

## A User Friendly Geopolymer Concrete Mix Design Procedure

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### Abstract:

Cast-in-situ concrete is one of the preferred types of concrete construction, which is poured into the moulds to cast concrete of desired shape. India being one of the populous countries of the world, most of the cast-in-situ concrete is handled by semi-skilled labors on the site. Thus, safety of the worker is one of the prime concerns. However, most of the mix design methodology proposed for making geopolymer concrete heavily rely on the use of highly concentrated sodium hydroxide for obtaining desired strength, which is unsafe to handle. Therefore, a user-friendly mix design methodology to produce geopolymer concrete using sodium silicate (SS) as alkali reagent and ground granulated blast furnace slag (GGBS) as the binder solid is proposed. The proposed mix design methodology also evaluates the correlation between the SS/GGBS ratio and the 28 day compressive strength for developing a rational mix design. Mix design for SS/GGBS ratios of 0.35 to 0.65 is proposed in the present paper. It was found that a strength in the range of 40 to 66 N/mm<sup>2</sup> can be produced at the end of 28 days curing period. An example explaining the step wise process of the mix design methodology has been given in this paper.

**Keywords:** Geopolymer concrete, User friendly, Ambient temperature, Cast-in-situ concrete, Ground granulated blast furnace slag, Geopolymer

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### 1. Introduction

For decades, ordinary Portland cement (OPC) has been used for the construction of building and infrastructures. However, amid the growing concern about global warming and climate change, OPC production is being seen as one of the major sources of CO<sub>2</sub> emission. This is due to the fact that each ton of OPC production emits about 0.8 tons of CO<sub>2</sub> into the atmosphere. Further, according to Chan et al., (2015), Therefore, geopolymer is being considered to replace OPC as the primary binder, which according to Davidovits, (1998) emits 90% lesser CO<sub>2</sub> than OPC. Owing to the environment friendly nature of geopolymer, the development of geopolymer based concrete has been on the fore-front of many research communities. In this effort, waste like fly ash (Mallikarjuna Rao and Gunneswara Rao, 2015), glass powder (Singh et al., 2021), steel slag (Guo and Pan, 2019; Zhu et al., 2021), copper slag (Arunachalam et al., 2022), rice husk ash (Detphan and Chindapasirt, 2009), silica fume (Bajpai et al., 2020; Priya and Rao, 2019) and so on have in used for the production of geopolymer.

However, cast-in-situ concrete requires strengths of as low as 25 MPa and as high as 50 MPa and more for structural application. Thus, a mix design methodology must be established to enable the user to

customize the mix design of the concrete as per his target strength of concrete. Earlier, most of the methods were based on trial-and-error basis. Lloyd and Rangan, (2010) proposed fly ash (FA) based methodology for the production of geopolymer concrete and established that the FA based geopolymer requires to be cured at a temperature of 60°C for strength gain. Further, FA based geopolymer concrete mix design methodology developed by Anuradha et al., (2012) and Ferdous et al., (2013) suggest that sodium hydroxide and sodium silicate mixed in the ratio of 2.5 yield better results, however, reaffirm that heat curing for at least 24 hours is needed for geopolymer to gain strength. Similar mix design developed by Pavithra et al., (2016) also established that oven curing at 60°C is need in order to develop strength. However, it suggested that the sodium hydroxide to sodium silicate ratio of 1.5 should be maintained. Above literatures also suggest that a sodium hydroxide concentration of 14 to 16M is needed for effective geopolymerisation of FA and strength development. Although, the above literature developed a mix design methodology for obtaining concrete of desired target strength, it requires to be cured at 60°C for at least 24 hours. As FA mostly consist of crystalline phases, it must be cured at an elevated temperature of 40 to 85°C for accelerating the reaction (Puertas et al., 2000). Thus, limits the application to pre-cast concrete construction. Since most of the cast-in-situ concreting is done in ambient temperature and humidity condition and is either cured by ponding or spraying water on the concrete. Considering, this as the drawback, Reddy et al., (2018) proposed a mix design methodology considering FA and ground granulated blast furnace slag (GGBS) binary blend using 16 molar (M) NaOH and sodium silicate solution for the production of ambient cured geopolymer concrete. Although, it established a mix design methodology for ambient cured geopolymer concrete, it still suggests the use of highly concentrated sodium hydroxide solution for its production. On the other hand, use of chemicals like sodium hydroxide, potassium hydroxide, sodium metasilicate ( $\text{SiO}_2:\text{Na}_2\text{O}=1$ ) or any other soluble silicate having  $\text{SiO}_2:\text{M}_2\text{O} < 1.45$  are categorized as user hostile (Davidovits, 2015). Thus, can cause sever burn injuries and are unsafe to handle. Further, most of the developed mix design methodology uses FA as the primary binder solid. However, as per the latest data released by the (Ministry of Power, 2022), 100% of FA produced during power generation is being utilized by most of the thermal power plants in India.

