An Experimental Study on Strength Properties of GGBS and Meta kaolin in Addition with Alkaline Solution of Sodium Hydroxide and Sodium Silicate

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***Abstract*—: The major problem the world is facing today is the environmental pollution. In the construction industry mainly the production of Portland cement will causes the emission of pollutants results in environmental pollution. We can reduce the pollution effect on environment, by increasing the usage of industrial by-products in our construction industry. Geo-polymer concrete is such a one and in the present study, to produce the geo-polymer concrete the Portland cement is fully replaced with GGBS (Ground granulated blast furnace slag) and alkaline liquids are used for the binding of materials. The alkaline liquids used in this study for the polymerization are the solutions of Sodium hydroxide (NaOH) and sodium silicate (Na_2Sio_3). Different molarities of sodium hydroxide solution 10M is taken to prepare different mixes. And the compressive strength is calculated for each of the mix. The geo-polymer concrete specimens are tested for their compressive strength at the age of 3 and 7 days. The result shows that there is significant increase in the strength of oven cured specimens after 3 days of oven curing and the strength of geo-polymer concrete is increasing with the increase of the molarity of sodium hydroxide.**

The objective of this project is to study the effect of Metakaolin (MK) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer oncrete (GPC) at different replacement levels (MK80-GGBS20, MK70-GGBS30, MK60-GGBS40). Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution have been used as alkaline activators. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength, split tensile strength of Metakaolin and GGBS based geopolymer concrete. These properties have been determined at different curing periods like 3, 7, 28, days and at ambient room temperature.

Index Terms : **Geo-polymer, GGBS, Alkaline solutions, curing, compressive strength.**

I. INTRODUCTION

The advancement of concrete technology can reduce the consumption of natural resources and energy sources and lessen the burden of pollutants on environment. Presently large amounts of Metakaoline, a dehydroxylated form of the clay mineral kaolinite came into existence. This project describes the feasibility of using in concrete production as partial replacement of cement

In India, the Metakaoline and GGBS are the most thriving industrial effects. These contain physical and mechanical properties of fresh and hardened concrete that have been investigated. Slump and air content of fresh concrete and absorption and compressive strength of hardened concrete were also investigated. Test results show that this Metakaoline and GGBS are capable of improving hardened concrete performance up to 10%, Enhancing fresh concrete behavior and can be used in architectural concrete mixtures. The compressive strength of concrete was measured for 7 and 28 days. In order to evaluate the effects of Metakaoline and GGBS on mechanical behavior, many different mortar mixes were tested.

Recycling waste as useful material is a very important environmental managing tool for achieving sustainable development. On the other hand, recycling waste without properly based scientific research and development can result in environmental problems greater than the waste itself. The successful research and development of a new building material or component using waste as raw material, is a very complex and multi disciplinary task having technical, environmental, financial, marketing, legal and social aspects.

II. LITERATURE REVIEW

Sabir.B.B et al (2021) carried out a study on the utilization of Metakaolin as pozzolanic material for mortar and concrete and mentioned about the wide range application of Metakaolin in construction industry .They reported that the usage of Metakaolin as a pozzolana ill help in the development of early strength and some improvement in long term strength. They mentioned that Metakaolin alters the pore structure in cement paste mortar and concrete and greatly improves its resistance to transportation of water and diffusion of harmful ions which lead to the degradation of the matrix.

Jian-Tong Ding et al (2022) experientally found out the effects of Metakaolin and Silica Fume on the properties of Concrete. Experimental investigation with seven concrete mixtures of 0, 5, 10, and 15% by mass replacement of cement with high-reactivity Metakaolin or Silica fume, at a water cement ratio of 0.35 and a sand-to-aggregate ratio of 40% was carried out. The effect of Metakaolin or Silica fume on the workability, strength, shrinkage, and resistance to chloride penetration of concrete was investigated. The incorporation of both Metakaolin and Silica fume in concrete was found to reduce the free drying shrinkage and restrained shrinkage cracking width. It is also reported that the incorporation of Metakaolin or Silica fume in concrete can reduce the chloride diffusion rate significantly. The performance of Silica fume was found to be better than Metakaolin.

