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Effct of NA2SIO3/Naoh on Compressive Strength of Fly Ash and GGBS Based Geopolymer Mortar

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***Abstract:*— Geopolymer concrete is an innovative alternative material for cement concrete thus decreasing greenhouse emissions and leading to better construction practices and is produced by complete replacement of cement and water with fly ash and GGBS & alkaline activators. To examine the use of Geopolymer as replacement to cement, it is essential to study the properties of binders and their combinations in preparing Geopolymer mix. The present research aims at studying the effect of fly ash and GGBS combination on Mechanical properties of Geopolymer mortars and also the effect of Na2SiO3/NaOH ratios on the production of fly ash and GGBS based geopolymer. Sodium silicate and sodium hydroxide (NaOH) solution were used as alkaline activator with a NaOH concentration of 4M. The geopolymer samples were prepared with different fly ash and GGBS contents and Na2SiO3/NaOH ratios (1.5, 2.0, 2.5and 3).The main evaluation technique in this study were compressive strength. The parameters considered in this research work are proportions of fly ash and GGBS (100-0, 75-25, 50-50, 25-75 and 0-100), Ratio of Na2SiO3/NaOH, curing condition is taken as the outdoor curing.**

***Index Terms* - Alkaline activator, Compressive Strength, outdoor curing, Geopolymerisation, Geopolymer Mortar**

I. INTRODUCTION

The most important material that plays the role of binder in the concrete production is ordinary Portland cement (OPC).Cement binds aggregate and loose materials in concrete but usage of cement releases enormous amount of carbon dioxide (CO2) and causes environmental pollution. Also, further production of OPC leads to reduction in raw materials. To overcome these problems, geopolymer concrete (GPC) has been introduced that can completely eliminate cement with by-products and water with alkaline solution. To produce geopolymer concrete, coarse and fine aggregate used in cement concrete industry can be used along with fly ash and GGBS as binders [1-2]. Fly ash is rich in alumina, silica and possesses pozzolanic properties that can react with alkaline activators to form alumino silicate hydrate. The strength of the fly ash based geopolymer concrete is due to alumino silicate hydrate, which forms due the polymeric chain process, whereas, in case of GGBS based geopolymer concrete, the strength gain is due to formation of the calcium silicate hydrate gel during the polymerization with alkaline solution. Thus GGBS based geopolymer concrete gives improved properties than fly ash based geopolymer concrete [3]. Hence it can be said that the strength and mechanical properties of geopolymer concrete depends on the proportions of fly ash and GGBS and also the type of curing. Alkaline solution made with the combination of Sodium Hydroxide (NaOH) and Sodium Silicate (Na2SiO3) are suitable solutions as alkaline activators for the preparation of GPC. Any change in proportions of binders (fly ash and GGBS), molarity of NaOH solution, ratio of Na2SiO3/NaOH, curing temperature will affect the concrete compressive strength. Alkali hydroxide is required for the dissolution process of aluminosilicate sources, while Na2SiO3 solution acts as binder [4]. [Villa et al., 2010] [5] Studied the influence of the Na2SiO3/NaOH ratio (0.4, 1.5, 5.0, 10.0, and 15.0) in natural zeolite based geopolymers showed that increasing the Na2SiO3/NaOH ratio up to 1.5 increased the compressive strength, but beyond that the strength was decreased. This may be due to excessive sodium silicate that retarded the geopolymerisation process by the precipitation of Al-Si phase, which prevented contact between the reacting material and activating solution and decreased the activator content **[6].** The optimum usage of Na_2SiO_3/NaOH ratio to produce high strength geopolymer is in the range 0.67–1.00 suggested by the researchers **[7].** Research studies suggested that the better compressive strength was achieved with NaOH solution at 8M-12M and Na_2SiO_3/NaOH ratio as 2.5 **[8-9].** Curing is also important in attaining sufficient strength. Different research experiments concluded that the compressive strength of hot air oven cured fly ash based geopolymer concrete specimens cured at 60ºC was higher than ambient cured specimens cured at room temperature i.e., 25±2ºC **[10].Chen and Chiu** reported the only information available to date on the quantitative measure of the setting time of geopolymer material using the Vicat's needle **[11]. Hardjito** carried out tests on strength and setting times of low calcium fly ash based geopolymer mortar. The test results revealed that as the concentration of alkaline