GGBS is another byproduct of steel industry, which is generated in abundance. In terms of steel production, India is ranked second after China and is soon expected to take second position in steel consumption as well. As a result, it generates about 15 million tons of GGBS annually (Singh et al., 2008). However, mere 20 to 30% of GGBS is utilized, rest is stored in large disposal areas. It is also known to contain high amounts of amorphous  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{CaO}$  (Aydin and Baradan, 2014; Imbabi et al., 2012) and hence is easier to activate (Phoo-Ngernkham et al., 2015). It also suggests that a 28-day compressive strength of as high as 173.0 MPa can be achieved by using sodium silicate as the alkali reagent in comparison to 171.7 MPa compressive strength of the GGBS geopolymer paste made with sodium hydroxide and sodium silicate solution (Phoo-Ngernkham et al., 2015). Further, NaOH of concentration 8 to 12 M are often used for Thus, GGBS treated with sodium silicate has the potential to be used as the binder for concrete. Therefore, there is need for mix design methodology which makes use of other industrial wastes such as ground granulated blast furnace slag (GGBS).

Therefore, a mix design methodology is proposed in this paper to achieve desired strength and workability. As most of the earlier proposed mix design methodology rely on the use of highly

concentrated NaOH solution and heat curing for strength gain, the present mix design methodology proposes a user-friendly method of geopolymer concrete production using sodium silicate as alkali reagent and without the use of heat curing. Further, no standard method of mix designing is available for designing GGBS based geopolymer concrete. Therefore, an attempt has been made to develop a mix design methodology for GGBS based geopolymer concrete.

## 2. Mix design methodology

A rational method of mix designing a user friendly geopolymer concrete using GGBS as the binder solid and SS as the alkaline solution is proposed in this paper. Since, SS is one of the costliest materials required for the production of geopolymer concrete, the SS content is fixed in order to keep the cost of geopolymer concrete in check. The proposed mix design methodology also takes into consideration the specific gravity of the materials and the total quantity of the ingredients was determined using absolute volume method. Further, additional water in specified quantity was used for maintaining adequate workability of the concrete. Fig. 1 shows the step wise process of developing the mix design and is described in the following paragraphs.

In case of conventional concrete, water is used as the reagent to react with Portland cement to form calcium silicate hydrate gel. The required water content is fixed based on the nominal maximum size of the aggregate as per Table 2 of IS 10262, (2019). Similarly, the maximum SS content ( $SS_C$ ) required for geopolymer concrete can be fixed.

Table 1 Maximum water content based on the nominal maximum size of aggregate size (IS 10262, 2019)

Sr. No.	Nominal maximum size of aggregate (mm)	Water content (kg)
1	10	208
2	20	186
3	40	165

As per (IS 10262, 2019), strength is dependent on the water to cement ratio of the mixture, which can be chosen based on the water to cement ratio versus 28 days compressive strength curve as per Indian Standard method. The Indian standard curve shown in Fig. 2 can be adopted to choose the SS to GGBS ratio corresponding compressive strength at the end of 28 days curing period. Thus, a minimum compressive strength to be achieved after 28 days curing can be fixed corresponding to the chosen SS to GGBS ratio based on curve shown in Fig. 2.

Based on the chosen SS/GGBS ratio and the quantity of SS fixed in the earlier steps, the quantity of GGBS (i.e the binder solid) is computed using Eq. 1.

$$Q_{GGBS} = \frac{SS_C}{\overline{GGBS}} \tag{1}$$

Where,  $Q_{GGBS}$  is the quantity of GGBS and  $SS_C$  is the quantity of SS base on the nominal maximum size of the aggregate (20 mm in the present case). Sodium silicate used in this experiment is highly viscous and hence is difficult to achieve a workable concrete. Based on several trials, it was found that

the addition of about 0.14% of water in the concrete mixture resulted in a workable concrete. Therefore, water equal to 0.14% of the total  $SS_C$  is added during mixing to achieve desired workability. Further, according to Heah et al., (2012), water to binder solid ratio plays a vital role in the geopolymer concrete. Therefore, the water content in the geopolymer mix with having  $W_{SS}$  as the mass of solids is calculated using Eq. 2 as follows.

$$\text{Water content} = \text{Mass of water in SS} + \text{Mass of Water added} \quad (2)$$

$$\therefore \text{Water content} = SS_C - (W_{SS} \times SS_C) + \left(\frac{0.14}{100} \times SS_C\right) \quad (3)$$

$$\therefore \text{Water content} = SS_C \times \left(1 - W_{SS} + \frac{0.14}{100}\right) \quad (4)$$

$$\text{Water content} = SS_C \times (0.9986 - W_{SS}) \quad (5)$$

$$\therefore \text{Water content} = SS_C \times (1 - W_{SS}) \quad (6)$$

To determine the total quantity of aggregate, absolute volume method was adopted. The total volume of aggregate included the fine aggregate (FA) and the coarse aggregate (CA) and was calculated using Eq. 7. The volume of geopolymer concrete ( $V_{GPC}$ ) was assumed to be  $1 \text{ m}^3$ .