Badogiannis.E et al (2023) evaluated the effect of Metakaolin on concrete. Eight mix proportions were used to produce high-performance concrete, where Metakaolin replaced either cement or sand of 10% or 20% by weight of the control cement content. The strength development of Metakaolin concrete was evaluated using the efficiency factor (k value). With regard to strength development the poor Greek Metakaolin and commercially obtained Metakaolin yielded the same results. The replacement with cement gave better results than that of sand. When Metakaolin replaced cement,its positive effect on concrete strength generally started after 2 days where as in case of sand it started only after 90 days. Both Metakaolin exhibited very high k-values (close to 3.0 at 28 days) and are characterized as highly reactive pozzolanic materials that can lead to concrete production with excellent performance.

Justice.J.M et al (2023) made a comparative study by replacing 8% by weight of cement with Metakaolin and Silica fume. Metakaolin addition proved to be beneficial, resulting in concrete with considerably higher strengths and greater durability than the normal mixes. The use of finer Metakaolin was more effective in improving concrete properties than the coarser Metakaolin. Addition of Metakaolin increased the use of super plasticizers. Addition of Metakaolin exhibited improvements in shrinkage, durability and other strength aspects.

Nabil M. Al-Akhras (2021) carried out an investigation by replacing cement with Metakaolin to find out the durability of concrete against sulphate attack. Three replacements of cement with Metakaolin (5, 10 and 15% by weight) were done with water cement ratio of 0.5 and 0.6. After the specified days, the samples were immersed in 5% sodium sulphate solution for 18 months. The effect of metakaolin addition proved to be beneficial in improving the resistance of concrete to sulphate attack. Metakaolin with water cement ratio of 0.5 exhibited better results in sulphate resistance than 0.6. Autoclaved cured specimens had better resistance against sulphate than moist cured specimens.

III. MATERIALS USED

Metakaolin:
High Reactivity Metakaolin (HRM) is an engineered pozzolanic mineral admixture, reacting aggressively with calcium hydroxide which results in significant performance of concrete. HRM has been introduced to be a beneficial alternative for silica fume, required in the formulation of high strength/performance concrete.
In this study, different aspects of concrete mechanical behaviors have been studied including compressive, flexural and splitting tensile strengths. Also some characteristics of concrete durability were investigated including water absorption, water penetration and gas permeability. In mixture proportioning, 5%, 10% and 15% of cement content is replaced by HRM or silica fume for comparative study. It was observed that both concrete with HRM and silica fume would perform almost the same in improving the mechanical properties of the materials. However in the case of workability and durability, a better performance was obtained in concrete with HRM. It was concluded from the investigation that HRM could be an appropriate substitute for silica fume in producing high performance concrete.

Ground Granulated Blast Furnace Slag (GGBFS) :
Ground Granulated Blast Furnace Slag (GGBFS) is a byproduct of the steel industry. Blast furnace slag is defined as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace.” In the production of

iron, blast furnaces are loaded with iron ore, fluxing agents, and coke. When the iron ore, which is made up of iron oxides, silica, and alumina, comes together with the fluxing agents, molten slag and iron are produced. The molten slag then goes through a particular process depending on what type of slag it will become. Air-cooled slag has a rough finish and larger surface area when compared to aggregates of that volume which allows it to bind well with Portland cements as well as asphalt mixtures. GGBFS is produced when molten slag is quenched rapidly using water jets, which produces a granular glassy aggregate.

