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Influence of Metakaolin on GGBS based Geopolymer Concrete

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Abstract: The Construction industry is dominated by new materials which are violable and feasible solution for ever growing architectural industry. Efforts are in progress all over the world to develop environment friendly construction materials which minimizes the utility of natural resources and helps to decrease greenhouse gas emissions into the atmosphere. In this study Geopolymer concrete (GPC) is prepared by using Ground granulated blast furnace slag (GGBS) for different activator ratios as 1, 1.5, 2, 2.5 and 3 with molar concentration of sodium hydroxide as 8M in order to get maximum Compressive strength for which activator ratio, it is to be maximum. This ratio was kept constant for further study in GPC carried out by replacing GGBS by Metakaolin (MK) for different percentages of 10%, 20%, 30% and 40% by weight of binder (GGBS). For all mixes of GPC with and without metakaolin mechanical properties like Compressive, Split tensile and Flexural strengths were observed and evaluated.

Keywords: Geo-polymer concrete GPC, Ground Granulated Blast Furnace Slag (GGBS), Alkali activators, Metakaolin, sodium hydroxide, Compressive strength, split tensile strength, flexural strength.

I. INTRODUCTION

With the continuous growth of industries in the world, the co_2 emission continue to rise. Manufacturing of cement contributes about 5-7% of co_2 emissions. A lot of studies have been done in past which examine the greenhouse emissions from concrete and how they affect the atmosphere. So many efforts are made in this regard to find an alternative to OPC. Sharath Chandra kumar et al. [1] evaluated that the workability of GPC decreased as the metakaolin content increases with GGBS. But increase in GGBS does not affect the workability. Mechanical properties shows increasing trend with the metakaolin. Nearly 90% of total strength is achieved within the 7 days. Pouhet.et al. [2] concluded that in the presence of non-porous silicious aggregates, the fresh metakaolin-based geopolymer activated by silicate solution was able to replace a traditional portland cement. It was also highlighted that, unlike cement, geopolymer concrete would have negligible effect on inter transition zone at their binder-aggregate interface, and that the amount of aggregate would have negligible effect on performance of concrete.

Chaitanya. et al. [3] demonstrated that the GPC based on GGBS and Metakaolin has got more compressive strength than conventional concrete. The strength of GPC increases between 2%-4% from 7-28 days that means there is no much increase in the strength after 7 days. Chandra Padmakar et al. [4] studied that the GPC based on GGBS and Metakaolin has got more compressive strength than the conventional concrete. They observed that the compressive, flexural and split tensile strengths of GPC are increased with increase in % of metakaolin. They concluded that the GPC based on GGBS and Metakaolin resists the attack of various chemicals and therefore it is durable. Compressive, split tensile and flexural strengths vary in direct relation to the age for a given proportion of a mix. The green concrete resists the attack of various chemicals and therefore, it is durable for the given proportion of mix. Compressive, flexural and split tensile strengths vary in direct relation to age for given proportion of mix. Kuenzel et al. [5] studied that there is no clear correlation between the AL content in MK samples and geopolymer setting, heat output or strength development. The unreactive content in MK may increases the rate of initial heat output and accelerate geopolymer setting possibly through accelerated nucleation and growth of geopolymer. Oh et al. [6] investigated that the geopolymerization uses a relatively lower solution/binder ratio, less than 0.6 and lower reaction temperature 90^oC. Addition of water to NaOH activator does not form any new phase in FA geopolymer although it largely enhanced the compressive strength. Khadiranikar et al. [7] evaluated that the mechanical properties are depends on activator ratios. The alkaline solutions varied in the ratios of 2, 2.5, 3 and 3.5 by mass. Maximum compressive strength and flexural strength was obtained when the ratio of NS/NH is equal to 2.5. Rangan et al. [8] dissected that the concentration of sodium hydroxide solution in the mix vary in between 8M-16M and also concluded that higher concentration of NaOH solution results in higher compressive strength. Lakshmi Deepak et al. [9] demonstrated that the strength properties for GPC with 12M of NaOH gives better results compared to 10 Molar solution. Compressive Strength of concrete with 1:3 alkaline liquid ratio has been increased compared to 1:2.5. They observed that increment in alkaline liquid ratio increases the strength of concrete when compared between 1;2.5 and 1:3. Optimum mixtures were observed by them as 80%MK+20%FA.

