Effect of Type of Curing on Mechanical Properties of Fly Ash-Based Geopolymer Concrete

J.V. Narasimha Raju, T. Chandrasekhar Rao, V. Ravindra

Abstract: This paper represents experimental data on compressive strength, split tensile strength and flexural strength of a geopolymer concrete which was prepared with source material is fly ash and sodium based alkaline solution as alkaline activator. The mix was produced taking combined aggregate content as 70% in unit mass of concrete and by thoroughly blending with sodium-silicate gel at a $NaOH/Na_2SiO_3$ ratio of 2.50. Two types of curing conditions were adopted ambient condition (7, 14 and 28 days) and heat-curing at 70º C (3, 12 and 24 hours) for studying the above properties. In two more independent series of tests, fly ash was replaced by GGBS and silica fume of varied dosages (0, 5, 10, 15 and 20% by dry weight), and all the above mechanical properties were studied upon specimens prepared with the above geopolymer and cured in the above-mentioned conditions. Casting and testing of geopolymer concrete specimens were done in a similar manner as in the case of conventional concrete. Specimens of cubes, cylinders and beams were casted and tested to study compressive strength, split tensile strength and flexural strength respectively. The mechanical strengths increased with increasing curing period in both the conditions; and strengths were higher under heat-curing condition than under ambient condition. Further, the strengths increased with increasing GGBS content and silica fume content.

***Index Terms*: Ambient Curing, Fly Ash, Geopolymer, GGBS, Heat-Curing, Silica Fume, Sodium-Silicate Gel.**

I. INTRODUCTION

Construction industry has been undergoing major developments in view of significant changes in concrete technology and concrete materials. In the recent times, industrial by-products like fly ash, Ground Granulated Blast furnace Slag (GGBS), Silica Fume (SF), meta-kaolin etc. of various industries like thermal power plants, Iron and Steel industry, ceramic industry etc. are used extensively in concretes for the partial substitute of cement in concretes. Further, Self- Compacting Concrete (SCC), High Performance Concrete (HPC), High Strength Concrete (HSC) and Fiber- Reinforced Concrete (FRC) are some of the latest faces of concrete appearing widely in construction industry. [1,2].

Another alternative concrete material is geo-polymer concrete which comprises polymeric silicon- oxygen-aluminium framework [3] i.e. poly- sialate-siloxo framework. The empirical formula of such geo - polymers is like Mn $[(SiO_2)_z\ (AlO_2)]_n$ where n represents the degree of poly-condensation. [4]. Geo-polymers are eco-friendly materials and require very little amount of energy for production. They do not produce harmful gases like CO, CO_2 etc. unlike cement. Besides, geo-polymers have excellent physical and mechanical properties. They are resistant to marine and acidic environments. They do not cause alkali aggregation reaction even though they contain highly alkaline material like a mixture of sodium silicate (Na_2SiO_3) solution and sodium hydroxide (NaOH) solution. [5]. The suggested curing - temperature range for geo-polymers is 60 - 80^0C, above this temperature, there is no considerable gain in strength.

The activation of alumino - silicate materials with the use of alkaline activators to prepare a binding material is one of the recent advancements towards an effective usage of by-products of various industries mentioned above. This lowers the impact of cement on environment. Curing periods of 24 - 48 hours is suggested for geo-polymer concretes to generate the required compressive strength etc. in them. There is no further gain in such strengths with further increase in curing period [6].

By increasing the alkaline content of geo-polymer, the compressive strength of the geo-polymer is also increases. This is due to the dissolution of high amount of fly ash in presence of higher alkaline content. This dissolution helps in the formation of further inter-molecular bonding. [7]. Thus, the concentration of alkaline content or caustic soda directly affects the dissolution of meta - kaolin particulates, which, in turn, affects the formation of the frame work of the geo-polymer [8].

Geo-polymers have high thermal resistance up to 800^0C. In fact, there is no excessive evaporation of water nor dehydration and crumbling into a powder like OPC. [9]. Because of their high thermal resistance, geo - polymers can be used as building materials over a wide range of temperatures even in environments like sea shores, industries, dumping sites etc. , in which ordinary building materials are prone to chemical changes. [10]. The study of the effect of mechanical activation of building materials such fly ash, GGBS as well as silica fume on the strength of geo - polymer subjected to ambient curing was attempted. [11].