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activator increases, the compressive strength of geopolymer mortar also increases. Specimens cured at temperature of 65˚C for 1 day showed the highest 28 days compressive strength **[12].** Compressive strength development in ambient cured geo-polymer mortar using marginal materials / industrial by-products for sustainable development is studied by **Manjunath [13]. Sahana.R** reported that the inclusion of GGBS at different replacement levels below 40% increases the setting time of mortar, but beyond this level, the setting time decrease and this could lead to loss of workability **[14]. Deb PS** described that the workability decreased with the high content of GGBS due to accelerated reaction of the calcium and the angular shape of GGBS **[15].** In this study, an attempt has been made to prepare geopolymer mortars with fly ash and GGBS and hardened properties such as compressive strength were determined as per relevant Indian and ASTM standards.

II. RESEARCH SIGNIFICANCE

Though many researchers proposed different methodologies for fly ash based geopolymer samples, still research work is to be concentrated on combination of fly ash and GGBS at different curing conditions **[16].** Hence proper quantification for geopolymer concrete materials is necessitated to use GPC with ease for practical applications. In this paper, an attempt was made to study the effect the effect of the Na_2SiO_3/NaOH ratio on fly ash and GGBS based geopolymer mortars. From the experimental results the geopolymer samples were prepared with different fly ash and GGBS contents and Na_2SiO_3/NaOH ratios (1.5, 2.0, 2.5, and 3.0) the maximum strength is produced when the ratio of Sodium Hydroxide to Sodium Silicate Solution in an alkaline activator was 2.5.

III. EXPERIMENTAL PROGRAM

The experimental Program consisted of finding the hardened state properties of geopolymer mortars by casting specimens of three different combinations of fly ash and GGBS (100-0, 75-25, 50-50, 25-75 and 0-100). Total of 480 cubes of size 100mmx100mmx100mm were casted and tested for determining the effect of Na_2SiO_3/NaOH for two different grades with varying the Na_2SiO_3/NaOH as 1.5, 2, 2.5 and 3.0 and the concentration of NaOH solution is taken as 4M.

1) Materials

Fly ash and ground granulated blast furnace slag are used as source materials in the present study. ground granulated blast furnace slag is obtained from Toshali Cements Pvt ltd, Bayyavaram, India and Fly ash is collected from National thermal power plant, Ramagundam, India. Specific gravity of Fly ash and GGBS are 2.17 and 2.90 respectively. Chemical Composition details are shown in Table I. The morphology of Fly ash and GGBS were examined using Scanning electron Microscope (SEM). Fly ash particles were spherical in shape. The Fly ash is mainly composed of large percentages of silica and alumina. The shape of the GGBS grains is crystalline and angular form and From the EDAX, it can be observed that GGBS is predominated with calcium and silica while compared to other elements. The mineralogical characterization of fly ash and GGBS sample has been carried out for the X-Ray diffraction analysis which has been shown in Fig. 3 and Fig. 4.

