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Effect of Na_2SiO_3/Naoh on the Compressive Strength of Inorganic Polymer Concrete Mixed with Ground Granulated Blast Furnace Slag (GGBS) At Ambient Condition

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***Abstract**: This paper aims to investigate the influence of alkaline activators solution i.e, Na_2SiO_3/ NaOH on compressive strength of geopolymer concrete mixed with Ground Granulated Blast furnace slag (GGBS) for constant molarity 8 M. The ratio of alkali to binder ratio is taken as 0.5 and the ratio of Na_2SiO_3 / NaOH is 2.5. The geopolymer mix is based on pervious sutdies. As per Indian standard size moulds for the cube, cylinder and prism are cast, cured and tested.The specimens were tested for fresh concrete properties such as slump cone test and hardened properties such as compressive strength for cubes, split tensile strength for cylinders and flexural strength for prism different days of curing under ambient temperature. Also, a microstructural study is done by using Scanning electron microscopy (SEM), Energy dispersive X-ray (EDX) for the tested sample. It is found from the test results that, with the aid of alumino-silicate solution, early strength is achieved by geopolymer concrete within 7 days under ambient condition due to the presence of ground granulated slag.*

***Keywords** : Ambient Temperature, Geopolymer Concrete, Strength, SEM and EDX analysis*

I. INTRODUCTION

Spectacular building demands in new concrete materials for the last few years. There is an emerging trend in the development of new material for building construction like 'Geopolymer' also known as inorganic polymer concrete [1].Pozzolonic materials and alkaline activator are the basic components of geopolymer . Geopolymer concrete strength is based on the compound arrangement of pozzolonic materials,should be rich in silica content and alumina content [2] . The binder materials, for example, flyash, GGBS, silica fume, metakaolin etc. could be utilized as pozzolonic materials. Basic activators as soluble fluids such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) or potassium hydroxide (KaOH) and potassium silicate (Ka_2SiO_3) are used to produce geopolymer concrete [3].

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The chemical reaction happens in the assembling of geopolymers is polymerization which is arrangement at room temperature. also called as Geopolymerization [4] .Geopolymers can be used in many fields due to of their different characteristics such as higher in compressive strength , lower in shrinkage, imperviousness to acid and fire [5]. Raw materials influence the compound responses amid the union consequently the properties of geopolymers. Microstructure, physical, mechanical and synthetic properties are likewise influenced by the raw material sort [6] . Another significant factor influencing the Geopolymerization is

$$M_n^{+}[-(SiO_2)_Z - AlO_2\ -]_n \qquad (1)$$

Where, M+ is soluble base cation, n is level of polymerization and z is the Si/Al proportion. Geopolymerization includes disintegration, reorientation and hardening responses. Mutiu A. Akinpelu et al [7]. stated that the compressive strength of geopolymer will be mostly influenced by the sodium silicate solution and the presence of silica and aluminum. Zarina Yahya et al [8]. stated that the proportion of Na_2SiO_3/NaOH additionally assumes a significant job in the blend plan of the geopolymer glue. When the Na_2SiO_3 /NaOH ratio is more than 2.5, the compressive strength for S/L (1.0, 1.25, and 1.5) is usually reduced due to abundance of the alkali material which impedes the Geopolymerization process. Shima Pilehvar et al [9]. inferred that the use of sodium silicate alone or a mixture of sodium silicate and sodium hydroxide has occurred, the addition of silicates contributes to the rapid geopolymerization process leading to increased compressive strength. The use of sodium silicate material realized the improvement in the formation calcium silicate hydrate gel (C_S_H) gel in small proportion in GGBFS . Weibo Ren et al[10]. expressed that flyash/slag based geopolymer with high NaOH ,falls under adversarial procedure and flyash/slag geopolymer concrete with dissolvable silicate.

II. EXPERIMENTAL WORK

A. Materials

Ground granulated blast slag (GGBS) which is commercially available act as binder content in this study. Table 1 shows the GGBS powder sample's chemical composition.

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Sodium hydroxide solution is prepared a day before by mixing pure pellets with distilled water at a concentration of 8M. A mixture of sodium silicate and sodium hydroxide solution that is used as an alkaline activator is been prepared.

The Manufactured sand (M-Sand) is used as a fine aggregate because of the lack of river sand,. Course aggregates of size 10 mm and 20 mm, which is locally available, are used. Table 2 gives the physical properties of the materials used for preparing geopolymer concrete and Fig 1 shows the materials used to prepare geopolymer concrete mixed with GGBS. CONPLAST superplasticizer is used to enhance the fresh concrete properties ie., workability.