Here, we present the fly ash-based geo-polymers (GPC) mechanical properties as well as how the mechanical

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properties could be changed by partially replacing the fly ash with GGBS and silica fume ranging from 0 to 20% by increments of 5%. The following section describes the materials used and the tests performed.

II. MATERIALS

The materials such as fly ash, GGBS, Silica fume, caustic soda, sodium silicate (Na_2SiO_3), coarse aggregate, fine aggregate etc are used in this study.

Fly ash is produced in thermal power stations by the combustion of pulverised coal and is transported along with flue gases. It is a light weight fine powder, which flies into atmosphere and causes health hazards. The rate of its annual production is much higher than its disposal. Hence it is used in various civil engineering applications such as modified concretes, fly ash bricks, compacted clay cushions. It is basically a pozzolanic material which causes flocculation.

GGBS is a byproduct of pig iron manufacture. Limestone, Coke and iron ore are fed into the furnace. The resulting molten slag floats above the molten iron at a temperature of 1500 - 1600^0 C. The composition of molten slag is close to that of Portland cement. In the blast furnace, the molten iron forms the bottom layer and the molten slag floats on it. Then, tapped off the molten iron, the molten slag**,** consisting of aluminous and $CaSiO_3$ residue, is removed. The molten slag is water - quenched rapidly, which represents the glassy granulate formation. The prepared glassy granulate is dried and then crushed to the required size. This resulted product is called GGBS. It is suitable for mass concreting as well as for the construction of buildings near sea shores.

Silica Fume is the by - product in the smelters producing alloys of silicon and ferro silicon. Silicon and ferro silicon alloys are mainly used in the industries such as aluminium and steel production, fabrication of computer chips and production of silicone production as well as also widely to be used as lubricants and sealants. In view of these concerns, the Silica Fume is the significant material in the concrete technology.

Table 1 Properties of GGBS, Fly ash & Silica fume

S.No	Property	Fly ash	Silica fume	GGBS
1	Specific Gravity	2.65	2.86	2.22
2	Fineness (kg/m^2)s	300 to 400	400 to 600	15000 to 20000

The quantities of the materials are arrived at by considering unit weight of the concrete as 2400 Kg / m^3. The mass of the combined aggregate is taken as 70% of the total mass of the GPC. The ratio of the alkaline liquid to binder is fixed at 0.5. NaOH and Na_2SiO_3 are chosen as alkaline activators in preference to respective potassium salts keeping economy in view. NaOH pellets are dissolved in the distilled water to get a solution of desired concentration of 14 M. Na_2SiO_3 is in gel form. 14 M solution of NaOH is mixed with Na_2SiO_3 gel by maintaining a ratio of 2.5. The alkaline solution is prepared one day before the casting.

III. EXPERIMENTAL INVESTIGATION

A. Test Variables and Tests Performed

Compression strength tests, flexural strength tests and split tensile strength tests are performed on fly ash based GPC and GPC in which the fly ash is replaced partially. Separate series of samples with partial replacement by GGBS and silica fume with varying amounts of 0, 5, 10, 15 and 20 % are prepared and tested for the strengths mentioned. All the samples for the above tests are cured in two different methods viz., ambient curing and heat - curing in an oven.

Heat - curing of the samples is done in an oven maintained at a constant temperature of 70^0 C . While the curing periods maintained for ambient curing are 7, 14 and 28 - days, those maintained for heat - curing are 3 hours, 12 hours and 24 hours.

The standard dimensions of samples prepared for all the tests and the procedures for the testing are as per IS 516.
The results obtained are presented graphically in Fig. 1 to 9.