Silica fume:

It is a byproduct of producing silicon metal or ferrosilicon alloys. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzalona. Concrete containing silica fume can have very high strength and can be very durable. Silica fume is available from suppliers of concrete admixtures and when specified, is simply added during concrete production. Placing, finishing, and curing of silica-fume concrete require special attention on the part of the concrete. Silicon metal and alloys are produced in electric furnaces as shown in this photo. The raw materials are quartz, coal, and woodchips. The smoke that results from furnace operation is collected and sold as silica fume, rather than being land filled. Perhaps the most important use of this material is as a mineral admixture in concrete.

Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fine particles, large surface area, and the high SiO_2 content, silica fume is a very reactive pozzalona when used in concrete. The quality of silica fume is specified by ASTM C 1240 and AASHTO M 307.

Fly ash:

It is a fine, glass-like powder recovered from gases created by coal-fired electric power generation. U.S. power plants produce millions of tons of fly ash annually, which is usually dumped in landfills. Fly ash is an inexpensive replacement for Portland cement used in concrete, while it actually improves strength, segregation, and ease of pumping of the concrete. Fly ash is also used as an ingredient in brick, block, paving, and structural fills.

Chemical properties of materials:

Chemical Composition	Fly Ash (%)	GGBS (%)	Silica Fume (%)
SiO_2	35.5-42.83	32.6	90.11
Al_2O_3	18.0-26.9	12.8	1.63
Fe_2O_3	6.5-8.2	1.3	1.98
MgO	3.5-4.1	7.2	0.78
SO_3	2.2-3.5	0.0.	-
$Na_2O + K_2O$	-	-	1.97
P_2O_5	-	0.05	1.18
CaO	18.8-19.8	41.0	-
H_2O	0.2-1.9	-	-

PREPARATION OF SOLUTION FOR 10M NaOH and Na2SiO3 :

Molecular Weight of NaOH = 40

For 10M NaoH = 10 x40 = 400 gm/lit.

Total NaOH to be mixed = 400/(specific gravity of NaOH)

= 400/2.541

= 157.43 gm/lit

Take the ratio of sodium silicate solution-to-sodium hydroxide solution by mass as 2.5 sodium hydroxide

Na2Sio3 = 2.5 x NaOH

= 2.5 x 400

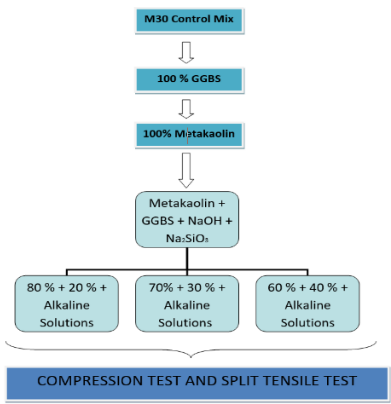
= 1000gm/lit

Total Na2Sio3 = 1000/(specific gravity of Na2Sio3

= 1000/2.7

= 370.37 gm/lit

IV. METHODOLOGY



V. MIX DESIGN PROCEDURE

Target Strength for Mix Proportioning:

$$f'ck = fck + 1.65\, s$$

where,

f'ck = target average compressive strength at 28 days,
fck = characteristic compressive strength at 28 days, and
s = standard deviation.

From Table I, standard deviation, *s* =5 N/mm^2

Therefore, target strength = 35 + 1.65 x 5
= 43.25 N/mm^2

SELECTION OF WATER CEMENT RATIO:
The target strength 43.25 n/mm^2 can be achieved in 28 days by using the water cement ratio (w/c) of 0.46
But as per table 5 of I S 456, a maximum w/c ratio permitted is 0.45
Therefore , adopt water cement ratio (w/c) of 0.45

SELECTION OF WATER CONTENT:
From Table 2, maximum water content for 20 mm aggregate

=186 litre (for 25 to 50 mm slump range)

As super plasticizer is not used, the water content can't be reduced.

CALCULATION OF CEMENT CONTENT
Water cement ratio (w/c) = 0.45

Cement content = 186/0.45

= 413 kg/m^3

From Table 5 of IS 456

Minimum cement content for 'severe' exposure condition = 320 kg/m3

413 kg/m^3 > 320 kg/m^3, hence, O.K.