Table 1 GGBS powder sample's chemical composition

Composition	%
SiO_2	26.6
Al_2O_3	11.4
Fe_2O_3	0.4
CaO	58.6
K_2O	0.6
Others	2.4

Table 2 GGBS mixed geopolymer concrete materials physical properties

Materials	Specific Gravity	Fineness Modulus	Bulk Density (kg/m^3)
GGBS	2.85	3.7	1200
Na_2SiO_3	1.39	-	513
NaOH	1.52	-	961
FA	2.71	2.60	1400
CA	2.68	2.46	1650

Fig.1 Constituents of GGBS mixed Geopolymer Concrete

A. *Mix Proportions for GGBS mixed geopolymer*

In this study, ground granulated blast slag (GGBS) was used as a substitute of fly ash as binder. The ratio of sodium silicate to sodium hydroxide as 2.5. Mixing ratio decided based on the previous research work. The ggbs based geopolymer concrete mix proportions given in the Table 3. Along with GGBS, M.Sand and course aggregates thoroughly mixed in pan mixer in dry condition to form the homogeneous mix, then the super plasticizer alkaline activator which is prepared a day before mixed with the dry mix. The mixer stopped for 10 -20 sec in order remove un-mixed materials around the pan mixer. With the medium speed again the mixing is continued. Once the mixing is completed, immediately the fresh geopolymer concrete was then cast into 150 x 150 x150 mm size moulds in three layers. A vibrating table was used to do compaction. When the samples are casted, demould after 24 h and it is placed in the laboratory at ambient curing temperature range between 26 – 35 ◦C till the date of testing. The mixing of geopolymer concrete, moulds preparation, casting and curing process shown in Fig 2 & 3 respectively.

Table 3
Mix design for GGBS mixed geopolymer concrete

Molarity	8 M
Ground Granulated Blast Slag (GGBS)	298 kg/m^3
(Na_2SiO_3+NaOH) /GGBS ratio	0.5
Na_2SiO_3/NaOH	2.5
Na_2SiO_3	0.605 kg/m^3
NaOH	0.188 kg/m^3
Fine Aggregate (M-Sand)	823 kg/m^3
Coarse Aggregate	1342kg/m^3
Superplasticizer	2% of binder

Fig. 2 Mixing of geopolymer concrete and preparation of moulds for casting

Fig. 3 Casting and curing under ambient temperature of GGBS mixed geopolymer concrete

B. Testing

The fresh geopolymer concrete, slump cone test was carried out immediately after the mixing was completed.. Flow of geopolymer concrete classified as per Indian standard based upon, the type of binder, alkaline activator solution and type of curing compressive strength.

III. RESULTS AND DISCUSSIONS

A. Workability Test

Slump cone test were used to evaluate the workability of alkali-activated GGBS based geopolymer concrete. The slump value obtained for the mixture is 90 mm which is shown in Fig 4. As per IS code if the slump value ranges between 50 mm to 100 mm is categorized that it is shear slump which includes that geopolymer provides medium workability Interestingly,

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it was found that higher value of alkali-binder ratio had a significant impact on the workability of geopolymer concrete mixed with GGBS. It is well known that increase in slump value of the geopolymer concrete by increase of alkali-binder ratio due to presence of aluminosilicate solution segregate the aggregates and binder to have a better flow. Influence of fine aggregate and course aggregate on slump was significantly is very less when compare to alkali-binder ratio. The finding indicates that lesser value of alkali-binder ratio results in more viscosity in the geopolymer concrete needs more additional water for good workability.

Fig. 4. Slump test and behaviour of slump

B. Compressive Strength enhancement

Fig 5 shows the alkali-activated geopolymer concrete compressive strength test for the curing periods of 3, 7, 28, 56 and 90 days at ambient temperature which is summarized in Table 4. It can be found that quick early compressive strength is developed in the sample specimens due to the contribution of GGBS material mixed in the concrete. This is due to the reaction of calcium content [11]. Within 7days of curing period, around 70% strength is achieved. The compressive strength varies between 51.06 N/mm^2 to 83.93 N/mm2, from 3 days to 90 days age respectively at ambient curing. Since GGBS is rich in calcium content, coupling effect of calcium silicate gel (C-S-H) and calcium aluminosilicate gel (C-A-S-H) are formed during the hydration process of alkali-activated GGBS based geopolymer. This enhances the strength and also another factor that enhances the strength is a concentration of the alkali solution. From research work reported [12].increase in molarity increases compressive strength. Development of geopolymeric bonds is formed due to solubilisation of Ca, Si and Al from the calcium, silica-alumina source. The results conjointly reveal that the impact of ageing on the compressive strength is not remarkable[13].