IV. DISCUSSION OF TEST RESULTS

A. Effect of method of curing and its duration on the mechanical properties of fly ash based GPC

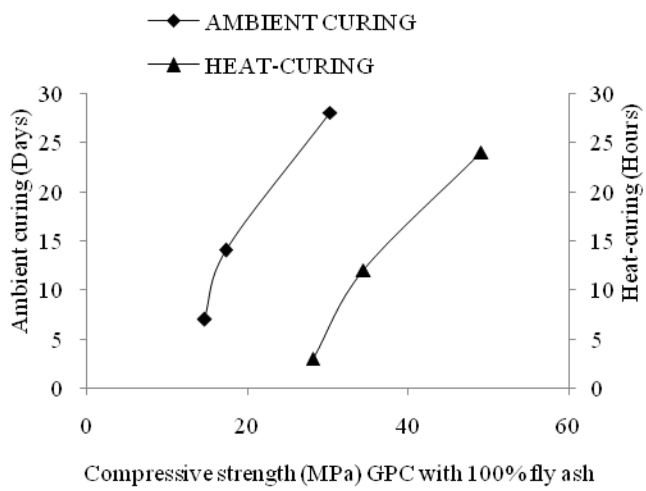

Fig. 1. Variation in compressive strength with ambient curing and heat-curing

Fig. 1 displays the variations of compressive strength (MPa) with curing period. The data pertain to samples cured under ambient condition and heat-curing conditions. The data show that compressive strength increases significantly with curing period. This is true for both the methods of curing. However, compressive strength of geo-polymer concrete samples in which fly ash is replaced partially and cured under heat - curing conditions is higher than that cured under ambient conditions. In the case of geo - polymer concrete in which fly ash is replaced partially and cured under heat - curing condition, the chemical reactions leading to the formation of alumino - silicate gel are substantially accelerated. It is observed, as can be seen from Fig. 1, that there is an increase of compressive strength from 14.66 MPa to 30.3 MPa when the curing is done by ambient method with

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the increase in curing period from 7 days to 28 days. A similar enhancement of compressive strength is also observed from 28.12 MPa to 49.11 MPa when the curing is done by heat - curing method with the increase of curing period from 3 hours to 24 hours.

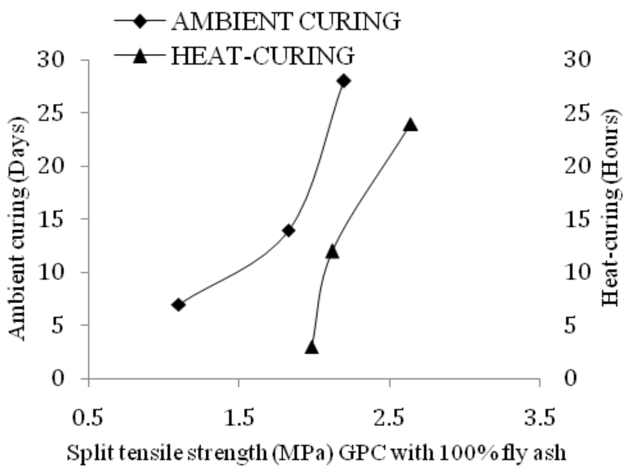

Fig. 2. Variation in split tensile strength with ambient and heat-curing

Figure 2 shows the variation of split tensile strength (MPa) with curing method and curing period. The data are of geo -polymer concretes cured under ambient condition and heat - curing condition separately. The graph shows that the split tensile strength increases significantly with curing period. This is true for both the methods of curing. However, in general, split tensile strength of geo - polymer cured under heat - curing condition is higher than that of it cured under ambient condition. In the case of heat - curing method the chemical reactions leading to the formation of alumino-silicate gel would be substantially accelerated. It is observed, as can be seen from Fig. 2, that there is an increase of split tensile strength of fly ash based geo - polymer concrete from 1.1 MPa to 2.2 MPa when the curing is done by ambient method with the increase of curing period from 7 days to 28 days. A similar enhancement of split tensile strength is also observed from 1.98 MPa to 2.64 MPa when the curing is done by heat - curing method with the increase of curing period from 3 hours to 24 hours.