Now, to proportion a mix containing fly ash and metakaolin the following steps are suggested:

a) Decide the percentage fly ash to be used based on project requirement and quality of materials.
b) In certain situations increase in cementitious material content may be warranted, the decision on increase in cementitious material content and its percentage may be based on experience and trial.

PROPORTION OF VOLUME OF COARSE AGGREGATE AND FINE AGGREGATE:
From Table 3, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate falling under (Zone II) and water-cement ratio of 0.50 =0.62

In the present case W/C is o.45

Volume of coarse aggregate required to be increased to decrease the fine aggregate content

As the w/c ratio is lowered by 0.05, the proportion of volume of coarse aggregate is increased by
= (0.01/0.05)*0.05
= 0.01
Therefore , corrected proportion of volume of coarse aggregate for the w/c ratio of 0.45 = 0.62+0.01
= 0.63m^3
Volume of fine aggregate = 1 – 0.63
= 0.37m^3

MIX CALCULATIONS:
Volume of concrete = 1m^3
Absolute volume of cement = (413/3.15)*1/1000
= 0.1311m^3
Volume of water = 186
= 0.186 m^3
Therefore ,
= 0.1311+0.186
= 0.3171 m^3
Final weight of aggregate = 1- 0.3171
= 0.6829 m^3
Weight of coarse aggregate
=(*f* x volume of coarse aggregate x Specific gravity of coarse aggregate x I 000)
= 0.682*0.63*2.80*1000
= 1203.048m^3
Weight fine aggregate = (*f* x volume of fine aggregate x Specific Gravity of fine aggregate x 1000)
= 0.682 x 0.37 x 2.7 x 1000
= 681.318 m^3

Cement	FA	CA	Water
413	681	1203	186

kg/m^3	kg/m^3	kg/m^3	kg/m^3

Field correction :

Absorption of fine aggregate = 681 x 1/100
= 6.81 kg/m^3

Absorption of coarse aggregate = (0.5/100) x 1203
= 6.015

Therefore,

Fine aggregate = 681 – 6.81
= 674 kg/m^3

Coarse aggregate = 1203 – 6.015 = 1196.9 kg/m^3

Water content = 186+6.81+6.015
= 198.82 kg/m^3

Therefore, the mix proportion is

Cement	FA	CA	Water
413	674	1196	198

In the normal ratio the proportion is

Cement	FA	CA	Water
1	1.63	2.89	0.479

V. RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH:

Material	Avg. compressive strength of cubes for 7 days(N/MM^2)	Avg.compressive strength of cubes for 28 days(N/MM^2)
100% GGBS	0	0
100% METAKAOLIN	38.4	39.4
80%MK+20% GGBS	44.6	44.9
70%MK+30% GGBS	46.9	48.4
60%MK+40% GGBS	49.5	52.6

SPLIT TENSILE STRENGTH:

Material	Avg. split tensile strength of cubes for 7 days(N/MM^2)	Avg. split tensile strength of cubes for 28 days(N/MM^2)
100% GGBS	6.7	8.84
100% METAKAOLIN	8.9	11.86
80%MK+20% GGBS	9.5	12.3
70%MK+30% GGBS	11.45	14.8
60%MK+40% GGBS	6.7	8.84

VI. CONCLUSION

Based on limited experimental investigations conducted on concrete the following conclusions are drawn

- The compressive strength of concrete is found to increases with increase in 60 % Metakaolin and 40% GGBS content. It is found that the strength is increasing from 37.0 to 44.56 MPa i.e.,20% The split tensile strength of blended concrete is found to vary from 2.4 to 2.56 MPa i.e., approximately equal.
- The strength of the Geopolymer concrete increases with 2%-4% from 7 to 28 days that means there is no much increase in the strength after 7days.
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- From the above results it is appearent that Geopolymer concrete based on GGBS and metakaolin has got more compressive than conventional concrete.

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