Fig. 5 GGBS mixed geopolymer concrete compressive strength test setup

C. Tensile strength enhancement

Concrete tensile strength of concrete is a crucial mechanical property uses in many ways for concrete structures such as those related to beginning and propagation of cracks, shear, and concrete reinforcing steel anchorage. To determine the effect of GGBS on the geopolymer concrete, cylindrical specimens are cast. It is found that, split tensile strength gradually increased with respect to curing days increases. Fig 6 represents the tensile strength test sample and test setup. There is no much difference in tensile strength between 3, 7 and 28 days of ambient curing. The average tensile strength is 3.22 MPa for these days and there is an increment of 19.52 % for 56 days. There is further increment of 25.2 % on 90 days and 10% on 120 days. There is a correlation between the tensile strength and compressive strength. There are many empirical formulas also given by the codes like ACI Building Code 318-89 (revised 1992), and BS 8007:1987.

$$f_t = k\,(f_c)^n \quad (2)$$
$$f_t = 0.3\,(f_c)^{2/3} \quad (3)$$
$$f_t = 0.2\,(f_c)^{0.7} \quad (4)$$
$$f_t = 0.12\,(fc)^{0.7} \quad (5)$$

Where f_t is the split tensile strength and f_c is the compressive strength and k and n are the coefficients,

Fig. 6 Geoploymer concrete mixed GGBS spilt strength test setup

D. Flexural strength enhancement

Flexural strength of concrete and its moment of resistance is around 10 to 20 percent of compressive strength depending upon the sort, size and volume of course aggregate used. It is a proportion of an unreinforced concrete specimen to oppose disappointing in twisting. Fig 7 shows to the flexural strength test setup. The test can be done with three bending test or four bending loading. In this study three bending test is conducted and obtained results are given in Table 4. One can see the gradual increase in flexural strength. The 7 days strength is 0.51 MPa. Further there is an increase of 0.25 MPa for 7 days and 0.32 MPa for 28 days. There is only small increase from 28 to 56 days i.e., 0.06 MPa and later there is sudden increase from 0.89 MPa to 0.96 MPa for 90 days, nearly 7.3% increase. And for 120 days the strength is not much increased. It is about 0.02 MPa.

Fig. 7 Geoplymer concrete mixed GGBS flexural strength test setup

The concrete attains the maximum strength at this stage. The flexural rigidity increases with the increment of age and quality of cement. The corresponding higher in the flexural strength at the same time of binder continues to decrease with an increase in the dimension of concrete strength [14]. Fig 8. Shows effect of Na_2SiO_3/NaOH on compressive strength of geopolymer concrete mixed with GGBS for various ambient curing days. Fig. 9 Effect of Na_2SiO_3/NaOH on development of split and flexural strength of GGBS mixed geopolymer concrete. Also, one can correlate the strengths i.e. between compressive and tensile strengths and compressive and flexural strengths by using regression analysis. Fig. 10 and 11, it is stated that a linear regression curve is drawn and the strength parameters are imposed on the linear regression curve. Generally, a regression is the statistical analysis used to predict the information. So, in the present study it is determined and the errors are also showed in the data labels in the graphs.

Table 4 Mechanical strengths properties of GGBS mixed geopolymer concrete for various age of ambient curing

Curing days	Compressive strength (N/mm^2)	Split Tensile strength (N/mm^2)	Flexural strength (N/mm^2)
3	51.06	3.07	0.51
7	56.00	3.21	0.76
28	65.33	3.38	0.83
56	79.33	4.20	0.89
90	80.88	5.62	0.96
120	83.93	6.25	0.98