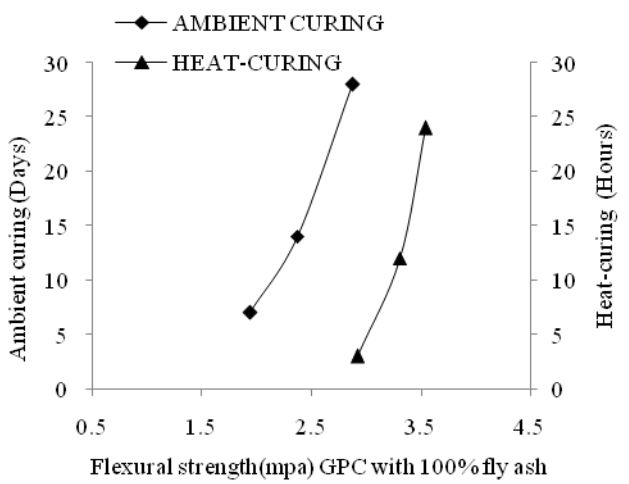

Fig. 3. Variation in flexural strength with ambient and heat-curing

Fig. 3 shows the variation of flexural strength (MPa) with curing method and curing period. The data are of geo -polymer concretes cured under ambient conditions and heat - curing conditions separately. The graph shows that the flexural strength increases significantly with curing period. This is true for both the methods of curing. However, in general, flexural strength of geo - polymer cured under heat - curing condition is higher than that of it cured under ambient condition. In the case of heat - curing method the chemical reactions leading to the formation of alumino - silicate gel would be substantially accelerated. It is observed, as can be seen from Fig. 3, that there is an increase of flexural strength of fly ash based geo - polymer concrete from 1.98 MPa to 2.88 MPa when the curing is done by ambient method with the increase of curing period from 7 days to 28 days. A similar enhancement of flexural strength is also observed from 2.92 MPa to 3.54 MPa when the curing is done by heat - curing method with the increase of curing period from 3 hours to 24 hours.

B. Effect of GGBS and Silica Fume contents on Fly ash - Based GPC Mechanical Properties

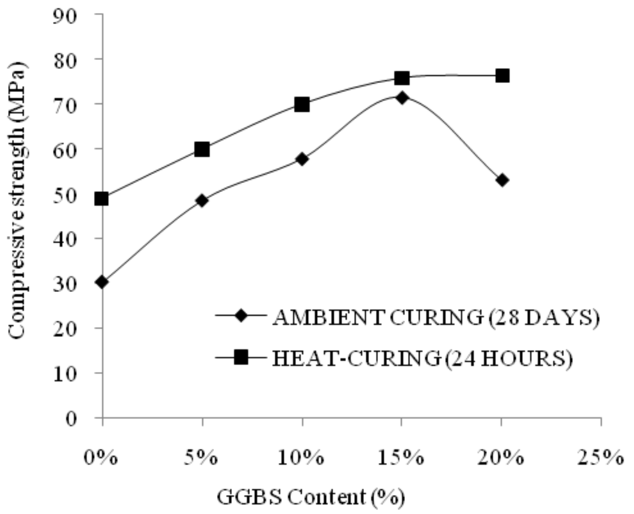

Fig. 4. Influence of GGBS content on compressive strength in ambient and heat-curing

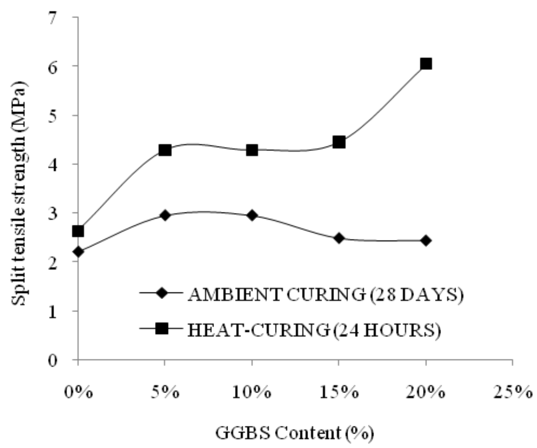

Fig. 5. Influence of GGBS content on split tensile strength in ambient and heat-curing

