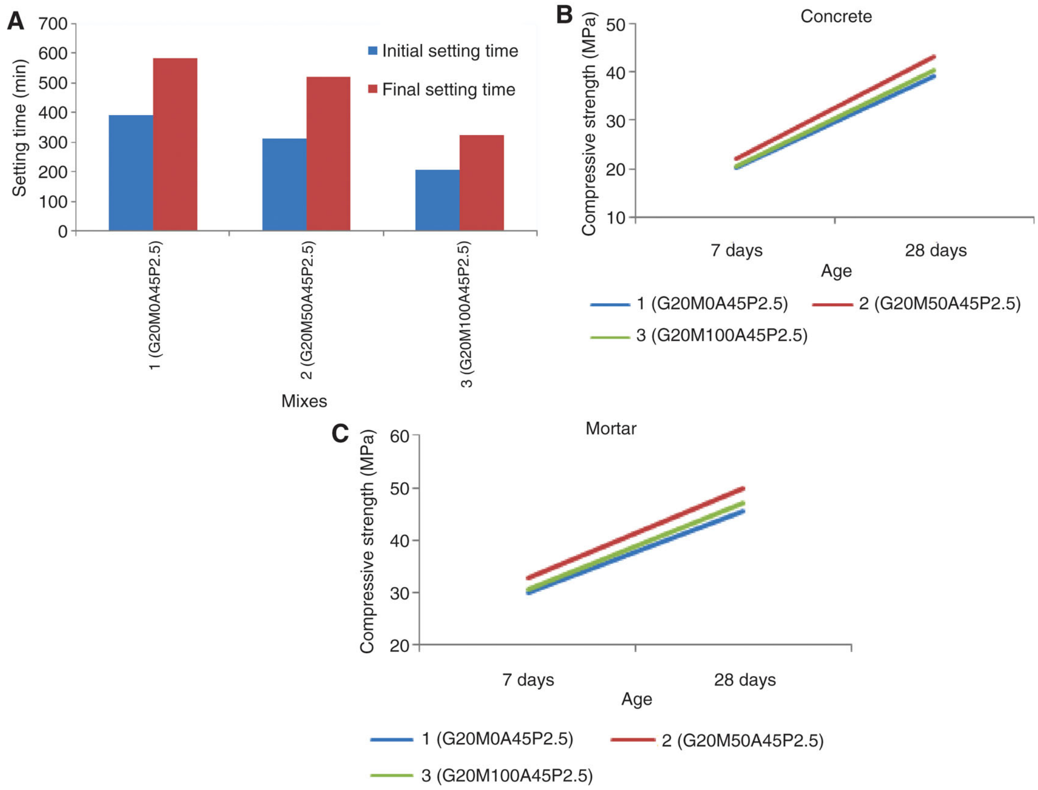

Figure 5: Effect of manufactured sand on the setting time (A), compressive strength of geopolymer concrete and mortar (B) and (C).

Figure 5(A) shows the influence of M-sand on the setting time of geopolymer concrete where the experimental test was carried out under ambient curing conditions. It shows that by increasing the percentage of M-sand in 20% GGBFS and in 80% fly ash based geopolymer pastes, the initial and final setting times of the pastes are decreased.

The initial setting time is decreased from 287 min and 205 min for mix no 2 (G20M50) and mix no 3 (G20M100) when compared with mix no 1 (G20M0) having 0% M-sand which shows an initial setting time of 310 min. The difference between the initial setting time and the final setting is reduced when the percentage of M-sand is increased.

The development of the compressive strength of geopolymer concrete is shown in Figure 5(B). By comparing the mixes of 1 (G20M0), 5 (G20M50) and 3 (G20M100), the compressive strength of the geopolymer concrete increases when the percentage of M-sand is increased up to 50% in the concrete mixes. At the same time after increasing the percentage of M-sand to 50% the compressive strength is slightly reduced. But compared with natural sand the full replacement of M-sand shows a higher strength than natural sand. The replacement of M-sand shows better compressive strength than natural sand.

Figure 5(C) explains the development of the compressive strength of a geopolymer mortar. It exposes that the compressive strength of geopolymer mortar is greater than the geopolymer concrete. The same trend was found for the geopolymer mortar as in the geopolymer concrete.

5.3 Effect of alkaline liquids

Mix numbers of 7 (A40), 3 (A45) and 8 (A50) were used to examine the effect of alkaline liquids by considering the percentage of alkaline liquid content at 40%, 45% and 50% in geopolymer concrete under ambient curing conditions and the results were compared. Figure 6 shows the effect of the alkaline liquid content on the setting time and the development of compressive strength in geopolymer concrete and mortar.