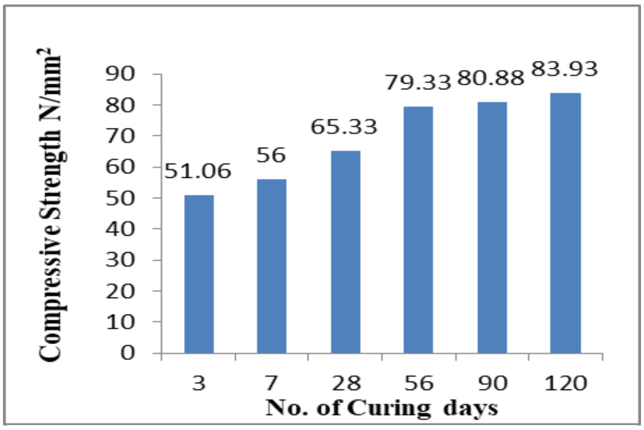


Fig. 8 Effect of Na_2SiO_3/NaOH on compressive strength for various curing days at ambient condition

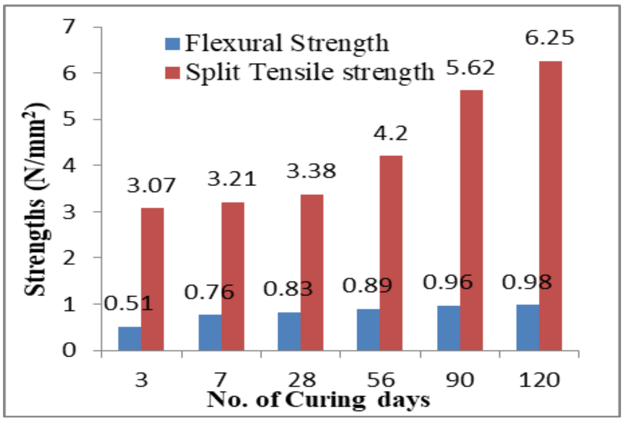


Fig. 9 Effect of Na_2SiO_3/NaOH on development of ggbs mixed geopolymer concrete split and flexural

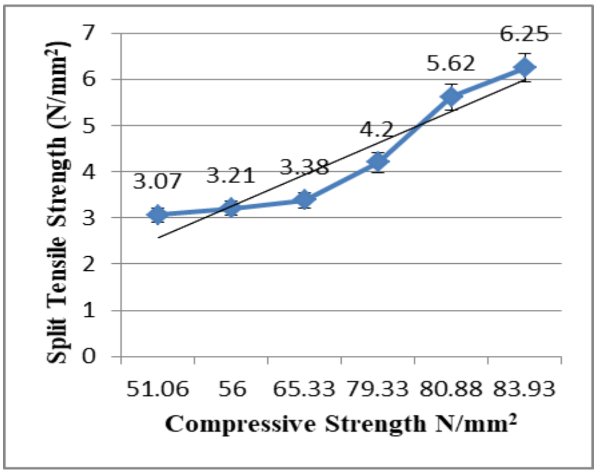


Fig. 10 Regression analysis for Split tensile strength Vs Compressive strength

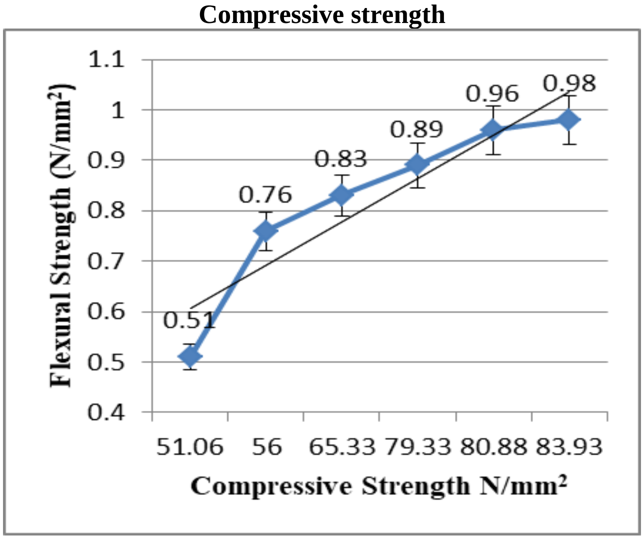
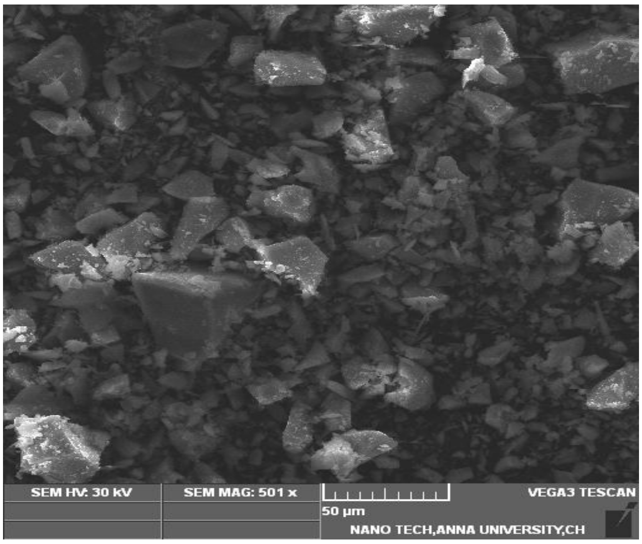