Fig. 4, 5 and 6 respectively show the effect of GGBS content on compressive strength, split tensile strength and flexural strength. The data depicted also show the influence of GGBS on the method of curing. The data pertain to a curing period of 28 days in ambient curing and 24 hours in heat - curing method. Similar data are obtained for other curing periods in both the conditions. It is observed that the compressive strength of heat - cured specimens increased continuously with GGBS content. Whereas the compressive strength of the specimens cured under ambient condition increased up to 15% GGBS content and thereafter it decreased up to 20% GGBS. (Fig. 4). As already mentioned, heat - curing of the specimens substantially accelerates the chemical reactions leading to the formation of alumino - silicate gel. Hence even at high GGBS content the compressive strength is on the increase when the samples are subjected to heat - curing. Further, as can be expected, the compressive strength of the heat - cured specimens is higher than that of ambient - cured specimens, whatever may be the GGBS content. As an example, it is observed that the compressive strength is increased from 49.11 MPa to 76.33 MPa in heat - cured condition when the GGBS content is increased from 0 - 20 %.

Fig. 5 shows split tensile strength data. It is clear that split tensile strength also increases continuously with GGBS content, when the specimens are heat - cured. But the split tensile strength of ambient - cured specimens increased up to a GGBS content of 15% and thereafter, it decreased. The reasons for this behaviour are already explained in the previous section. It can be seen that split tensile strength increases from 2.64 MPa to 6.04 MPa in heat - cured condition when the GGBS content is increased from 0 - 20 %. However, the compressive strength of the heat - cured specimens is higher than that of ambient - cured specimens, whatever may be the GGBS content.

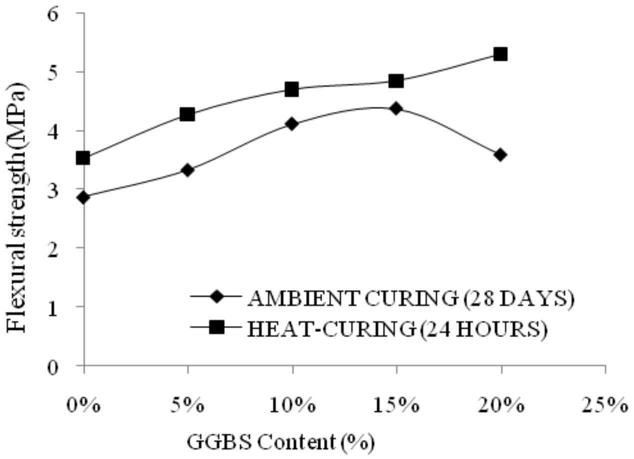

Fig. 6. Effect of GGBS content on flexural strength in ambient and heat-curing

Fig. 6 shows flexural strength data for ambient - curing and heat - curing. It is clear that flexural strength also increases continuously, but slightly, with GGBS content, when the specimens are heat - cured. The reason for this is in heat-curing the chemical reactions are substantially accelerated. However, in ambient - curing, the flexural strength increased up to a GGBS content of 15% and thereafter, it decreased. It can be seen that the flexural strength increases from 3.54 MPa to 5.31 MPa in heat - cured condition when the GGBS content is increased from 0 - 20 %. However, the compressive strength of the heat – cured specimens is higher than that of ambient - cured specimens, whatever may be the GGBS content.

Fig. 7, 8 and 9 respectively show the effect of Silica Fume (SF) content on compressive strength , split tensile strength

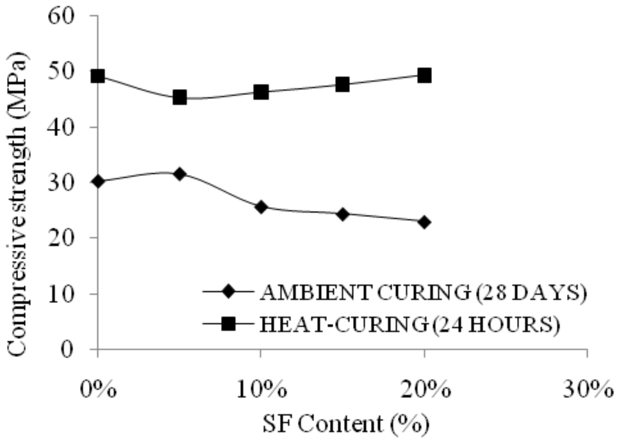

Fig. 7. Influence of silica fume content on compressive strength in ambient and heat-curing