$$V_{GPC} = V_{FACA} + V_{GGBS} + V_{SS} + V_a \quad (7)$$

Where,  $V_{FACA}$  is the total volume of FA and CA,  $V_{GGBS}$  is the volume of GGBS (binder solid),  $V_{SS}$  is the volume of sodium silicate and  $V_a$  is the volume of air in the geopolymer concrete. The values of  $V_{GGBS}$ , and  $V_{SS}$  is computed using Eq. 8 and 9, respectively as given below.

$$V_{GGBS} = \frac{Q_{GGBS}}{G_{GGBS}} \times \frac{1}{1000} \quad (8)$$

$$V_{SS} = \frac{Q_{SS}}{G_{SS}} \times \frac{1}{1000} \quad (9)$$

Where,  $Q_{GGBS}$  is the quantity of GGBS,  $G_{GGBS}$  is the specific gravity of GGBS,  $Q_{SS}$  is the quantity of sodium silicate and  $G_{SS}$  is the specific gravity of SS. The volume of air ( $V_a$ ) is assumed to be 1% of the  $V_{GPC}$ . Therefore, the Eq. 2 for  $V_{GPC}$  can be rewritten as Eqn. (5)

$$0.99 = V_{FACA} + \left[ \left( \frac{Q_{GGBS}}{G_{GGBS}} + \frac{Q_{SS}}{G_{SS}} \right) \times \frac{1}{1000} \right] \quad (10)$$

Therefore,

$$V_{FACA} = 0.99 - \left[ \left( \frac{Q_{GGBS}}{G_{GGBS}} + \frac{Q_{SS}}{G_{SS}} \right) \times \frac{1}{1000} \right] \quad (11)$$

The quantity of FA and CA is then determined as per IS 10262 (2019). The quantity of CA and FA was assumed as  $Q_{CA}$  and  $Q_{FA}$ . The proportion of CA and FA in the proposed mix design is assumed as  $x_{CA}\%$  and  $y_{FA}\%$  respectively. The quantity of CA and FA is then computed using Eq. 7 and 8 as given below.

$$Q_{CA} = x_{CA}\% \times V_{FACA} \times G_{CA} \times 1000 \quad (12)$$

$$Q_{FA} = y_{FA}\% \times V_{FACA} \times G_{FA} \times 1000 \quad (13)$$

Where,  $G_{CA}$  and  $G_{FA}$  are the specific gravity of CA and FA, respectively.

After obtaining the quantities of GGBS, SS, FA and CA using the above methodology, concrete cubes of 150×150×150 mm were casted, cured in air at the ambient temperature and tested at the end of 28 days air curing. If the strength obtained at the end of 28 days satisfies the requires strength as per design curve of IS 10262, (2019), the mix design can be adopted or else the design should be changed by changing the parameters controlling the strength of SGC.

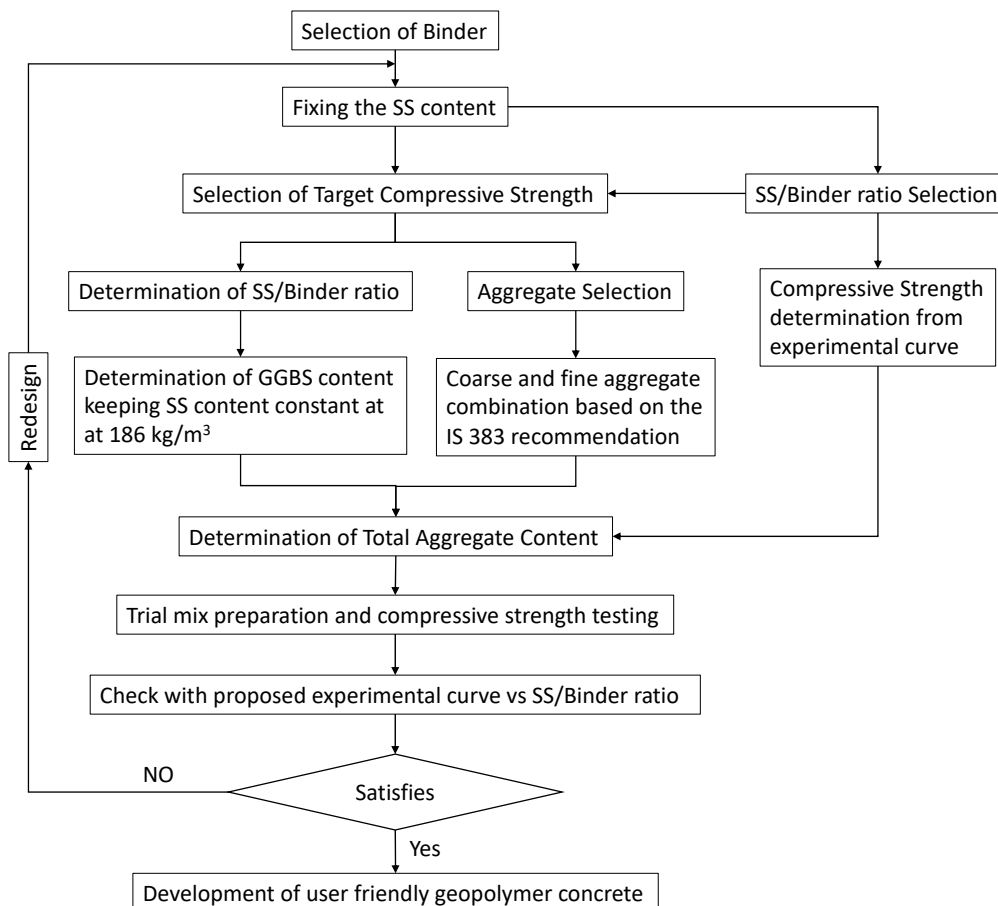


Fig. 1 Flow chart for the proposed GGBS based geopolymer concrete.

