Fly Ash Based Geopolymer Mortar- Strength Performance

Salmabanu Luhar, Ismail Luhar

Abstract: ***On one hand, going through the roof exigency of cementitious material and on the other hand, catastrophic impacts on environments through a titanic quantity of a primary Green House Gas emissions of CO_2 from Ordinary Portland Cement production has altogether twisted the arm of construction and infrastructure industries to come forward with novel, durable, sustainable, eco-friendly and of course, economically affordable alternatives for present binding and construction materials. Geopolymer binders produced through the process of Geopolymerization – a synthesis of Silica and Alumina rich pozzolanic precursor material, such as Fly Ash, with alkali solution as activator, have emerged out as brilliant promising alternative to conventional cement. The goal of this study is performance evaluations of Fly Ash based Geopolymer mortar whereby the cement is replaced entirely, i.e., 100% , with Fly Ash. This study examined the influence of a variety of mix composition parameters and process parameter on the compressive strength of Geopolymer mortar. The mix composition parameters taken into account are Sodium Hydroxide concentration and aggregate to binder ratio, whereas process parameter includes curing temperature.***

Keywords : Compressive strength, Waste utilization; Mortar; CO_2 emissions; Sustainability; Construction; fly ash, landfilling .

I. INTRODUCTION

A revolution in the history of concrete technology has witnessed the incessant progress and development in the constructional exercises. Conventional mortar is consisting of cement as a significant binder material, fine aggregate, and water which is for the most part used for bridging the gap between masonry or brick blocks. Also, it can be prepared with Asphalt, cement, and mud. Present production process for Ordinary Portland Cement (OPC) – one of the momentous constituents of ordinary mortar, involves the heating of Limestone at 1450°C in the kiln, for Calcination process. This high energy necessary to achieve high temperature is contributed by burning restricted natural resources of mineral coals. Unfortunately, this process emits embodied primary Green House Gas (GHG) Carbon Dioxide (CO_2) into the atmosphere on converting Calcium Carbonate into Calcium Oxide. Copious studies unearthed that more or less equal quantity of CO_2 is emitted in accordance with the production of OPC [1-8]. The OPC industry on its own contributes to just about 7% of global CO_2 emissions! [9] The Indian production of OPC in 2014 was around 390 million tons! This figure increasing day by day as India's OPC demand is expected to reach 550 million tons per year by 2025 [10-16]! The literature study suggests that the global construction activities devour 2.6 Billion Tons of OPC annually! Not merely that, an escalation in the demand for OPC in forthcoming decade is estimated roughly 25% more than the present day! On the other side of the coin, Limestone is the fundamental raw material for the production of OPC, in the wake of increasing worldwide demand, restricted natural resources of it may face a possible scarcity in approaching 25 years [1]. Consequently, it seems evidently that now the time has came to go green by limiting or abolishing the use of OPC since its production process poses scores of challenges to not only environment by contributing to dilemma of global warming through emission of CO_2 but also in conservation of restricted natural resources disrupting the eco-system on the globe and a threatening to lives on it.

Quite recently, an innovative mortar of Geopolymeric origin has attracted the attention of researchers on account of its excellent attributes. Geopolymer mortar is an inorganic construction material which is found durable and sustainable by touching acceptance limits. Geopolymer construction technology has lent its hand in order to offer the same through the exhibition of their excellent strength, durability, thermal, freeze thaw, etc. attributes establishing them as novel promising sustainable construction materials.

On the other hand, an application of Geopolymeric construction materials have come forward as the best alternatives lending a hand for solving the above challenges. At a glance, Geopolymers are inorganic solid and stable Alumino-silicates material formed by a low temperature exothermic reaction among Alkali hydroxide or Alkali silicate activation of a pozzolonic precursor like Fly Ash, Blast Furnace Slag, etc. in alkaline medium through the process of Geopolymerization. These user and eco-friendly innovative materials for construction exhibit excellent properties. Moreover, Geopolymeric building materials can be manufactured by consuming diverse wastes found profuse in landfills creating health hazards. The incorporation of wastes by-products not only make them cost-effective but also provide a systematic solution for their management too. Their types vary as per utilization of different precursors from industrial by-product, etc. and a variety of concentrations of Alkali Hydroxide and Alkali Silicates ratios as activators. Also, these cementitious pozzolonic by-products replace OPC as a binder material in making mortar.