Fig. 11 Regression analysis for Flexural strength Strength Vs Compressive strength

E. SEM and EDX Analysis

To examine the microstructure of GGBS based geopolymer concrete, samples are prepared for 8M of sodium hydroxide solution and with 100% GGBS of the total binder. Based on previous research studies, alkaline activator solution with SS/SH ratio of 2.5 is used [4.7,9,16].

Cured samples, investigated for microstructural study by using a Scanning Electron Microscope (SEM), Energy-dispersive X-ray spectroscopy (EDX) spectrum analysis, are analyzed to found the chemical reaction compounds. Figure 12 shows EDX analysis images for GGBS powder and samples at 28 days of ambient curing. Table 5 summarizes compound present in the GGBS sample. The SEM image shows that amorphous phases of the geopolymer concrete. According to EDX spectrum analysis for the geopolymer concrete, amorphous phase substantially consists of oxygen, Aluminium, Silicon, Manganese & Calcium as shown in Figure 13 and Table 6. The geopolymer, having a higher portion of GGBS, reveals some unreacted and reacted GGBS particles. It traces very less presence of concrete matrix. Dissolution of calcium alumino-silicate hydrate (C-A-S-H) gel forms the dense geopolymeric gel. The portion of samples, examined for this study, confirms calcium in the geopolymeric gel. Consequently, the presence of calcium in 100% increases the setting time of the geopolymeric gel at an early age. Lee et al. [15] in a similar manner, observed that the compressive strength of specimens with a of silica to alumina ratio of > 1.90 was increased by up to 30%,. Kumar et al. [16] expressed that extended Si/Al ratio makes 3D orchestrated polysialate-siloxo and polysialate-siloxo polymer structure. These low convergences of calcium and sodium, despite silicon, oxygen and Aluminium presence, are attributed to the course of action of 3D compose (Ca, K)- polysialate-siloxo. [17] expressed that the high substance of calcium and alumina-silicate in the blend prompts calcium alumina-silicate hydrate gel (C-A-S-H). GGBS is found as extra measure of calcium and added to an extra restricting item which frames the geopolymer gel. Yazdi et al.,[18]expressed that calcium enriched with slag causes f trailblazers to deteriorate and releases a few gathering of creature . For instance, Ca and Al outline C-A-S-H gels in the midst of its reaction with the antacid arrangement. The EDX examination of samples, containing slag, also shows the closeness of magnesium, silicon, aluminum, sulphur and other minor parts, which, in addition to calcium consolidation, may affect the rate of cementing.