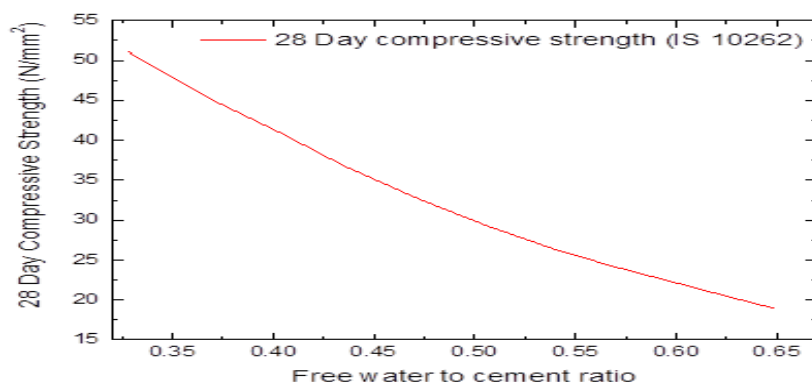


Fig. 2 Water to cement ratio vs 28-day compressive strength curve as per IS 10262, (2019)

### 3. Experimental investigation and validation of proposed mix design methodology

In a concrete mix design, the bulk of the concrete is made up of coarse aggregate (CA) and fine aggregate (FA) which are bound by the binder phase. In case of OPC base concrete, OPC on reaction with water forms calcium silicate hydrate gel (C-S-H) which binds the CA and FA together to form concrete. It is also a well-established fact that the ratio of water to cement in concrete plays an important role in strength development. In fact, lower water cement ratios are often associated with higher compressive strength and vice versa. Therefore, similar approach was adopted to geopolymer concrete. However, in case of geopolymer an aluminosilicate material reacts with alkali reagent to form geopolymeric binder.

For the purpose of developing mix design methodology, ground granulated blast furnace slag (GGBFS) purchased from the local vendor is used as the sole binder solid. The chemical composition of GGBFS determined using X-ray fluorescence is presented in Table 2. It shows that SiO<sub>2</sub>, CaO, Al<sub>2</sub>O<sub>3</sub> and MgO make up 96.5% of the GGBFS, with SiO<sub>2</sub> and CaO being the most dominant oxides. Further, sodium silicate with a modulus of 1.5 consisting of about 31.25% SiO<sub>2</sub>, 12.57% Na<sub>2</sub>O and 56.18% water is used as the alkali reagent for making the binder. Although, binder is responsible binding and strength development, the coarse aggregate (CA) and fine aggregate (FA) make up the bulk of the material. Therefore, natural aggregate of nominal 20 mm size and river sand was procured from the local vendor. The particle size distribution of the CA and FA is shown in Fig. 3 (a) and (b) along with the recommended upper and lower gradation limits for CA and FA as per IS 383, (2016). The specific gravity of GGBFS, CA and FA as determined according to IS 2386- Part III, (1963) was 2.93, 2.69 and 2.63, respectively. The water absorption values of CA and FA was found to be 1.7% and 2.65% and is determined as per IS 2386- Part III, (1963). Further, Fig. 4 shows the X-ray diffraction of GGBFS. It shows that the GGBS is amorphous in nature which is indicated by a large hump between 2θ position of 20° to 40°.