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For this reason, countless researchers investigated on the substitution of OPC in conventional concrete and mortar with Geopolymer concrete and mortar.

Geopolymers are inorganic Zeolite like materials which can be produced by reaction between pozzolanic Alumina and Silica rich precursor and alkali activators through an exothermic process of Geopolymerization at low temperature in alkaline medium. Fly Ash is such an Alumina and Silica rich pozzolanic industrial by-product found in copious quantity filling lands and posing challenges of not only health hazards but also polluting air, soils, surface and sub-surface water. As a result, to get rid of such a titanic amount wastes of Fly Ash its systematic disposal management is the need of the hour. Thus, to use it for manufacturing of Geopolymer mortar can lend a hand to solve the purpose. This study throws lights on a range of aspects like strength of Geopolymer mortar.

II. PREVIOUS RESEARCH

Mechanical strength and durability of the geopolymer mortar are essentially governed by the type of geopolymer gel, the microstructure of the final product. Study of the microstructure of the geopolymer mortar gives the opportunity to understand the mechanism and influence of the particular parameter on the performance of the mortar. Various researchers used advanced analytical techniques such as SEM (Scanning Electron Microscope) and XRD (X-Ray diffraction) techniques for delving deeper into and understanding the microstructure of the geopolymer.

Xueying L. et al. [17], investigate the workability, compressive strength and microstructure for geopolymer pastes and mortars made of class C fly ash at mass ratios of water-to-fly ash from 0.30 to 0.35. In XRD patterns, they observed un-reacted quartz and some reacted product. They reported that the SEM examination indicated reacted product has formed and covered the unreacted particles in the paste and mortar that were consistent with their high strength.

Sahana. R. [18], reported the Scanning Electron Microscopy (SEM) is to ascertain the microstructure properties of the produced polymeric pastes of the samples. She investigates the combination of Fly ash and GGBS which varies from 100 percent of fly ash to 100 percent of GGBS, using 12M solution a 50mm cubes were cast and compressive strength were determined after 7days. She suggests that the Scanning Electron Microscopy (SEM) image gives an approximate idea about the size of particles. The shape of the particle in the material can be easily identified with the study. The images can be taken for the required magnification.

Radomir Z. et al. [19], investigated the influence of synthesis parameters on the mechanical properties of the fly-ash-based geopolymer paste and mortars. They also show the influence of an addition of limestone sand on the microstructure of fly-ash-based geopolymers.

Bakri A.M. et al. [20], reported that the microstructure of the optimum strength geopolymer appears to be homogenous and contains minimum proportion of unreacted fly ash microspheres, with continuous matrices of aluminosilicate and microcracks.

Ranjbar. N. et al. [21], Explained that the development of compressive strength of plam oil fuel ash (POFA)/ Fly ash (FA) based geopolymers was investigated using X-ray florescence (XRF), X-ray diffraction (XRD), Fourier transform infrared (FTIR), and field emission scanning electron microscopy (FESEM). They were observed that the particle shapes and surface area of POFA and FA as well as chemical composition affects the density and compressive strength of the mortars.

Thakur and Ghosh [22],they show that The effect of main synthesis parameters such as alkali content, silica content, water to geopolymer solid ratio and sand to fly ash ratio of geopolymer mixture and processing parameters such as curing time and curing temperature on development of compressive strength and microstructure of fly ash based geopolymer paste and mortar From their microstructure studies they showed formation of a new amorphous alumino-silicate phase such as hydroxy sodalite and Hersch elite, which influenced development of compressive strength.