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II. EXPERIMENTAL STUDY

A. Materials

1) *GGBS:* Ground granulated blast furnace slag (GGBS) used in this works is obtained from JSW steel Ltd, Gadivemula and is as shown in Fig. 1.

The physical properties and chemical compositions of GGBS are shown in Table 1 and Table 2.

Fig. 1 GGBS

Table 1 Physical properties of GGBS

S. No	Properties	Values
1	Specific gravity	2.92
2	Specific surface area	350-450 m^2/kg

Table 2 chemical composition of GGBS

S. No	Oxide	Percentage by mass (%)
1	Cao	37.34
2	Al_2O_3	14.42
3	Fe_2O_3	1.11
4	SiO_2	36.71
5	MgO	8.71
6	SS	0.39
7	LOI	1.41
8	MnO	0.02

2) *Metakaolin:* Metakaolin is a highly efficient pozzolana and amorphous in nature. The high amorphicity of metakaolin lead to the high reactivity when it is activated in alkali solutions. MK has the smallest particle size in comparison to FA or GGBS. The fine and irregular particle shape of MK often mean that MK generally requires more solution for wetting and reaction to take place appropriately. Metakaolin obtained from raw material manufacturing industries, Kottoor, Telangana for the present study and is as shown in Fig. 2. The physical and chemical properties of metakaolin are shown in Table 3 and table 4.

Fig. 2 Metakaolin

Table 3 Physical Properties of Metakaolin

Colour	Pink / Off white
Pozzolan Reactivity	900
Average partical size	1.4 micron
Brightness	75 ± 2
Bulk density	320 to 370
Specific gravity	2.5

Table 4 Chemical Composition of Metakaolin

Oxides	Metakaolin %
Silica	55.9
Alumina	37.2
Lime	0.11
Iron	1.7
Sulphur	0.18
Magnesia	0.24
Alkaline	0.27
Loss of ignition	0.8

3) *Aggregates*

a) *Coarse Aggregate:* Coarse Aggregate are broad category particulate inert material used in construction. Locally available Coarse aggregate of size down 20mm were used for present study and the properties are as shown in Table 5.

Table 5 Properties of coarse aggregates

S. No	Property	Test results
1	Maximum nominal size	20mm
2	Bulk density (kg/m^3)	1405
3	Specific gravity	2.85

b) *Fine Aggregate:* Fine aggregate should consist of natural sand or crushed stone sand. Locally available sand from the river Tungabhadra bed was used in this study and properties of Fine aggregate are shown in Table 6.

Table 6 properties of Fine aggregate

S. No	Properties	Results
1	Bulk density (kg/m^3)	1592
2	Specific gravity	2.77
3	Fineness modulus	2.91

4) *Alkaline Liquids:* A combination of Sodium Silicate and Sodium hydroxide solution was chosen as the alkaline liquid. Sodium based solutions were chosen because they are cheaper than Potassium based solutions. The solutions of sodium hydroxide is prepared by dissolving either flakes or pellets in water. Combination of sodium hydroxide of 8M and sodium silicates solution containing H_2O of 52.7%, SiO_2 of 31.4% and Na_2O of 15.9% used in alkaline activator preparation.
5) *Admixture:* CONPLAST-SP430 super plasticizer was used in this work.

B. Mix Design

The different mixes of GGBS based GPC with 8M concentration were studied with different alkaline activator ratio of 1, 1.5, 2, 2.5 and 3. The mix with alkaline activator ratio 2.5 was obtained maximum compressive strength among all activator ratios and the corresponding compressive strength works out to be 74.8 MPa. The mix proportions to the corresponding mix is as shown in Table 7. Further study was carried out in GGBS based GPC mix with alkaline activator ratio of 2.5, different mixes were cast by replacing GGBS in above mix, by metakaolin at different percentages like 10%, 20%, 30% and 40%. The mixes were designated as shown in Table 8. Strength properties such as compressive strength, flexural and split tensile strengths were studied this study.