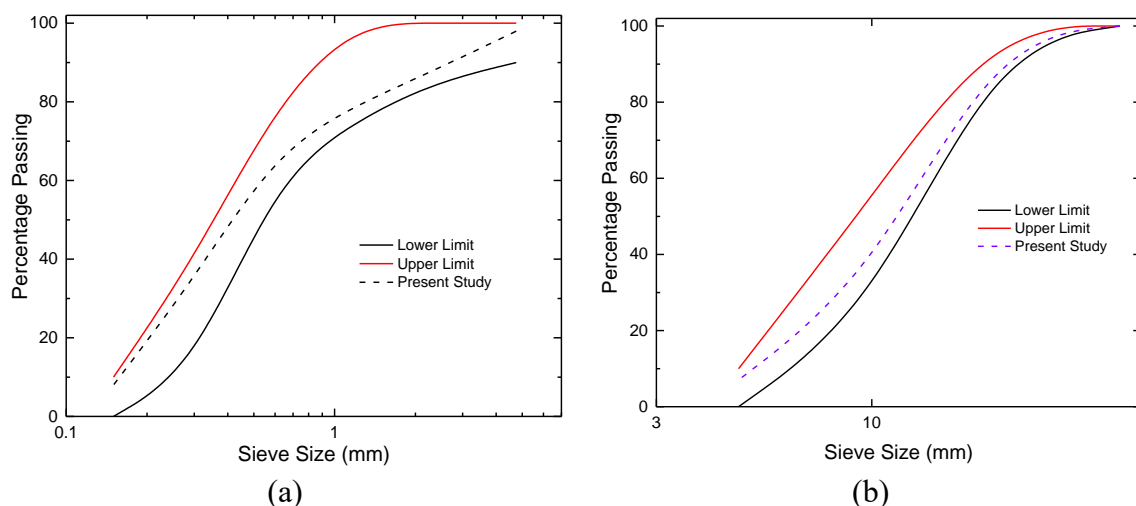


Fig. 3 Particle size distribution of (a) fine and (b) coarse aggregate

Table 2 Chemical composition of GGBFS

Oxide	SiO <sub>2</sub>	CaO	Al <sub>2</sub> O <sub>3</sub>	MgO	Fe <sub>2</sub> O <sub>3</sub>	Others
Weight percentage (%)	35.40	34.33	16.82	9.95	0.35	0.38

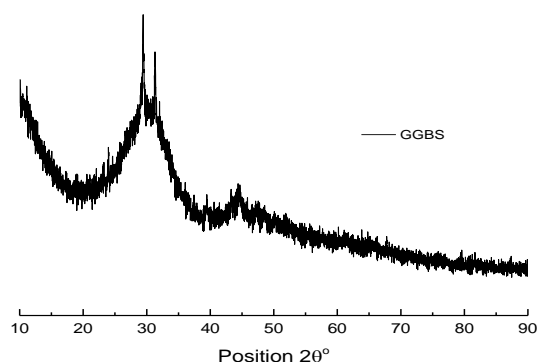


Fig. 4 X-ray diffraction of GGBS

The proposed mix design was validated by conducting an experimental work. The geopolymer concrete specimens were prepared by considering SS/GGBS ratio of 0.35, 0.40, 0.45, 0.50, 0.55, 0.60 and 0.65. Based on various SS/GGBS ratios the proportions of CA, FA, GGBS were computed as shown in Table 3. It shows that depending upon the ratio of SS/GGBS ratio, the quantity of CA and FA increases with increase in the SS/GGBS ratio. However, the quantity of GGBS decreases with increasing SS/GGBS. The properties of SS, GGBS, FA, and CA are as described in the above. The mix design process is described with an example below.

Table 3 Composition of ingredients to produce geopolymer concrete.

Mix	CA (kg/m <sup>3</sup> )	FA (kg/m <sup>3</sup> )	GGBS (kg/m <sup>3</sup> )	SS (kg/m <sup>3</sup> )	SS/GGBS ratio
M1	1261.27	528.49	531.43	186.00	0.35
M2	1303.96	546.38	465.00	186.00	0.40
M3	1337.16	560.29	413.33	186.00	0.45
M4	1363.73	571.42	372.00	186.00	0.50
M5	1385.46	580.53	338.18	186.00	0.55
M6	1403.57	588.11	310.00	186.00	0.60
M7	1418.90	594.54	286.15	186.00	0.65

A sample design for a SGC considering a SS/GGBS ratio of 0.4 is presented as an example to verify the process of mix design. In order to verify the mix design, three cubes of 150×150×150 mm were prepared for determining the compressive strength at 14 and 28 days. A concrete pan mixer was employed for the preparation of mix for the geopolymer concrete. The mix for geopolymer concrete was prepared by first mixing SS and GGBS till obtaining a homogeneous mixture. The CA is then gradually poured into the SS and GGBS mix and mixed for about three minutes. FA was then added to the mixture and further mixed for three more minutes. During mixing FA with the mixture of CA, SS and GGBS, water equal to 0.14% of the total SS content was added. The workability of the prepared mix is then measured using slump cone method as per IS 1199, (1959). Fig. 5 (a) shows the slump cone test for SGC prepared with SS to binder solid ratio of 0.35. The concrete cubes were then cast and covered immediately with thin plastic sheet for 24 hours at room temperature. The concrete cubes were then demolded after 24 hours (as shown in Fig 5 (b)) and then kept in air for 14 and 28 days curing period. The compressive strength of the SGC was then determined as per IS 516, (1959). The

average of three specimen is considered as the compressive strength. An example showing mix design procedure is describe below.



Fig. 5 Images showing (a) Slump cone test for SGC prepared with SS/GGBS = 0.35 and (b) SGC demolded cubes after 24 hours

Laboratory trials were carried out to check whether  $SS_C$  of  $186 \text{ kg/m}^3$  was sufficient to obtain workable and strong SGC. It was observed that adding 0.14% of  $SS_C$  content was sufficient to obtain a workable concrete. Therefore, SS content of  $186 \text{ kg/m}^3$  along with 0.14% water was used to produce geopolymer concrete.