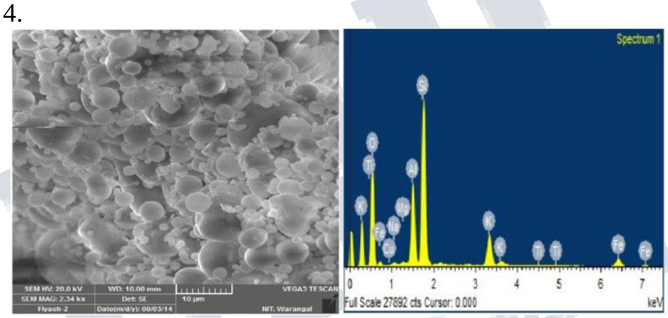

Fig 1: Scanning electron microscope of fly ash and EDXA of fly Ash

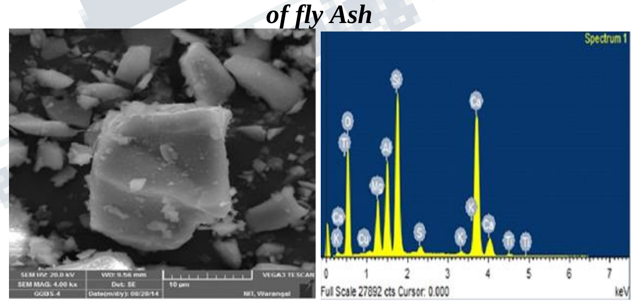

Fig 2: Scanning electron microscope of fly ash and EDXA of GGBS

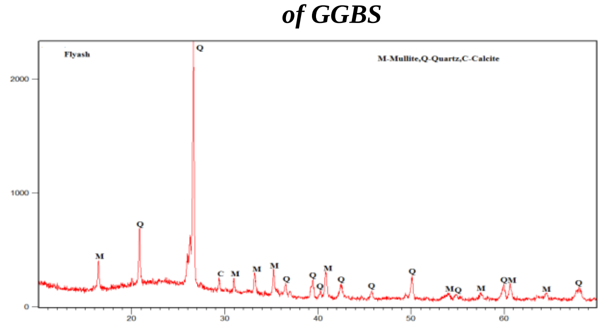

Fig 3.XRD analysis for fly ash

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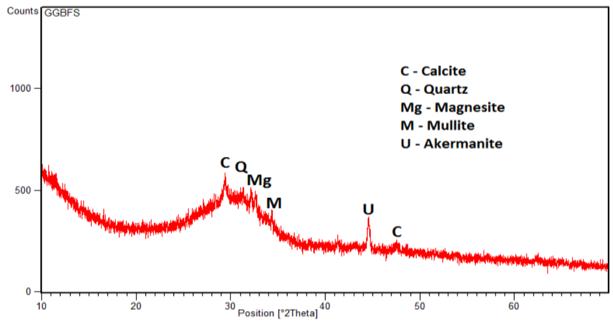

Fig 4.XRD analysis for GGBS

Table I. Chemical composition of fly ash and GGBS (% by mass)

Chemical Composition	Fly ash	GGBS
SiO_2	60.11	34.06
Al_2O_3	26.53	20
Fe_2O_3	4.25	0.8
SO_3	0.35	0.9
CaO	4.00	32.6
MgO	1.25	7.89
Na_2O	0.22	NIL
LOI	0.88	NIL

Preparation of Alkaline Solution

Molarity of NaOH solution plays a crucial role in the strength of geopolymer concrete. The nominal molarity for fly ash and GGBS mixes range from 2–10 M, but higher strength can be obtained when the concentration approaches the maximum range **[17].** From 8M to 16M there was a rise in the compressive strength for all mixes **[18].** According to previous studies it was found that with the higher concentration of NaOH solution i.e. above 10M, a lower rate of polymerization takes place and results in decreased compressive strength **[19].** In present experimental work examines the properties of geopolymer concrete were examined with 4M NaOH.

160 gms of NaOH pellets were dissolved in potable water to make one litre of 8M sodium hydroxide solution. To achieve the required strength the ratio of sodium silicate solution to sodium hydroxide solution is considered as 2.5 and the mixed solution is stored for 24 hours at room temperature (25±2ºC) and relative humidity of 65%, before it is used for casting. Because dissolution of NaOH in water is an exothermic reaction and a substantial amount of heat will be generated when added in concrete, hence the heat liberated is to be reduced and come down to room temperature

Mortars

The fine aggregate, fly ash and GGBS are dry mixed before adding to the alkaline solution for 2 minutes in an electrically operated mortar mixer. The calcined source materials, fine aggregate and alkaline solution are mixed for another 10 minutes in mortar mixer to ensure homogeneity. The fresh mixes prepared are cohesive and segregation resistant. Conventional table vibrator is used for compaction of the mortar. Steel moulds of dimensions 100mm × 100mm ×100mm are used for casting cube mortar specimens. The specimens are demoulded after 24 hours of casting and cured in outdoor and oven. For outdoor curing, specimens are left out in outdoor (Temperature- 35±2^{0}C and relative humidity - 75%) up to specified age of testing. Temperature and humidity control is not necessary for outdoor cured specimens.