III. EXPERIMENTAL INVESTIGATION

A. *Materials Characterization, Mix Proportioning and method*

Material characterization:

Class F fly ash, acquired from thermal power plant was used as source material in this experimental investigation. Calcium, Alumina and Silica are exhibited in higher amount in fly ash particles. Fly ash particles are sedate of spherical shape particles. These types of spherical particles increase the workability of fresh geopolymer concrete. The XRD analysis of fly ash, disclosing the Hematite, Magnetite, Quartz and Mullite minerals in fly ash.

Locally available aggregates were used in this experimental work. Crushed basalt aggregate was used as coarse aggregate having, specific gravity, a maximum size, water absorption and fineness modulus 2.59, 20 mm, 0.5% and 2.7, respectively [8]. Fine aggregate, water absorption, fineness modulus, specific gravity of 0.5%, 2.56 and 2.61, respectively [8].

Sodium silicate and Sodium hydroxide were used as alkaline activator. Sodium hydroxide flakes having 98% purity in distilled water were used. The flakes were dissolved in distilled water to prepare sodium hydroxide solution with concentration of 8M, 11M and 14M (M = Molarity). The alkaline solution was prepared by mixing solutions of sodium hydroxide and sodium silicate [14].

Preparation of geopolymer Mortar specimens:

To prepare the geopolymer mortar specimens, fly ash and alkaline activating solution (NaOH and Na_2SiO_3) were blended in predefined proportions using mortar mixture machine. Further, the fine aggregate was mixed into the activated fly ash mix paste for a further 5 min. The prepared mortar was mixed up to a good consistency, and the prepared mortar was poured into steel moulds of length 50 mm, breadth 50 mm, and height 50 mm. The moulds were vibrated for 2 min to remove entrapped air. The specimens were preserved at room temperature for a duration of 300 min.

The specimens were cured at a constant temperature of 60°C or 90°C for 24 h. After curing, the mortar samples were removed by unpacking the moulds and kept at room temperature. The mix proportions details are shown in Table-I.

Table- I: Mix Proportion

S.N	Test legends	NaOH concentration	aggregate to binder ratio	Curing temperature (°C)
1	S-1	14M	1:1	60°
2	S-2	14M	2:1	60°
3	S-3	14M	3:1	60°
4	S-4	11M	1:1	60°
5	S-5	11M	2:1	60°
6	S-6	11M	3:1	60°
7	S-7	8M	1:1	60°
8	S-8	8M	2:1	60°
9	S-9	8M	3:1	60°
10	S-10	14M	1:1	90°
11	S-11	14M	2:1	90°
12	S-12	14M	3:1	90°
13	S-13	11M	1:1	90°
14	S-14	11M	2:1	90°
15	S-15	11M	3:1	90°
16	S-16	8M	1:1	90°
17	S-17	8M	2:1	90°
18	S-18	8M	3:1	90°

Test Programme:

Compressive strength

Based on the literature, several parameter combinations of the alkaline activator to fly ash ratio, sodium silicate to sodium hydroxide ratio, curing time, and delay time were adopted for the mix compositions. The delay time refers to the time duration between pouring the mix into the moulds and the start of curing by heating. The value of the alkaline activator to fly ash ratio, sodium silicate to sodium hydroxide ratio, and delay time were set to 0.4, 1, and 5 h, respectively. In the present study, the NaOH concentration, aggregate to binder ratio, and curing temperature were varied while the above-mentioned parameters were held constant. Table-I summarizes the test programme for Series A. It is important to note that the test programme given in Table-I was conducted twice: in Series A1, samples were cured for up to 7 days, whereas in series A2, the samples were cured for up to 28 days.

IV. EXPERIMENTAL METHODS

A. *Compressive Strength:*

The mortar samples obtained after curing were subjected to compression tests. Specimens were tested according to IS-2250 [13]. Three samples with an identical mix design were tested using machine CTM. The average compressive strength was computed from these samples. Further, crushed samples were obtained for further microscopic analyses. The crushed powder was used to analyse the mineralogical composition and structural arrangement.

