STRENGTH AND WORKABILITY PERFORMANCE OF SELF COMPACTING GEOPOLYMER CONCRETE INCORPORATING METAKAOLIN

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Abstract - *Geopolymer is a type of amorphous alumino-silicate cementitious material which can be synthesized by poly-condensation reaction of geopolymeric precursor ions and alkali-polysilicates. The major factor in development of geopolymer is to reduce greenhouse gas emissions from the production of concrete products and an opportunity to convert a variety of waste by-products into useful materials. The main limitation in the usage of geopolymer concrete lies in its lower workability and early setting time which is enhanced with the help of new generation polycarboxylic ether based Superplasticizer to make it a Self-compacting Geopolymer Concrete (SCGC). A Self-Compacting Concrete is capable of spreading through congested reinforcement and consolidating under its own weight without any external vibration. However the investigation of fresh and hardened properties of SCGC needs to be expanded to optimize this concrete type. Here, GGBS and Fly ash based SCGC is developed with the incorporation of Metakaolin at 0%, 5%, 10%, 15% and 20% and its effect on concrete is studied. The objective of this study is to determine the optimum mix having both adequate strength and flow-ability based on their workability and strength parameters.*

Key Words: Poly-condensation, Superplasticizer, Metakaolin, Self-Compacting, flow-ability.

1. INTRODUCTION

In this era of modernisation, construction sector has become an important indicator of progress and development. The construction sector is known for its important role to enhance the economic growth of the country. The usage of cement based concrete is being increased day by day in almost all the construction activities. Cement, being the most widely used material is a global pollutant as it releases huge amounts of Carbon-di-oxide into the atmosphere. Studies reveal that literally one tonne of cement gives out one tonne of carbon-di-oxide into the atmosphere [1,2,4]. Hence, there comes a severe need to reduce or to eliminate the amount of cement used to produce concrete. Whereas on the other hand, there are many waste by-products namely Fly ash, Ground Granulated Blast Furnace Slag (GGBS), Silica Fume, Rice Husk Ash, Metakaolin, Red mud etc that are produced from industries. A little quantity of these industrial by-products are being used as landfills, whereas the remaining quantity remains unutilised [1,2,7]. One good solution to completely eliminate the usage of cement by utilising the industrial wastes is the Geopolymer Concrete [5].

The geopolymerisation process goes like – the silica and alumina atoms from the industrial waste materials like Fly ash, GGBS react with the alkaline activator solution which is a combination of Sodium hydroxide and Sodium Silicate to form the precursor ions [3,6]. These precursor ions are then reoriented to form the monomers. The monomers are poly-condensed to form a rigid three-dimensional structure of silica and alumina [6]. On further polymerisation, a chain of polymers are formed which is the Geopolymer concrete.

This geopolymer concrete is in research for many years. The main drawback with its implementation lies in its workability and early setting [2]. When Fly ash based geopolymer concrete is developed, heat curing becomes necessary whereas when GGBS and Fly ash based Geopolymer concrete is used, ambient curing itself is sufficient [9]. Hence in this study, a geopolymer concrete having binder materials as Fly ash, GGBS and Metakaolin is derived. The usage of GGBS in concrete provides enormous strength but whereas it decreases the workability and gives flash setting. [9]

In order to overcome this drawback, the Geopolymer concrete is supposed to be developed as a Self-compacting Geopolymer concrete by incorporating the features of self-compacting concrete into the geopolymer concrete. The features includes the proportion of fine aggregates and coarse aggregates, the size of coarse aggregates, superplasticizer content etc. Therefore, a second generation poly-carboxylic ether based superplasticizer [12] at certain amounts is added in order to enhance the fluidity and to delay the setting time.

2. MATERIALS

The materials used in this study are - binder materials as Fly ash, GGBS and Metakaolin, the activator solution as a combination of Sodium Hydroxide and Sodium Silicate, Fine aggregates, Coarse aggregates, Water and Superplasticizer.

Table -1: Mix proportion for SCGC

Total mass of binder (kg/m³)	Mass of alkaline liquid (kg/m³)	NaOH (kg/m³)	Na_2SiO_3 (kg/m³)	Coarse aggregate (kg/m³)	Fine aggregate (kg/m³)	Super plasticizer (kg/m³)	Extra water (kg/m³)
429	171	57	114	720	1080	25.74	64.35

2.1 Fly ash

Fly ash is the industrial waste by-product which is obtained by burning pulverised coal in thermal power plants. Here Class F fly ash is used instead of Class C Fly ash, since Class F fly ash possess more quantity of Silicon di oxide, Aluminium oxide and Iron oxide compared to Class C fly ash [9]. This is helpful as the geopolymerisation reaction takes place only due to the aluminosilicate ions present in the binder materials. The specific gravity of fly ash used is 2.2.