Mix Proportions of Fly ash-GGBS Geopolymer Mortars

Five mixes were proposed according to the ratio of Fly ash - GGBS. The percentage ratio of Fly ash: GGBS was selected as 100:0, 75:25, 50:50, 25:75 and 0:100 for the source material. The ratio of Na_2SiO_3/NaOH was varied as 1.5, 2.0, 2.5 and 3.0. By assuming the alkaline liquid to binder ratios as 0.5.The molarity of alkaline activator is chosen as 4M. The density of geopolymer samples are varied is 2000-2200 kg /m^3. By knowing the density of mortars the amount of binder and quantity of alkaline liquids were determined.

Table II: Mix Proportions of geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 1.5

Mix ID/ Proportion of binders	Fly ash (kg/m^3)	GGBS (kg/m^3)	Fine Aggregate (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Alkaline liquid (kg/m^3)
	Na_2SiO_3/NaOH = 1.5					
$M_1F_{100}G_0$	880	0	880	176	264	440
$M_2F_{75}G_{25}$	660	220	880	176	264	440
$M_3F_{50}G_{50}$	440	440	880	176	264	440
$M_4F_{25}G_{75}$	220	660	880	176	264	440
$M_5F_0G_{100}$	0	880	880	176	264	440

Table III: Mix Proportions of geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 2

Mix ID/ Proportion of binders	Fly ash (kg/m^3)	GGBS (kg/m^3)	Fine Aggregate (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Alkaline liquid (kg/m^3)
	Na_2SiO_3/NaOH = 2					
$M_1F_{100}G_0$	880	0	880	146.66	293.32	440
$M_2F_{75}G_{25}$	660	220	880	146.66	293.32	440
$M_3F_{50}G_{50}$	440	440	880	146.66	293.32	440
$M_4F_{25}G_{75}$	220	660	880	146.66	293.32	440
$M_5F_0G_{100}$	0	880	880	146.66	293.32	440

Table 1V: Mix Proportions of geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 2.5

Mix ID/ Proportion of binders	Fly ash (kg/m^3)	GGBS (kg/m^3)	Fine Aggregate (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Alkaline liquid (kg/m^3)
	Na_2SiO_3/NaOH = 2.5					
$M_1F_{100}G_0$	880	0	880	125.7	314.28	440
$M_2F_{75}G_{25}$	660	220	880	125.7	314.28	440
$M_3F_{50}G_{50}$	440	440	880	125.7	314.28	440
$M_4F_{25}G_{75}$	220	660	880	125.7	314.28	440
$M_5F_0G_{100}$	0	880	880	125.7	314.28	440

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Table V: Mix Proportions of geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 3

Mix ID/ Proportion of binders	Fly ash (kg/m^3)	GGBS (kg/m^3)	Fine Aggregate (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Alkaline liquid (kg/m^3)
	Na_2SiO_3/NaOH = 3					
$M_1F_{100}G_0$	880	0	880	110	330	440
$M_2F_{75}G_{25}$	660	220	880	110	330	440
$M_3F_{50}G_{50}$	440	440	880	110	330	440
$M_4F_{25}G_{75}$	220	660	880	110	330	440
$M_5F_0G_{100}$	0	880	880	110	330	440

IV. RESULTS AND DISCUSSIONS

The results of the different tests are discussed and analyzed to study the strength properties of geopolymer Mortars. Four different mixes are prepared varying Fly ash and GGBS 100:0, 75:25, 50:50, 25:75 and 0:100 with Alkaline/Binder Ratio is maintained constant for all the mixes as 0.5 for different Na_2SiO_3/NaOH ratios as (1.5,2.0 2.5 and 3.0) and curing regime is selected as outdoor in order to eliminate the oven curing. Three cubes of each geopolymer mortar set with dimensions 100mm × 100mm × 100mm were cast and tested in compression for 1,3 7 and 28days compressive strength.