V. RESULT ANALYSIS AND DISCUSSION

A. *Influence of NaOH Concentration on Compressive Strength:*

The results for series A are reported in terms of compressive strength. The compressive strength of each mix composition was computed by taking the average compressive strength obtained from the three samples with identical compositions. As discussed in Table-I, the present section shows the influence of mix composition parameters on the compressive strength of the mortar.

Fig. 1 and 2 show the variation in compressive strength achieved after 7 days with respect to the concentration of NaOH. As can be seen, the compressive strength increases with the concentration of the alkali activator. The increase in compressive strength can be attributed to the greater amount of leaching of Si^{4+} and Al^{3+} ions. The leaching of Si^{4+} and Al^{3+} ions leads to the formation of alumino-silicate gel, which in turn provides compressive strength to the mortar sample. The maximum compressive strengths for the mortar cured at 60°C and 90°C are 30.53 MPa and 32.92 MPa, respectively. The maximum compressive strengths are given by the 14M concentration of the alkali activator.

Fig. 3 and 4 compare the variation in compressive strength (after 28 days) of the mortar cured at temperatures of 60°C and 90°C with respect to the concentration of NaOH. It can be observed that the compressive strength increases significantly with the addition of NaOH at increased concentrations (8M, 11M, and 14M). The increased compressive strength is a result of the higher dissolution of Si^{4+} and Al^{3+} ions, which results in the presence of more alumino-silicate gel within the matrix of the mortar. The alumino-silicate gel attains compressive strength when subjected to higher temperature. The increase in temperature (up to a certain extent) may help in achieving higher strength, which is evident from the higher compressive strength in the mortar cured at 90°C than in that cured at 60°C.

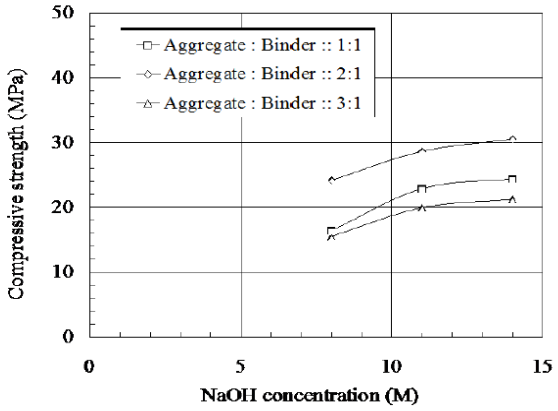

Fig. 1 Variations in 7 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 60°C)

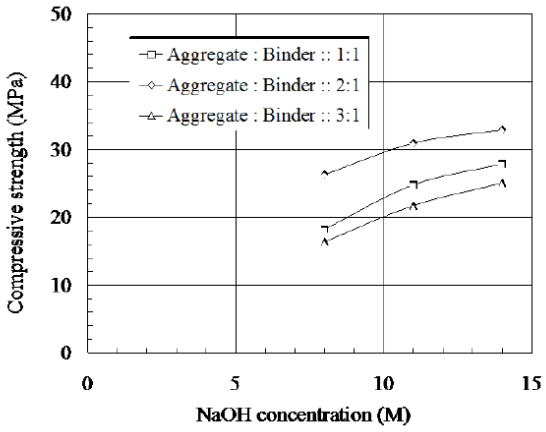

Fig.2 Variations in 7 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 90°C)

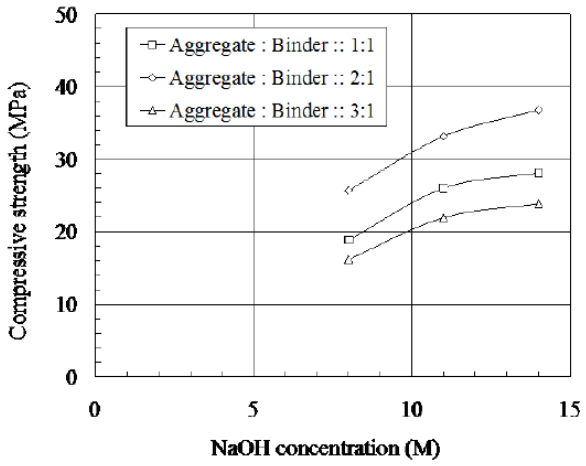

Fig.3 Variations in 28 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 60°C)