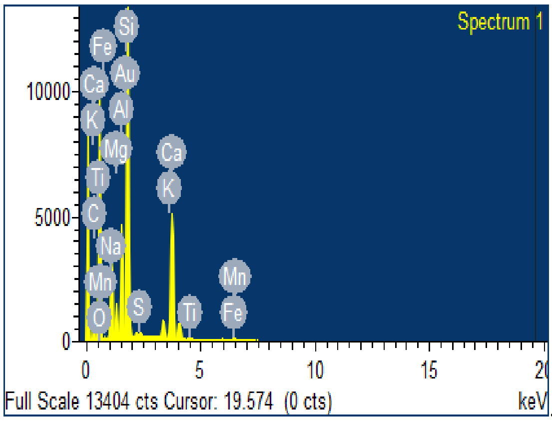


Fig. 12 SEM and EDX spectrum of GGBS powder sample

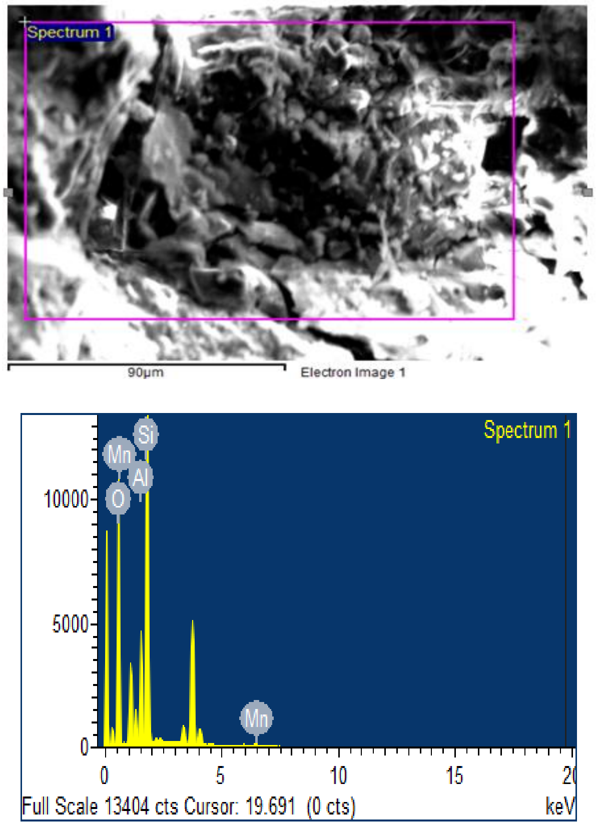


Fig. 13 SEM and EDX spectrum analysis of GGBS mixed geopolymer concrete

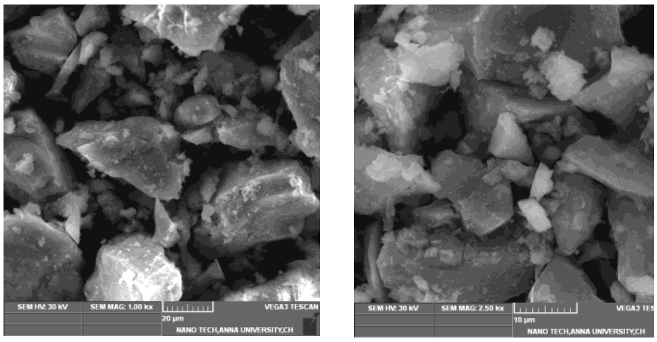


Fig. 14 SEM images of GGBS mixed geopolymer concrete

Table 5 Percentage of constituents in the GGBS powder sample from EDX analysis

Element	Weight%	Atomic %
C K	6.51	10.32
O K	54.51	64.85
Na K	5.53	4.57
MgK	1.58	1.24
Al K	5.04	3.56
Si K	14.91	10.11
S K	0.19	0.11
K K	1.22	0.59
Ca K	9.05	4.30
TiK	0.16	0.06
Mn K	0.26	0.09
Fe K	0.40	0.14

Table 6 Percentage of constituents in GGBS mixed geopolymer concrete from EDX analysis

Element	Weight%	Atomic %
O K	63.77	75.78
Al K	8.67	6.08
Si K	27.10	18.27
Mn K	0.47	0.16

IV. CONCLUSION

In the properties of geopolymer concrete, raw materials play a crucial role. Geopolymer concrete, activated by aluminosilicate solution, can be an alternative for cement concrete. The purpose of this research is to examine the properties for GGBS mixed geopolymer concrete due to the effect of sodium silicate and sodium hydroxide solutions in terms of fresh concrete property, hardened concrete properties and microstructural analysis. The following conclusions may be drawn from the experimental .

(1) The effect on fresh properties of the Na_2SiO_3 / NaOH ratio and alkaline binder ratio results in medium concrete workability.

(2) The setting time of concrete is very fast due to presence of 100 percent GGBS and the compressive strength of geopolymer concrete is achieved nearly within 7 days of ambient curing by almost 80 percent.

(3) Obtained value for split tensile strength of geopolymer concrete of 3.33 MPa for 7days of testing is very close to the empirical formula given by BS 8007:1987.

(4) It is observed that after 7 days of ambient curing there is no significant increase in the flexural strength of the samples.

(5) From the regression analysis, the correlations, obtained for compressive strength Vs split tensile strength and compressive strength Vs flexural strength curve, are very nearer to linear regression curve.

(6) SEM on 100% GGBS based geopolymer concrete shows the dense gel formation of C-S-H and C-A-S-H bond predominantly.

(7) Tracing compounds by EDX analysis shows the presence of Si ions and Al ions with the matrix. When the GGBS reacts with those ions, formations of C-S-H and C-A-S-H geopolymer gel are found.

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