As per Fig. 4, the 28 day compressive strength of 41 MPa needs to be achieved by a concrete with SS/GGBS ratio of 0.4. Therefore, as per Eq. 1, the quantity of GGBS is as follows.

$$Q_{GGBS} = \frac{186}{0.4} = 465 \text{ kg/m}^3$$

Further, the water content in the SS is computed using Eq. 6, where the  $W_{SS}$  is taken as 43.82%.

$$\begin{aligned} \text{Water content in SS} &= SS_C \times (1 - W_{SS}) \\ &= 186 \times (1 - 0.4382) \\ &= 104.49 \text{ kg/m}^3 \end{aligned}$$

The above calculation shows that the water content in  $186 \text{ kg/m}^3$  of solution is  $104.49 \text{ kg/m}^3$  including 0.14% of  $SS_C$ .

The total volume of aggregate ( $V_{FACA}$ ) to produce geopolymer concrete is computed using Eq. 11.

$$\begin{aligned} V_{FACA} &= 0.99 - \left[ \left( \frac{Q_{GGBS}}{G_{GGBS}} + \frac{Q_{SS}}{G_{SS}} \right) \times \frac{1}{1000} \right] \\ &= 0.99 - \left[ \left( \frac{465}{2.93} + \frac{186}{1.34} \right) \times \frac{1}{1000} \right] \\ &= 0.692 \text{ m}^3 \end{aligned}$$

The total quantity of coarse and fine aggregate are computed using Eq. 12 and 13, respectively. As the quantity of CA ranges between 65 to 80%, the quantity of CA and FA in the present investigation is considered as 70 ( $x_{CA}\%$ ) and 30% ( $y_{FA}\%$ ), respectively. Therefore, quantity of CA and FA is computed using Eq. 12 and 13.

$$\begin{aligned}
 Q_{CA} &= x_{CA}\% \times V_{FACA} \times G_{CA} \times 1000 \\
 &= 0.7 \times 0.692 \times 2.69 \times 1000 \\
 &= 1303.96 \text{ kg/m}^3
 \end{aligned}$$

$$\begin{aligned}
 Q_{FA} &= y_{CA}\% \times V_{FACA} \times G_{CA} \times 1000 \\
 &= 0.3 \times 0.692 \times 2.63 \times 1000 \\
 &= 546.38 \text{ kg/m}^3
 \end{aligned}$$

After obtaining the quantities of SS, GGBS, FA and CA, cubes were tested after a period of 28 days. At the end of 28 days curing period, the strength of slag based geopolymer concrete was found to be 59 MPa. Thus, the mix obtained a strength higher than the strength of 41 MPa required as per Fig. 4. Thus, it validates the proposed mix design process.

#### 4. Results and discussion

Compressive strength test at 14 and 28 days and slump test of fresh geopolymer concrete were conducted on different SGC with SS/GGBS varying from 0.35 to 0.65 and is shown in Table 4. The result of the slump test shows that the slump increased with increase in the SS/GGBS ratio, which is similar to the slump values of conventional concrete obtained at increasing free water to cement ratio. Table 4 also shows that the strength of geopolymer concrete at various SS/GGBS ratio is much higher than the strength of conventional concrete at different water to cement ratios (Fig. 2).

It is also evident that the SS to GGBS ratio versus strength curve do not fit free water to cement ratio versus strength curve of Indian standard code. A plot (Fig. 6) between the SS/GGBS ratio versus 28-day compressive strength is plotted along with water to cement ratio versus 28 day compressive strength curve of conventional concrete for comparing the strength obtained. Where, the SS/GGBS ratio is considered equivalent to the free water to cement ratio of the conventional concrete. The strength of SGC is found to decrease with increase in the SS/GGBS ratio which is similar to the conventional concrete. Thus, the strength obtained by considering various SS/GGBS ratio is found to be following a trend similar to the conventional concrete. However, the strength of SGC is much higher as compared to the conventional concrete.

Table 4 also show the strength of SGC at 14 days air curing period. A comparison of 14 day compressive strength of SGC and 28 day compressive strength of conventional concrete is shown in Fig. 7. While the dotted line shows the desired 28 day compressive strength of conventional concrete, the vertical bars show the average strength of 14 day cured SGC. It shows that the strength of SGC prepared as various SS/GGBS ratios easily surpasses the compressive strength requirement of conventional concrete prepared at various free water to cement ratio.

Mix design curve for FA and FA-GGBS blend geopolymer concrete using NaOH and Na<sub>2</sub>SiO<sub>3</sub> as the alkali activator at alkali activator to binder ratios of 0.4, 0.5, 0.6, 0.7 and 0.8, has also been proposed by Pavithra et al., (2016) and Reddy et al., (2018), respectively. While, FA based geopolymer concrete was subjected to heat curing at a temperature of 60°C for 28 days, FA-GGBS based geopolymer was cured at ambient temperature. Fig. 8 show a comparison between the proposed SGC mix design curve along with the design curve proposed by Pavithra et al., (2016) and Reddy et al., (2018). It shows that

the 28 day strength of ambient temperature cured SGC is lower than the heat cured FA based geopolymer. However, the strength of SGC at all SS/GGBS ratio is higher than the ambient temperature cured FA-GGBS based geopolymer. Therefore, the proposed design curve for SGC can be used for the structural concrete applications.