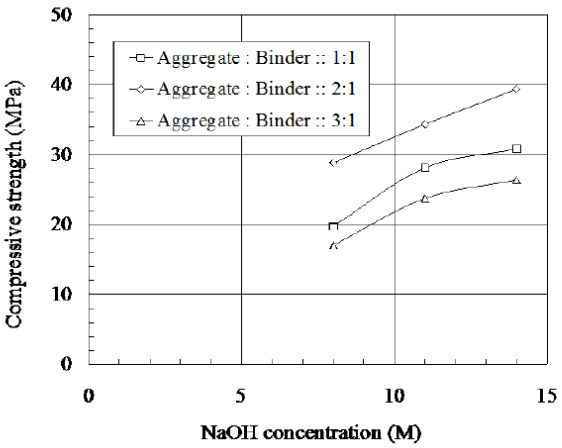

Fig.4 Variations in 28 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 90°C)

B. *Influence of Aggregate to Binder Ratio on Compressive Strength:*

Fig. 5 and 6 depict the variation in the 7-day compressive strength of geopolymer mortar with respect to changes in the aggregate to binder ratio. For this purpose, various concentrations of NaOH were used. It can be seen that the compressive strength of the mortar increases as the aggregate ratio decreases from 3:1 to 2:1. Further, a decrease in aggregate content from 2:1 to 1:1 causes a decrease in compressive strength. The compressive strength of alkali-activated fly ash geopolymer mortar is governed by the strength of the binder (alkali-activated fly ash) and proper bonding between the fine aggregate and binder material. An increase in compressive strength at low aggregate to binder ratios can be attributed to proper bonding between the fine aggregate and geopolymer paste. Further, a decrease in compressive strength following a decrease in aggregate content can be attributed to the increased porosity of the geopolymer mortar in the presence of a smaller fraction of fine aggregates.

The influence of changes in the concentration of sodium hydroxide on the compressive strength of similar specimens was investigated. For each concentration of NaOH, an identical pattern of variation in compressive strength was observed with respect to the change in aggregate content. However, specimens prepared with high concentrations of NaOH possessed higher compressive strengths. This is because of the increased alkali activation of fly ash and proper leaching of Al^{3+} and Si^{4+} ions from fly ash to the geopolymer matrix.

Fig. 6 demonstrates the variation of the 7-day compressive strength of geopolymer mortar with respect to the aggregate and concentration of NaOH for a curing temperature of 90°C. The nature of this curve is identical for curing temperatures of 60°C and 90°C. Maximum compressive strengths of 26.31 MPa, 30.93 MPa, and32.92 MPa were obtained for NaOH concentrations of 8M, 11M, and 14M, respectively, at the optimum binder to sand ratio of 2:1.

Figs. 7 and 8 demonstrate the variation in 28-day compressive strength with respect to the concentration of NaOH and aggregate to binder ratio for specimens cured at temperatures of 60°C and 90°C. Maximum compressive strength was attained by mixing an aggregate-binder ratio of 2:1 for NaOH concentrations of 8M, 11M, and 14M. Higher compressive strength was observed for higher concentrations of NaOH, which signifies the importance of leaching phenomena in achieving good compressive strength.

Further, the influence of curing temperature on the compressive strength was also examined. It was found that the higher curing temperature resulted in higher compressive strength. This is because the geopolymer matrix hardens under heating.