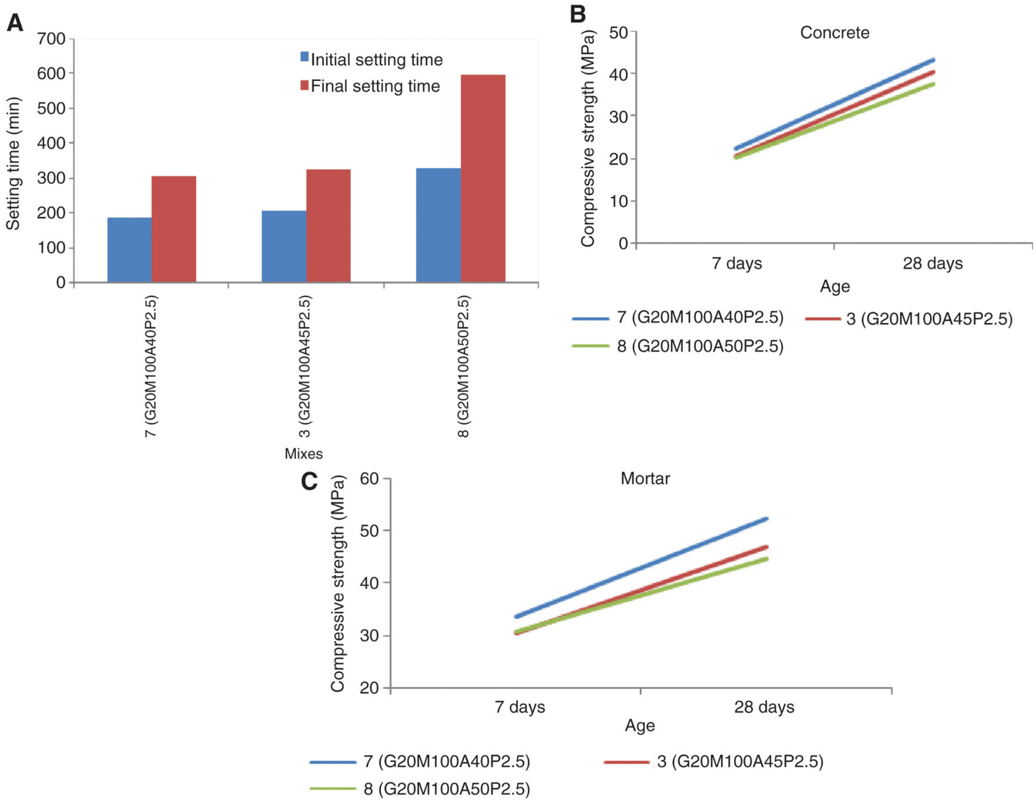

Figure 6: Effect of alkaline liquid on the setting time (A), compressive strength of geopolymer concrete and mortar (B) and (C).

Figure 6(A) gives an overview on the influence of alkaline liquid content on the setting time of geopolymer concrete and all the variables are constant (20% slag, 100%M-sand and SS/SH = 2.5) and the experimental test were carried out under ambient curing conditions. By comparing the mixes of 7 (A40), 3 (A45) and 8 (A50), 40% activator solution is stiffer than the other two mixes and 50% activator solution has a higher flow than the other two mixes. It shows that by increasing the percentage of alkaline liquid content by 20% GGBFS and the full replacement of M-sand based geopolymer pastes, the initial and final setting time of pastes are also increased. The times taken for the setting of geopolymer pastes are high when the percentage of alkaline liquids is increased.

The initial setting time is increased by 205 min and 328 min for mix no 3 (A45) and mix no 8 (A50) when compared with mix no 7 (A40) which has an initial setting time of 188 min . The difference between the initial setting time and final setting is reduced when the percentage of the alkaline liquid content is increased.

The development of the compressive strength of geopolymer concrete is shown in Figure 6(B). By comparing the mixes of 7(A40), 3(A45) and 8(A50), the compressive strength of geopolymer concrete decreases when the percentage of alkaline liquid content in the concrete mixes is increased. By 28 days, the compressive strength of the geopolymer concrete with 45% and 50% alkaline liquid content shows decreased strength of around 7% and 14% compared with the 40% alkaline liquid content of the geopolymer concrete.

Figure 5(C) explains the development of the compressive strength of geopolymer mortar. It exposes that the compressive strength of the geopolymer mortar is greater than the geopolymer concrete. By 28 days, the compressive strength of geopolymer mortar with 45% and 50% alkaline liquid content shows decreased strength around 11% and 17% compared with the 40% alkaline liquid content of the geopolymer mortar.

5.4 Effect of proportions of sodium silicate to sodium hydroxide

Mix numbers of 3 (P2.5) and 9 (P1.5) were used to examine the effect of SS to SH by considering the proportions by 2.5 and 1.5 ratio in geopolymer concrete under ambient curing conditions and the results were compared. Figure 7 provides the proportions of SS to SH on the setting time and the development of compressive strength in geopolymer concrete and mortar.