The compressive strength of SGC is found to depend on the ratio of SS/GGBS and on the quantity of CA and FA. Higher SS/GGBS ratio and CA, FA content leads to lower strength, which can be attributed to the creation of larger voids due to the inclusion of large quantity of FA and CA. Further, at higher SS/GGBS ratios the quantity of GGBS reduces significantly, thus the quantity of geopolymer paste binding the FA and CA also reduces. Geopolymer paste were also analyzed using scanning electron microscope as shown in Fig. 9 (a) to (f). It shows a smooth texture throughout the paste sample without any unreacted GGBS.

The excellent strength of SGC obtained from the compressive tests show that the SGC can be used for most of the structural applications. Further, most of the design mixes prepared at SS/GGBS ratio of 0.35, 0.40, 0.45, 0.50, 0.55, 0.60 and 0.65 surpassed the strength requirement of the Indian standards design curve. The proposed mix design curve was used for obtaining SGC of strength varying between 40 to 66 N/mm<sup>2</sup>. The SGC design curve is in line with the design curve proposed by other authors for structural concrete. Thus, the proposed mix design curve can be used for designing slag-based user friendly geopolymer concrete of desired strength.

Table 4 The fresh and hardened properties of SGC

Mix	M1	M2	M3	M4	M5	M6	M7
SS/GGBS ratio	0.35	0.40	0.45	0.50	0.55	0.60	0.65
Compressive Strength (MPa)	59.07	53.10	47.30	42.15	40.80	39.15	35.70
	65.63	59.00	52.46	46.83	45.38	43.49	40.86
Slump (mm)	100	110	113	125	140	150	190

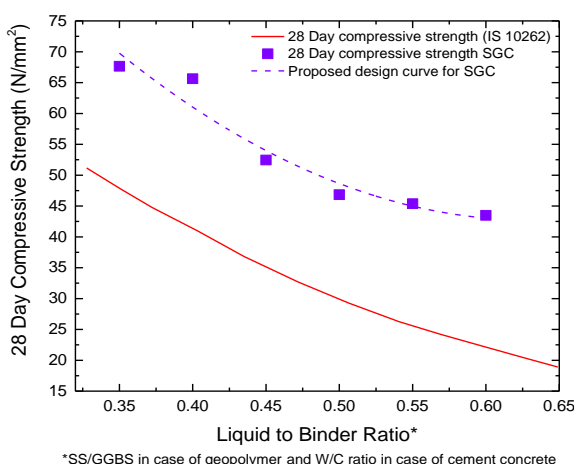


Fig. 6 Comparison of 28 day compressive strength of SGC with IS 10262, (2019) mix design curve

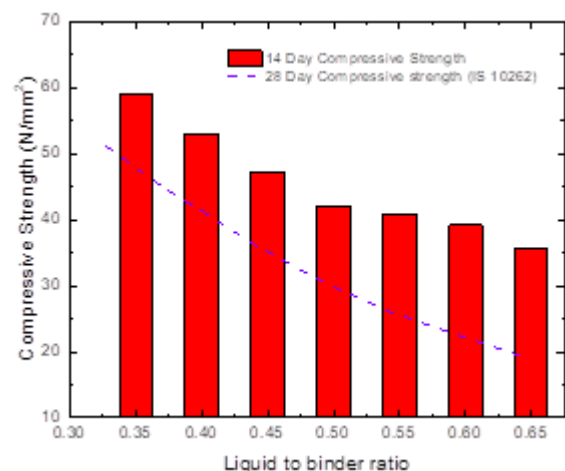


Fig. 7 Comparison of compressive strength of 14 day cured SGC and 28 day strength as per IS

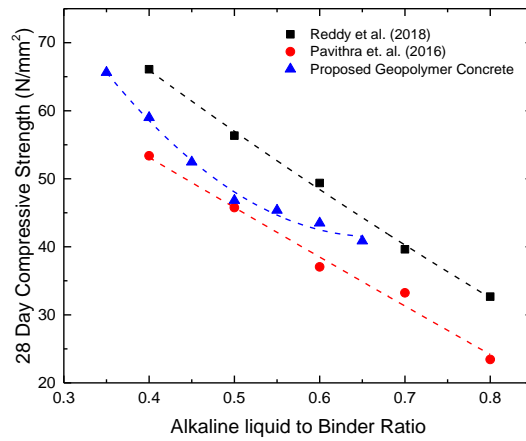
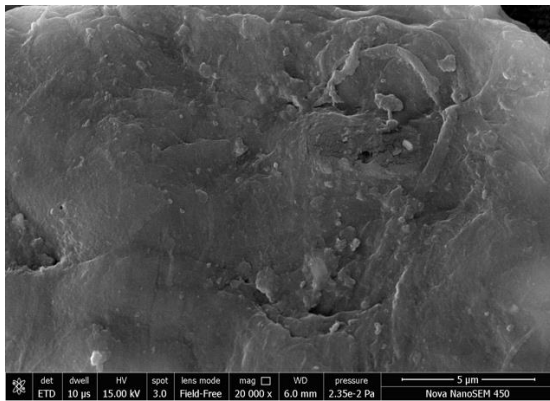
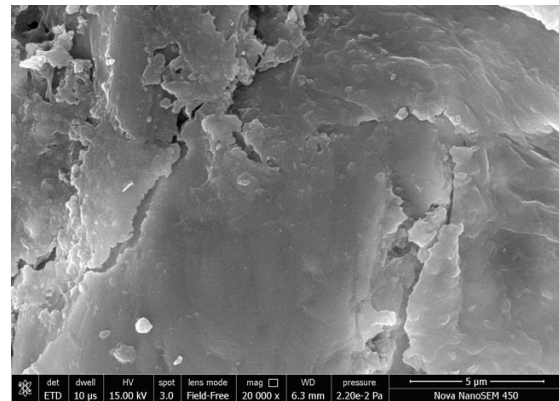