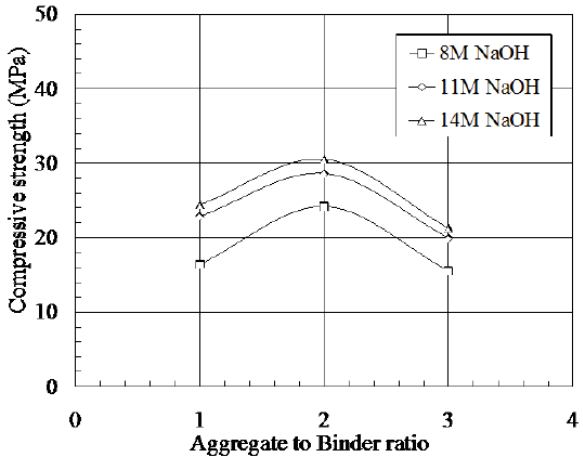

Fig.5 Variations in 7 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 60°C)

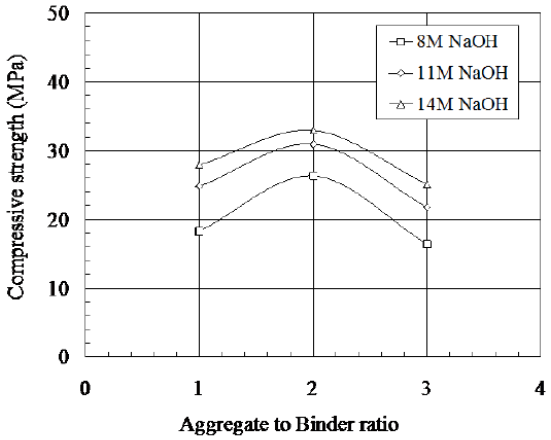

Fig.6 Variations in 7 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 90°C)

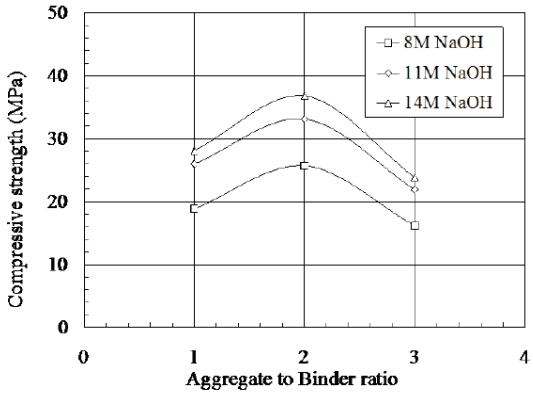

Fig.7 Variations in 28 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 60°C)

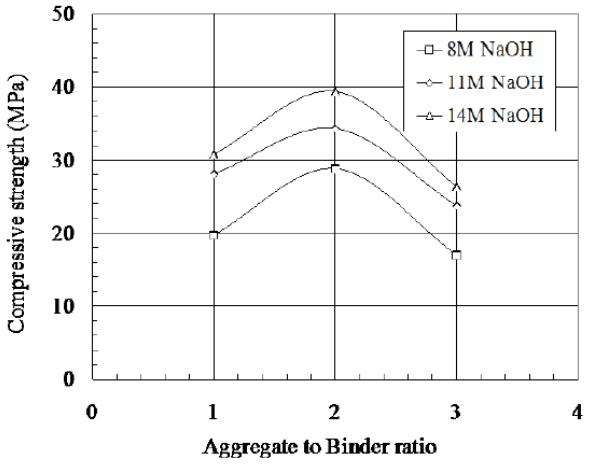

Fig.8 Variations in 28 days compressive strength of mortar with NaOH concentration (curing temperature (Tc) = 90°C)

VI. CONCLUSION

In this study, the effect of mix composition parameters and process parameters on the performance of the alkali activated geopolymer mortar was examined.The following conclusions can be drawn from this study:

1) NaOH helps the dissolution of fly ash and its dissolution into the mortar matrix. Higher concentrations of NaOH lead to the formation of a gel that increases the compressive strength.
2) The influence of the aggregate to binder ratio was investigated, and the optimum ratio for maximum compressive strength was identified. In the present study, an aggregate to binder ratio of 2:1 was found to be optimal, as this ensures suitable compactness of the mortar, as evident from the porosity values.

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