Materials used	Cementitious materials	Fine aggregate	Coarse aggregate	Sodium Hydroxide	Sodium silicate
Quantity of materials in Kg/m^3	414	720	1080	53	133

Table 7 Mix Proportions

Mix ID	M1	M2	M3	M4	M5
GGBS	100	90	80	70	60
Metakaolin	0	10	20	30	40

Table 8 Combinations of GGBS and Metakaolin

1) *Preparation of Geopolymer Concrete:* To prepare 8 molarity concentration of sodium hydroxide solution, 320 grams (molarity x molecular weight) of sodium hydroxide flakes were dissolved in distilled water and make up to one liter. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete to get the desired alkaline solution. The constituents of the GPC mix i.e. Metakaolin, GGBs and the aggregates were dry mixed in the mixer for about 3 minutes. After dry mixing, alkaline solution was added to the dry mix and mixing was continued for 4 minutes.

C. Testing

Compressive strength test was performed in accordance with IS 516:1959.[10] The test was performed on 150*150*150 mm cube samples at 28days. Compressive strength of each mix was taken as average value of three specimens. The flexural strength of geopolymer concrete was carried out as per IS 516:1959. Beams of size 500*100*100*mm size were cast then subjected to the flexural strength test using universal testing machine (UTM). The split tensile strength test was carried out as per IS 5816:1999.[11] Cylindrical specimens of size 150mm diameter and 300mm height were cast. The specimens were then tested for 28days splitting tensile strength using universal testing machine (UTM).

III. RESULTS AND DISCUSSIONS

A. Compressive Strength of GPC

Mechanical properties of GGBS based GPC using different % of Metakaolin are depicted in Table 9. Fig 3 explains the variation of compressive strength of geopolymer concrete with and without Metakaolin at 28 days. At 20% of metakaolin percentage development in compressive strength of GPC mix M3 is maximum and is 15.3% over the control GPC mix M1 after that the compressive strength of mixes decreases.

Table 9 Mechanical properties of GGBS based GPC with metakaolin

Mix Type	Compressive strength (MPa) (28 days)	Flexural strength (MPa) (28 days)	Split tensile strength (MPa) (28 days)
M1	74.8	0.92	4.90
M2	82.1	1.23	5.35
M3	86.23	1.51	5.6
M4	61.7	1.31	5.25
M5	42.6	1.10	5.10

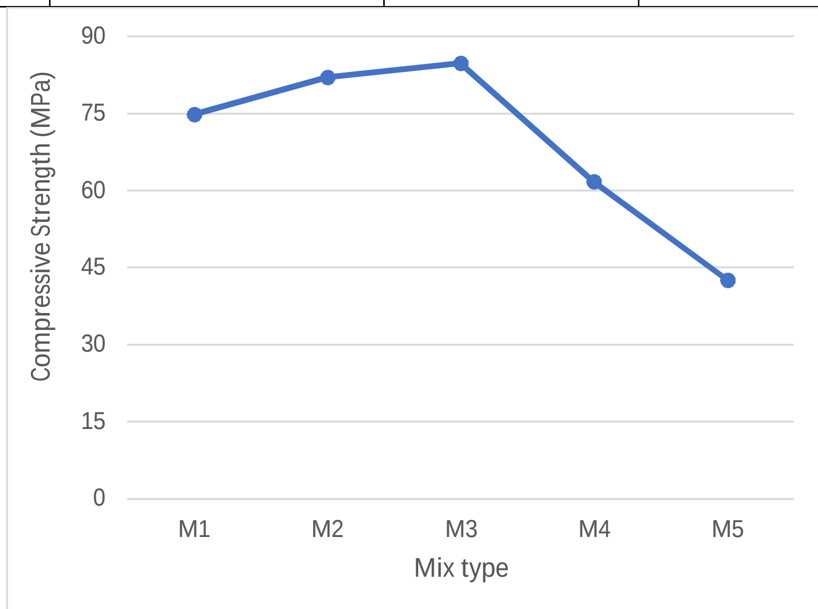

Fig. 3 Variation of Compressive Strength of GPC with and without Metakaolin

B. *Flexural Strength*

The Variations in flexural strength with different percentage of Metakaolin is as shown in Fig 4. At 20% of metakaolin, percentage improvement in flexural strength of GPC is maximum and is 64.13% over control GPC.