2.2 GGBS

Ground Granulated Blast Furnace Slag is an eco-friendly material which is the by-product obtained from iron industries. It is an off-white colour powder which is lighter than the cement [8]. GGBS contains more amount of calcium, silica and alumina which is helpful to initiate the geopolymerisation process. The specific gravity of GGBS used is 2.5.

2.3 Metakaolin

Metakaolin is the anhydrous calcined form of the clay mineral kaolinite when it is heated to a temperature between 600 °C and 800 °C. It is considered to have twice the reactivity of most other pozzolans. Metakaolin is filled with maximum amounts of silica and alumina. Metakaolin has a specific gravity of 2.6.

2.4 Activator Solution

The combination of sodium hydroxide and sodium silicate is considered to be more reactive than a combination of potassium hydroxide and potassium silicate [4]. Alkaline activator solution facilitates the polymerisation process by reacting with the binder which leads to the formation of molecular chains. Sodium silicate is a clear, colourless liquid which is a highly versatile and inorganic chemical. Sodium hydroxide is a white crystalline odourless solid which when dissolved in water produces a colourless liquid which is denser than water. The specific gravity of Sodium hydroxide is 2.13 and that of Sodium Silicate is 1.40.

2.5 Aggregates

In this study, coarse aggregates and fine aggregates are used in the ratio 40:60 in order to make the concrete self-compacting. Here, 12 mm coarse aggregates are used having specific gravity of 2.8. The specific gravity of fine aggregate used is 2.7.

2.6 Superplasticizer

The superplasticizer used here is Master Glenium SKY 8233, which is an admixture of a new generation based on modified polycarboxylic ether. It has been primarily developed for applications in high performance concrete where the highest durability and performance is required [13]. This superplasticizer has specific gravity of 1.08.

3. MIX PROPORTION

In this study there are two major objectives - one is to achieve the required workability in order to make the concrete a self-compacting one and the other is to achieve the stipulated strength. The mix design is calculated by keeping the ratio of Sodium silicate to Sodium hydroxide as 2:1 [9,11] based on the previous studies which could give good performance for GPC. The alkaline liquid to binder ratio is taken as 0.4 [11], the molarity of sodium hydroxide is considered as 8M and the superplasticizer content is maintained at 6% of the binder materials [14]. The mix is varied based on the percentage of Metakaolin in concrete. Metakaolin is varied in percentages as 0%, 5%, 10%, 15% and 20% keeping the percentage of GGBS at 60% [9,10] and varying Fly ash based on the percentage of Metakaolin. The mixes are termed as M0, M1, M2, M3 and M4 based on the percentage of Metakaolin. Based on the proposed mix design, workability tests for self-compacting geopolymer concrete [18] namely Slump cone, V-funnel and L-box are performed and specimens like cubes and cylinders are cast for arriving out the Compressive strength and Split tension of concrete respectively. The mix having the proper strength and the desired workability is chosen as the optimum mix. The quantities per m³ for all the materials are represented in Table 1.

4. EXPERIMENTAL WORK

4.1 Fresh properties test

Filling ability, Passing ability and Segregation resistance are the three properties for a concrete mix to be characterized as a Self-compacting concrete [14,15,18]. In this study, Slump flow by Abrams cone, V-funnel and L-box are done to figure out the fresh properties of mixes. Figure 1 shows the different workability test apparatus. The acceptable values given by the EFNARC standards [18] are given in the following Table 2.

Fig -1: Workability Test Apparatus

Table - 2: EFNARC Standards

Method	Property	Unit	Typical range of values	
			Minimum	Maximum
Slump flow by Abrams cone	Filling ability	mm	650	800
V-funnel	Filling ability	sec	6	12
L-box	Passing ability	h_2/h_1	0.8	1.0

4.2 Hardened properties test

Fig -2: Compressive strength Test Apparatus

The mechanical properties like Compressive strength and Split tensile strength are carried out for cube and cylinder specimens respectively. The specimens are cast, demoulded and cured under ambient temperature for 28 days and the tests are carried out. The compressive strength for all the samples was performed on cube specimens of size 150 mm [19] using a 2000 kN Digital compressive testing machine. The maximum load applied to the cube specimen up to failure of specimen was recorded to calculate the compressive strength. The split tensile strength was performed by cylinder splitting test on 150 mm diameter x 300 mm height cylinder specimen [20]. The test was performed on compression testing machine. The maximum load applied at failure of specimen was recorded.