A. Compressive strength

The compressive strengths of geopolymer mortars having different proportions of fly ash and GGBS along with different Na_2SiO_3/NaOH ratios and sodium hydroxide is maintained constant are presented in figures 5, 6, 7 and 8. The compressive strength of geopolymer mortar ranges from 0.5 MPa to 59MPa. The outdoor cured samples have shown variation in compressive strength with variation of both the Na_2SiO_3/NaOH and GGBS content in the mix. Increase in Sodium Silicate to Sodium Hydroxide in alkaline activator increased the compressive strength of the mortars up to some extent of ratio 2.5 and there is a degradation of strength at ratio 3 and similar trend is reported by **Mustata Al Bakri [10]**. In case of outdoor cured samples, increase in percentage of replacement of fly ash by GGBS increased the compressive strength of geopolymer mortar. Total replacement of fly ash by GGBS has shown a compressive strength of 59MPa. This indicates that geopolymer can attain strength even under outdoor curing if GGBS and Fly ash together are used as source material. The reason for increase in compressive strength due to GGBS can be attributed to higher calcium content present in GGBS **[21].**

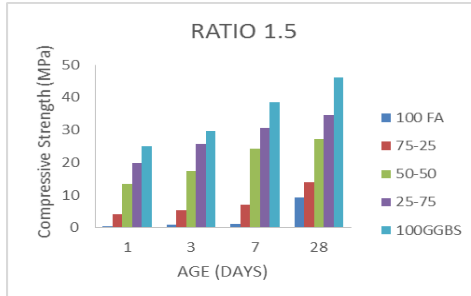

Fig. 5: Compressive Strength of Geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 1.5

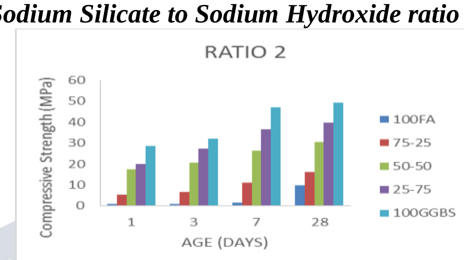

Fig. 6: Compressive Strength of Geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 2

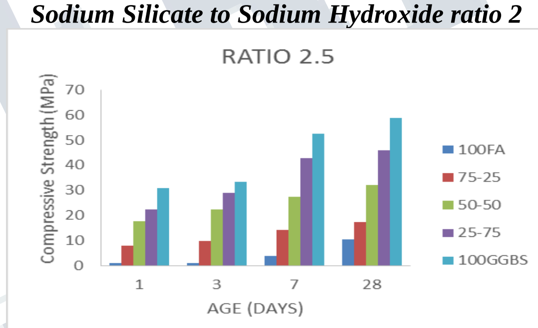

Fig. 7: Compressive Strength of Geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 2.5

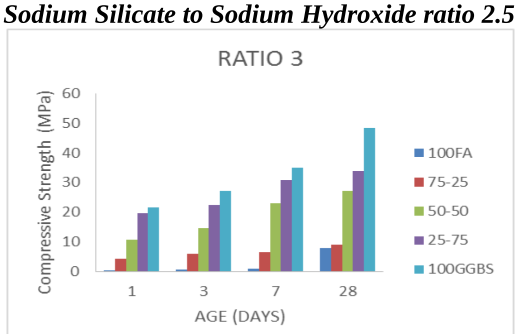

Fig. 8: Compressive Strength of Geopolymer Mortar of Sodium Silicate to Sodium Hydroxide ratio 3

B. Effect of Na_2SiO_3/NaOH Ratios on the Compressive Strength of Geopolymer Mortar

The strength of the geopolymer mortars with different fly ash and GGBS contents and Na_2SiO_3/NaOH ratios is shown in Figures 5,6,7 and 8. For different binder contents,

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at different Sodium Silicate to Sodium Hydroxide ratios the maximum compressive strength was obtained at a Na_2SiO_3/NaOH ratio of 2.5. The compressive strength of geopolymer concrete increased when the amount of Na_2SiO_3 increased up to 2.5.The use of Na_2SiO_3 helps to improve the geopolymerisation process by accelerating the dissolution of source material **[Xu, H. van Deventer, J.S.J., 2000].** The highest compressive strength for 100% GGBS is 59 MPa were observed at Na_2SiO_3/NaOH ratio of 2.5. The increase in compressive strength due to the increase in the sodium content, which mainly required for the polymerization process. The compressive strength of the product for a Na_2SiO_3/NaOH ratio of 3 was low, however which could be due to the excess OH^- concentration in the mixtures. The excess sodium content can form sodium carbonate by atmospheric carbonation and this may disrupt the polymerization process **[Barbosa, V.F.F. Mackenzie, K.J.D and Thaumaturgo, C., 2000].**