and flexural strength. The data depicted also show the influence of Silica Fume on the method of curing. The data pertain to a curing period of 28 days in ambient curing and 24 hours in heat - curing method. Similar data are obtained for other curing periods in both the conditions. It is observed that the compressive strength of heat - cured specimens increased only marginally with Silica Fume content , whereas the compressive strength of the specimens cured under ambient condition decreased with increase in Silica Fume content. (Fig. 7). As already mentioned, heat - curing of the specimens substantially accelerates the chemical reactions leading to the formation of alumino - silicate gel. Hence even at high Silica Fume content the compressive strength is on the increase when the samples are subjected to heat - curing. Further, as can be expected, the compressive strength of the heat - cured specimens is higher than that of ambient - cured specimens, whatever may be the Silica Fume content. Basically, Silica Fume is less pozzolanic material when compared with GGBS. Hence, the chemical reactions leading to gel formation would be mild. But they are enhanced in heat – curing and could not be accelerated under ambient conditions.

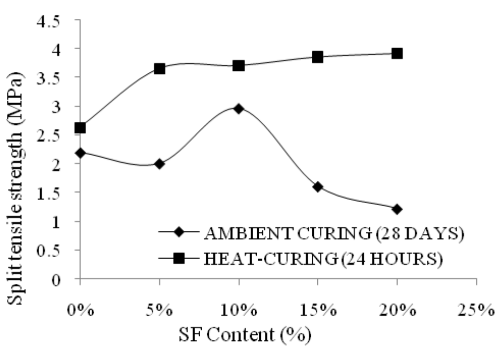

Fig. 8. Influence of silica fume content on split tensile strength in ambient and heat-curing

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Fig. 8 shows split tensile strength data. It is clear that split tensile strength also increases marginally with Silica Fume content , when the specimens are heat - cured. But the split tensile strength of ambient - cured specimens decreases with increase in Silica Fume content. The reasons for this behaviour are already explained in the previous section. It can be seen that split tensile strength increases from 2.64 MPa to 3.92 MPa in heat - cured condition when the Silica Fume content is increased from 0 - 20 %. However, the split tensile strength of the heat - cured specimens is higher than that of ambient - cured specimens, whatever may be the Silica Fume content.

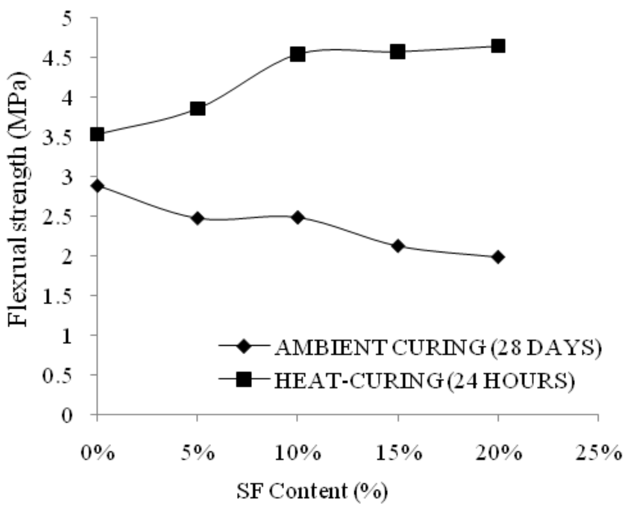

Fig. 9. Effect of silica fume content with flexural strength in ambient and heat-curing

Fig. 9 presents the flexural strength data for ambient curing and heat-curing. Flexural strength increased but slightly with increase in silica fume content in the case of specimens heat-cured. The reason for this is, in heat-curing chemical reactions are substantially assisted though silica fume is a low pozzolanic material. However, in ambient curing, flexural strength decreased with silica fume content. Flexural strength of heat-cured specimens increased from 3.54 MPa to 4.64 MPa when silica fume content increased from 0% to 20%. And the flexural strength of heat-cured specimens was higher than that of the ambient cured specimens for all silica fume contents.