5. RESULTS AND DISCUSSIONS

5.1 Workability results

From table 3, it is evident that the workability of M4 mix for all the 3 tests is found to be deviating the EFNARC standards [18] which exceeds the maximum limit. Hence the mix M4 has to be neglected. Similarly for mix M1, it is just in the lower range of the limits for all the workability tests and the mix M3 is just in the higher range of the limits. The mix M1 and M2 lies between the minimum and the maximum range.

From this it can be observed that increase in Metakaolin percentage, decreases the workability which is also evident with respect to various previous studies [8,16]. Here as the GGBS content is maintained constant, it does not affect the workability and hence the varying parameters like Fly ash and Metakaolin greatly influences the workability. This is due to the spherical shape of fly ash particles compared to the angular shape of Metakaolin particles which has a greater influence in workability.

Table - 3: Workability results

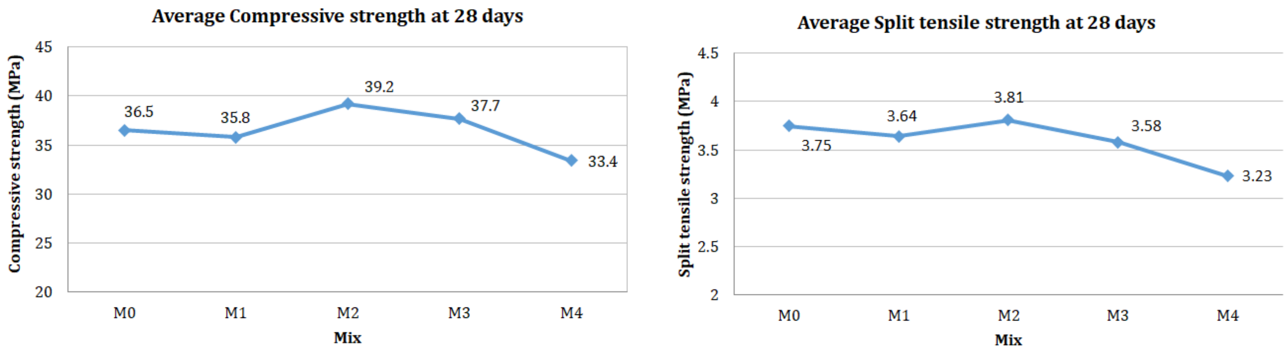
Mix	Proportion	Slump flow	V-funnel	L-box
M0	0% Metakaolin	800	7	1
M1	5% Metakaolin	760	9	1
M2	10% Metakaolin	720	11	0.9
M3	15% Metakaolin	660	13	0.8
M4	20% Metakaolin	610	15	Not workable

5.2 Mechanical properties results

From table 4, the compressive strength of the mix M2 is higher than the control mix M0 whereas the compressive strength for M1 is less than that of the control mix M0. Beyond M2, the compressive strength decreases gradually. This is the same for the Split tensile strength, where it is the highest for the mix M2 incorporating 10% Metakaolin and beyond which the Split tensile strength also decreases. This is in accordance with the previous studies [8,16], where the incorporation of Metakaolin up to 10% increases the

(a) (b)

Fig - 3(a) & 3(b): Tested cube and cylinder specimens



(a) (b)

Fig - 4(a) & 4(b): Compressive Strength and Split Tensile strength at 28th day

Compressive and Split tensile strength, beyond which there will be no increase in the strength. So with respect to the compressive strength and split tensile strength, the mix M2 is regarded as the optimum mix.

Table - 4: Mechanical properties results

Mix	Proportion	Average Compressive strength at 28 days (N/mm^2)	Average Split tensile strength at 28 days (N/mm^2)
M0	0% Metakaolin	36.5	3.75
M1	5% Metakaolin	35.8	3.64
M2	10% Metakaolin	39.2	3.81
M3	15% Metakaolin	37.7	3.58
M4	20% Metakaolin	33.4	3.23

6. CONCLUSIONS

From the study, it is clearly evident that the Self-compacting Geopolymer concrete with a desired strength and required workability as per EFNARC Standards can be achieved. The conclusions can be summarized as follows:

- The optimum mix from this study is achieved with 60% GGBS, 30% Fly ash and 10% Metakaolin as the binder materials, Alkaline liquid to binder ratio as 0.40, Ratio of sodium silicate to sodium hydroxide as 2:1, the molarity of sodium hydroxide as 8M and with superplasticizer content of 6% of the binder materials which gives the adequate workability and adequate strength.
- It can be seen that the workability and strength is high for the mix incorporating 10% Metakaolin, beyond which both decreases.
- For the above mentioned mix, the compressive strength is found to be 7.39% higher than the control mix and the split tensile strength is found to be 1.6% higher than the control mix.
- Therefore, a self-compacting geopolymer concrete can be achieved in order to meet the limitations like lower workability and early setting.

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