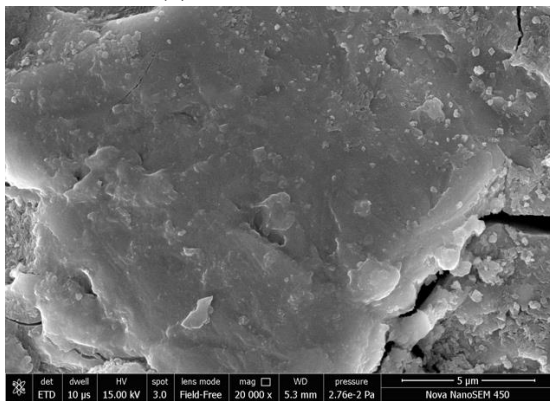
Fig. 8 Geopolymer concrete mix design curve comparison



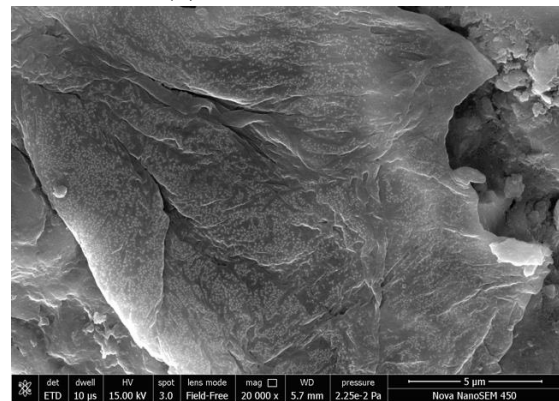
(a) SS/GGBS=0.35



(b) SS/GGBS=0.40



(c) SS/GGBS=0.45



(d) SS/GGBS=0.50

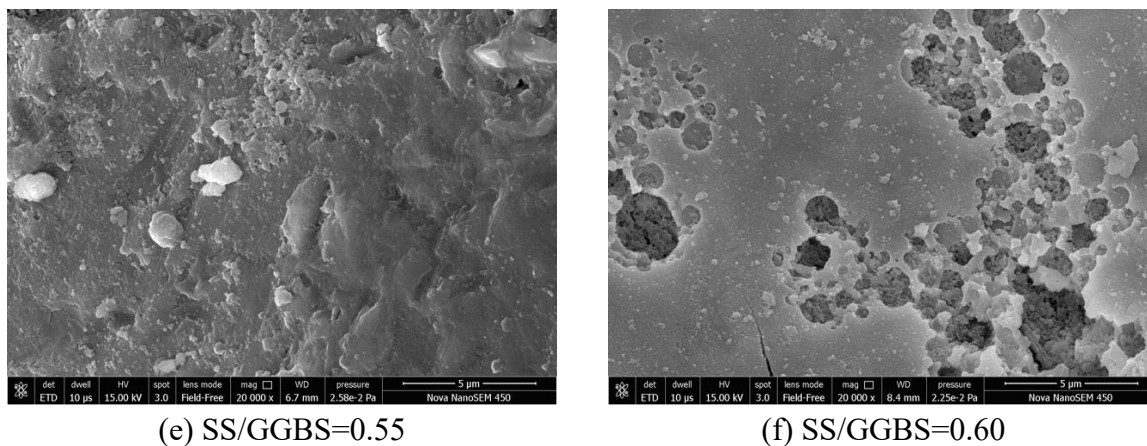


Fig. 9 SEM image of SGC at different SS/GGBS ratio

## 5. Conclusions

An experimental investigation was carried out to develop a mix design methodology for the production of user friendly geopolymer concrete. As most of the earlier mix design methods heavily relied on the use of highly concentrated NaOH to produce geopolymer concrete, which makes it unsafe during handling and production of concrete. Therefore, a user-friendly system for the production of geopolymer concrete using GGBS as binder solid and SS as the sole alkali reagent is proposed. The results of the experimental work suggest that GGBS based user friendly geopolymer concrete of desired strength can be produced by employing various SS/GGBS ratios. Geopolymer concrete with target strength ranging between 40 to 66 N/mm<sup>2</sup> can be produced by adopting a suitable SS/GGBS ratio between 0.35 to 0.65 and following the mix design steps.

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