V. CONCLUSIONS

A through experimental investigation was conducted to study compressive strength, split tensile strength and flexural strength on geopolymer concrete specimens prepared by completely replacing cement with fly ash and curing them under two different conditions , namely ambient condition and heat-curing condition(70ºC).

The following are the chief conclusions drawn from the experimental study:

1. Compressive strength, split tensile strength and flexural strength of geopolymer concrete specimens in both types of replacement, increased with increasing curing period in both the curing conditions. However, the heat-curing resulted in much higher compressive strength, split tensile strength and flexural strength than ambient curing. Corresponding to 28-days ambient curing compressive strength increased by 67% when cured for 24hrs under heat curing condition.
2. When fly ash was replaced by GGBS and silica fume (SF), all the mechanical strengths increased with increasing GGBS content and silica fume content in heat-curing. In ambient curing, the mechanical strengths of GGBS specimens increased up to 15% and thereafter decreased when GGBS content was increased to 20%. In the case of silica fume specimens, however, the strengths continuously decreased with increase in silica fume content in ambient condition. This was because silica fume is a material of low pozzolanic property. However the mechanical strengths were found to have been higher in heat-curing condition than in ambient condition.
3. For example, the increase in compressive strength was 77% at 28-day ambient curing when GGBS content increased from 0% to 15%. And at 24-hours heat-curing the increase in compressive strength was 56% when GGBS content increased from 0% to 20%.

REFERENCES

1. A.M. Nevile, (2013), 'Properties of concrete', Fifth edition Text book, published by Pearson Education Limited.
2. A.R. Santhakumar(2018), 'Concrete Technology", Second edition Text book, published Oxford University Press.
3. Palomo, A., and de la Fuente J.I.L. (2003), 'Alkali-activated cementitious materials: alternative matrices for the immobilization of hazardous wastes'. Part I. Stabilization of boron, CemConcr Res, 33, pp. 281–8.
4. Davidovits J. (1991), 'Geopolymers: inorganic polymeric new materials'. J Thermnal, pp. 37:1633–56.
5. Yunsheng Z, Wei S, Qianli C and Lin C. (2007) 'Synthesis and heavy metal immobilization behavior of slag geopolymer'. J Hazard Mater pp,143:206–13.
6. Sun W, Zhang YS, Lin W and Liu ZY (2004), 'In situ monitoring of the hydration process of K-PS geopolymer cement with ESEM'. CemConcr Res pp.34:935–40.
7. Wang H, Li H and Yan F (2005). 'Synthesis and mechanical properties of metakaolinite based geopolymer'. Coll Surf A: Physicochemical Eng Aspects, 268, pp.1–6.
8. Sofi M, van Deventer JSJ, Mendis PA and Lukey GC (2007). 'Engineering properties of inorganic polymer concretes, (IPCs)'. Cem Concr Res, 37, pp. 251–7.
9. Alvarez-Ayuso E, Querol X, Plana F, Alastuey A, Moreno N and Izquierdo M. (2008), et al. 'Environmental, physical and structural characterization of Geopolymer matrixes synthesized from coal (co-combustion fly ashes)'. J Hazard Mater, 154, pp. 175–83.
10. Duxson P, Provis JL, Luckey GC, Mallicoat SW, Kriven WM, van Deventer JSJ (2005). 'Understanding the relationship between geopolymer composition, microstructure and mechanical properties'. J Coll surf A: PhysiochemEng Aspects, 269, pp.47–58. Bakharev T. Resistance of geopolymer materials to acid attack. CemConcr Res, 35, pp. 658–70.
11. Bakharev T. (2005), 'Durability of geopolymer materials in sodium and magnesium sulphate solutions'. CemConcr Res, 35, pp. 1233–46.
12. IS: 516:1959, 'Method of Tests for Strength of Concrete'/21ps03-vidmar.

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