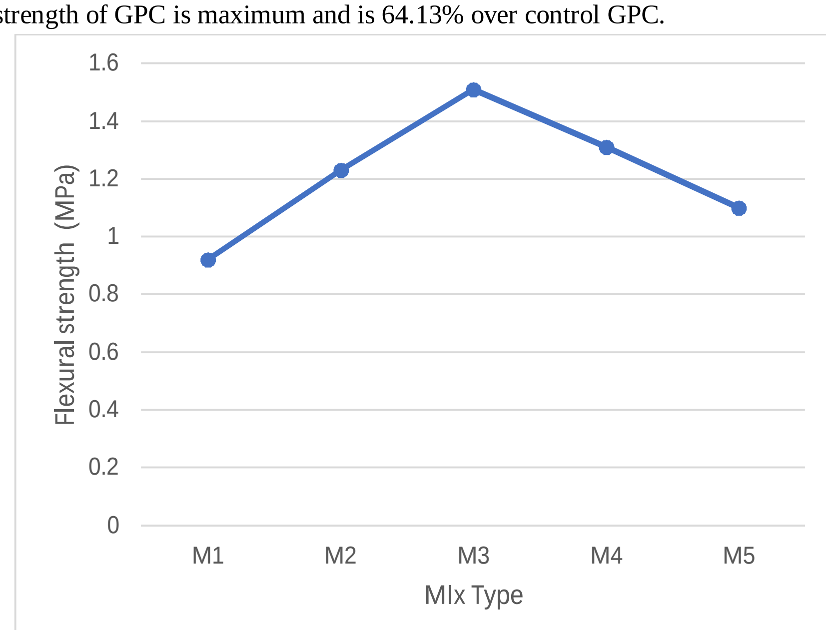

Fig. 4 Variation of Flexural strength of GPC with and Without Metakaolin

C. Split Tensile Strength

The variation of split tensile strength at the age of 28 days with different percentage of metakaolin is shown in Fig 5. At 20%of metakaolin, % improvement in split tensile strength of GPC is maximum and is 14.76% over control mix.

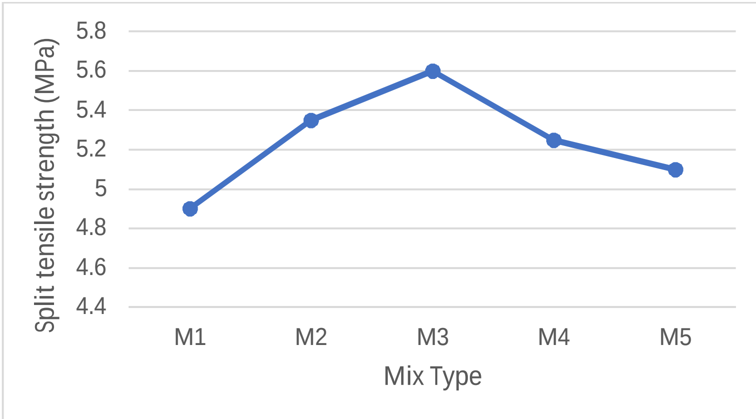

Fig. 5 Variation of Split tensile strength of GPC with and without metakaolin

IV. SUMMARY AND CONCLUSIONS

Mechanical properties of GGBS based GPC with metakaolin were studied. The following conclusions are proposed based on the experimental study.

A. The strength of GPC increased with increase in activator ratio up to 2.5 and thereafter decrease in strength was observed.
B. Up to 20% replacement of GGBS by Metakaolin, the strength properties of GPC were increased and there after decreased. As the % of metakaolin increased, decreased in the workability of GPC was observed.
C. Based on limited study, it was concluded that, addition of metakaolin up to 20% in GGBS based GPC, improves compressive, split tensile and flexural strengths as 15.3%, 14.76% and 64.13% over respective strengths of controlled GPC mix.

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