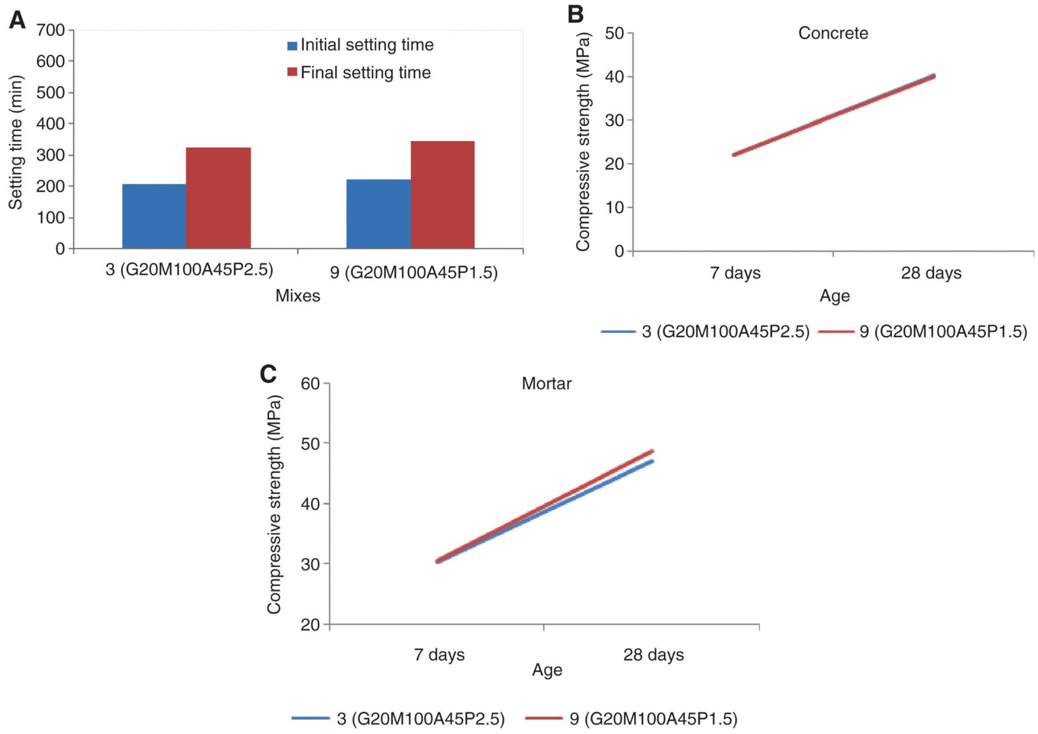

Figure 7: Effect of proportions of SS/SH on the setting time (A), compressive strength of geopolymer concrete and mortar (B) and (C).

Figure 7(A) demonstrates the influence of SS to SH on the setting time of geopolymer concrete and all the variables are constant (20% slag, 100% M-sand and 45% A) and the experimental test were carried out under ambient curing conditions. When increasing the proportions of SS/SH, the setting time is in a decreasing trend. Mix no 9 (P-1.5) took more time to set as compared with mix no 3 (P-2.5).

The development of the compressive strength of geopolymer concrete is shown in Figure 7(B). By comparing the mixes of 3 (P2.5) and 9 (P1.5), the compressive strength of geopolymer concrete is nearly equal in both the concrete mixes. The proportions of SS to SH does not give a greater effect in the concrete mixes. Figure 7(C) explains the development of the compressive strength of geopolymer mortar. It shows that the compressive strength of the geopolymer mortar is greater than the geopolymer concrete. When increasing the proportions of SS/SH, the compressive strength of geopolymer mortar slightly decreases over 28 days.

6 Conclusion

Nine mixtures of geopolymer concrete were considered with fly ash and GGBFS as the binder source materials and the replacement of natural sand with M-sand as the fine aggregates.One ordinary Portland cement concrete mixtures were considered using M-sand as the fine aggregates. The effect of varying the percentage of GGBFS, M-sand, alkaline liquid content, the proportions of SS to SH on geopolymer concrete and mortar are discussed.

The following conclusions were made from the experimental works.

- In fly ash based geopolymer concrete, while varying the percentage of GGBFS from 10% to 30%, the workability of geopolymer concrete decreases and the compressive strength values of geopolymer concrete and mortar increases.
- Manufactured sand increases by 0%, 50% and 100%, the workability of geopolymer concrete decreases and the compressive strength of both concrete and mortar is high when 50% replacement and slightly high when 100% replacement compared with natural sand. Hence, manufactured sand is an alternative material for natural sand.
- When increasing the percentage of alkaline activator solution, the workability of geopolymer concrete increases and compressive strength of geopolymer concrete and mortar are decrease in trend.
- The Slump of geopolymer concrete is high when the proportion of SS to SH is reduced in the geopolymer concrete. There is no effect on the compressive strength of geopolymer concrete due to proportions of SS/SH.

But in geopolymer mortar, the compressive strength decreases slightly when the proportions of SS/SH is reduced.

- Based on the results it is concluded that the materials of fly ash, GGBFS and manufactured sand are substitute materials for cement and fine aggregates.

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