C. Effect of age on strength of geopolymer Mortar

The work has attempted to estimate the strength of geopolymer mortar at 1, 3, 7 and 28 days strength. The strength of geopolymer concrete depends mainly on curing regime, type of binder content and molarity of alkaline activator and the ratio of sodium silicate and sodium Hydroxide Solution. The gain of strength is faster at early age compared to that later age. This was observed in Outdoor curing in order to eliminate the hot air oven curing. The mortar cubes were cast and cured for 1, 3, 7 and 28 days were tested for evaluating its compressive strength. The initial curing temperature influences the polymerization process. Before the age of 7 days, the gain in the strength was very less in the outdoor curing for all the mixes. In outdoor curing the gain in the strength is less due to slow polymerization process. Compressive strength of all the combinations increased over the time and higher at 28 days for the mix 0:100 at Na_2SiO_3/NaOH 2.5. The gels which are formed during polymerization is responsible of the mechanical development of fly ash and GGBS based materials. With the age of curing, a higher amount of gels was formed. The mixes containing the more slag gives the better strength than other mixes due to their chemical composition and their slag content had much effect on strength development of the geopolymer samples at any age.

D. Effect of Ca/Si on the compressive strength of Geopolymer Mortar

The compressive strength of geopolymer mortars cube for outdoor were shown in the figures 9, 10, 11 and 12. GGBS plays an important role for compressive strength development. A higher dosage of GGBS results in a higher compressive strength of geopolymer mortar. The compressive strength of geopolymer mortars is shown in figures 5, 6, 7 and 8. Mix with 100% fly ash shows the less compressive strength among all the mixes. The mixes with 75FA-25GGBS, 50FA-50GGBS, 25FA-75GGBS and 0FA-100GGBS shows the higher compressive strength with inclusion of GGBS content in the mix produced the highest strength, while a further decrease in the GGBS content reduced the compressive strength. Another reason is that the quantity of soluble Calcium content depends on the volume of GGBS present in the mixture, which has a direct effect on the compressive strength. The Ca/Si Plays an important role in attaining the strength of GPC mortar as we are increasing the Ca/Si present in the total mix there is an increase in the compressive under outdoor curing with increase in the age of the mortar. With increase in the Na_2SiO_3/NaOH ratio there is increase in the strength up to Na_2SiO_3/NaOH ratio 2.5. The calcium content present in the mix plays an important role in attaining the strength of GPC.As the GGBS content in the mix increases the strength of the geopolymer is also increases.

The Ca/Si ratio increase the strength also increases irrespective to the Sodium silicate/Sodium Hydroxide ratio. The attainment of the strength in GPC mainly depends on the GGBS content in the mix. The calcium present in the GGBS content dissolution will be more compared with silica and alumina present in the fly ash. Due to the faster dissolution the formation of the dissolution reactants like N-A-S-H gel and C-A-S-H gel will be formed and which contribute the strength for GPC.

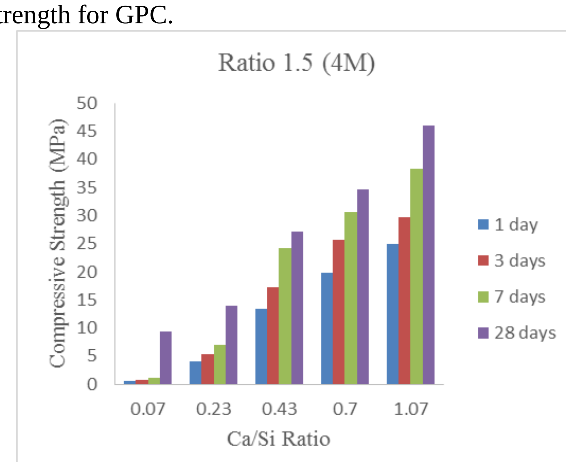

Fig. 8: Compressive Strength of Geopolymer Mortar with variation of Ca/Si ratio (Na_2SiO_3/NaOH -1.5)

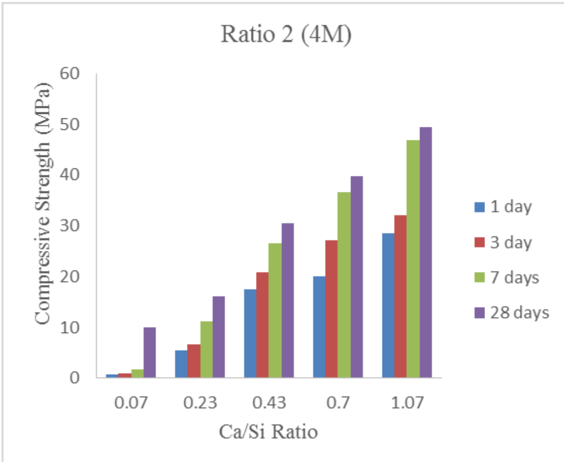

Fig 9: Compressive Strength of Geopolymer Mortar with variation of Ca/Si ratio (Na_2SiO_3/NaOH -2)

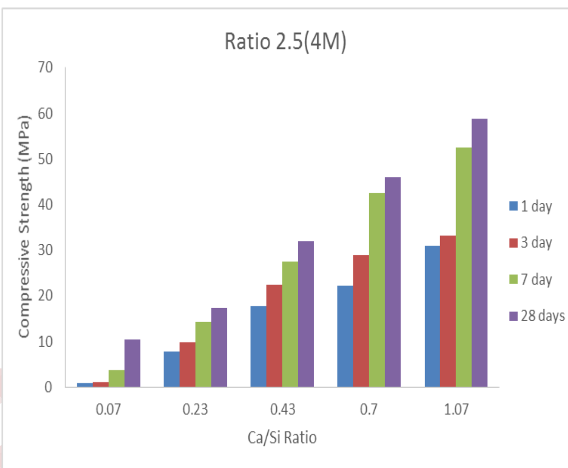

Fig. 10: Compressive Strength of Geopolymer Mortar with variation of Ca/Si ratio (Na_2SiO_3/NaOH -2.5)

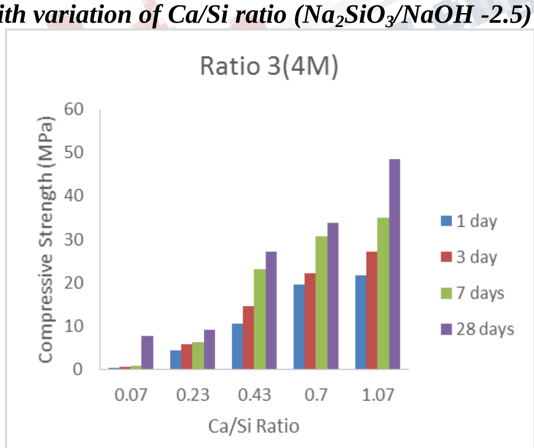

Fig. 11: Compressive Strength of Geopolymer Mortar with variation of Ca/Si ratio (Na_2SiO_3/NaOH -3)

V. CONCLUSIONS

Based on the results presented in this work, it is reasonable to assume that fly ash and GGBS are used directly affect to the final properties of geopolymers derived from waste materials. The compressive strength, investigated alkali activated binders highly depended on the blend composition. The combination of fly ash and GGBS used for the development of GPC has yielded satisfactory levels of compressive strength without the need for any heat curing. The optimum mix design for geopolymer paste using fly ash and GGBS combination Na_2SiO_3/NaOH = 2.5 with maximum compressive strength 59 MPa. The ratio of Na_2SiO_3/NaOH also plays an important role in the mix design of the geopolymer mortar.

1. The combination of fly ash and GGBS used for the development of GPC has yielded satisfactory levels of compressive strength without the need for any heat curing.
2. Compressive strength of geopolymer mortar increases with increase in percentage of replacement of fly ash with GGBS.
3. To develop geopolymer concrete under outdoor curing condition, combination of fly ash with GGBS can be a possible solution.
4. The strength of the geopolymer mortar increases with increase in the age of the mortar.
5. The Ca/Si ratio plays an important role in affecting the strength of the geopolymer mortar as there increase in Ca/Si ratio the strength of the geopolymer mortar also increases.

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