www.ijemr.net ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962

Volume-7, Issue-4, July-August 2017

International Journal of Engineering and Management Research

Page Number: 114-120

Studies on Fly-Ash Aluminum Composite Produced

Sitender[1], Mahender[2]

[1]Assistant Professor, Department of Civil Engineering, GITAM, Kablana, Jhajjar, INDIA

[2]M.Tech Scholar, Department of Civil Engineering, GITAM, Kablana, Jhajjar, INDIA

ABSTRACT

This research studies the utilization of alumina waste and silica waste for geopolymer production. The study makes the reuse of aluminum hydroxide waste (Al-waste) for geopolymers. For cement materials, both Al-waste and fly ash (FA) were mixed at different water, sand, fly ash contents of 10–60 weight%. The mass ratio of sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH) solution was fixed at 2.5. Here, the NaOH concentrations of 5, 10, and 15 M were used as alkaline activators for geopolymerisation. The composite has been cured at room temperature for a week and also in an oven at 60 °C and 80 °C for 24 h, the geopolymerisation was increased with increasing concentration of NaOH. The mechanical properties, microstructure, bonding, and phases of the resultant geopolymers has been analyzed after curing. In geopolymer production, the mortar was cast in 50x50x50 mm cubic shape for both methods with cured temperature at 60 degree Celsius. Compressive strength has been tested at 1, 7, 14 and 28 days. The results has revealed that the best SiO_2:Al_2O_3 ratio must be 3.5:1 mixed by alumina waste 48.3 g. and silica waste 22.89 g. with 10 ml of sodium hydroxide and 20 ml of sodium silicate. This proportion gains the highest compressive strength for 265.8 kg/cm^2 at 28 days of curing. The study concluded that the production of geopolymer mortar from alumina waste and silica waste cannot be considered as hazardous waste.

Keywords--- Geopolymers, Geopolymerisation, Silica, alumina waste, NaOH

I. INTRODUCTION

Traditional monolithic materials have got some limitations in achieving combinations of strength, stiffness, and density.Metal composite materials have discovered applications in numerous regions of everyday life for a long while in structural building. Aluminum is a concoctioncomponent in the boron assemble with image Al and nuclear number is 13. It is shiny white, and it is insoluble in water under typical conditions. Aluminum compounds are composites in which Aluminum (Al) is the most grounded metal. The commonplace alloying components are silicon and zinc. Fly ash is one of the buildups created in the burning of coal. It is a mechanical by-item recuperated from the vent gas of coal consuming electric power plants. In view of the source and cosmetics of the coal being singed, the fly fiery remains segments created changes significantly. When all is said in done, fly ash contains Fe_2O_3, Al_2O_3, SiO_2, as significant extent and oxides of Ca, Na, Mg and so on as minor extent. Fly powder particles are for the most part round fit as a fiddle and range from under 1 µm to to100 µm with an upper zone, in the vicinity of 250 and 600 m^2/ kg. The particular gravity changes between 0.6-2.8 g/cc. Physical properties of fly ash basically rely on upon the kind of coal consumed and the states of consuming. Class F sort fly ash is created from consuming high rank (containing high carbon content) coals, for example, anthracite and bituminous coals, while, Class C fly slag is delivered from low rank coals.

Geopolymer is emerging as another development material which could be delivered by the substance activity of inorganic atoms, without utilizing any Portland cement. The geopolymer binder can be produced through chemical reaction between alumino-silicate materials such as fly ash or metakaolin that are rich in SiO_2 and Al_2O_3 and alkaline solutions such as Sodium Hydroxide or Sodium Silicate. Geopolymerisation alumino-silicate material which can be applied for many applications due to thereasonthat geopolymers have several attractive properties of high strength, low permeability, high acid resistance, hazardous materials, and immobilization of toxic materials (Onutai, S). Generally, the geopolymer materials are activated in a high alkali solution (Davidovits, 2008) asalumino silicate geopolymers consist of tetrahedral AlO_4 and SiO_4 units that occur easily in a polycondensed polymer framework in high-alkali conditions (Davidovits, 1991).The structural

behavior of heat-cured fly ash geopolymer concrete has been found to be similar or superior to that of OPCconcrete when tested for reinforced columns and beams, bonding and bending properties. The hardening mechanism for geopolymers essentially contains the polycondensation reaction of geopolymeric precursors, regularly aluminosilicate oxides, with alkali polysilicates yielding polymeric silicon –oxygen aluminum framework. Consistently, aluminum utilization is expanding for some applications, for example, anodizing forms for delivering enriching and defensive movies on aluminum and amalgams. The initial step of anodizing procedures is pre-treatment of the metal. The second step is scratching the surface of the aluminum metal in pre-treatment before fixing and shading. This step, which most often uses NaOH in warm solution, gives the metal surface a light grey sati finish. After etching, Al-waste in gibbsite phase ($Al(OH)_3$) is wasted: typically about 360 tons/year from various industries are discarded in landfills. Utilization of non-renewable energy sources in power plants for vitality creation is expanding, leaving fly ashes waste. Around 3 million tons/year of such modern waste are delivered by substantial and little power plants. For fly ash, pozzolanic materials are normally reused in cement and concrete industries. Subsequently, these fly ashes ought to be recovered to create novel materials.On the off chance that individuals can do this, then such materials can end up noticeably reasonable items that give natural, social, and monetary advantages. Particularly, as sustainable assets of both aluminum hydroxide waste and fly ashes remains, these appear to be pertinent for reuse in solid materials. The study would also analysis the effect of degree of heating on compressivestrength after specified period of heat curing of fly ash- aluminum based geopolymer mortar.

The present study (a) identifies the application of available industrial waste, i.e., fly-ash in a useful manner, (b) obtains composites produced with different percentage of reinforcing phase (c) demonstrate theenhancement in the strength of the geoploymers on adding aluminum to the mixture, (d) identifies the change in the properties of the geoploymers on experimenting with different percentages of aluminum, (e) demonstrates the mechanical properties like compressive strength, tensile strength, bending strength, hardness of the fly-ash aluminum based geoploymers.

II. EXPERIMENTAL SETUP

Raw materials of geopolymer were taken aluminum hydroxide waste (Al-waste) from Apex Aluminum Extrusion Pvt. Ltd (Jaipur, Rajasthan) and fly ash (FA) supplied from Shree Shyam Industries ((Jaipur, Rajasthan) as shown in the Figure 1. The Al-waste particles were of diameter of about 100 lm and irregularly shaped. The particle distribution of the Al-waste (Table 3.2) was 42–113 lm. In contrast, the FA contained spherical particles with about 42 lm diameter in the fine powder. The composition of the fly ash (weight%) by ASTM C 618 test report has been shown in Table 1. The laser-scattered particle distribution of fly ash showed that thee powder size was 0.19–134 lm. The chemical composition of silica waste and alumina waste were determined using X-ray fluorescence. The SEM and particle size distribution of fly ash and aluminum has been shown in the Figure 2.

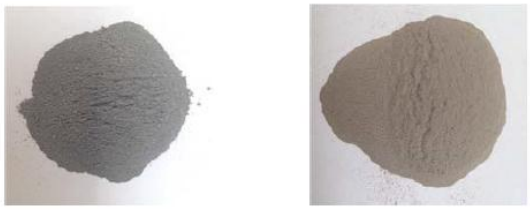

Figure 1: Aluminum hydroxide waste and fly ash

Table 1: Composition of the fly ash (weight%) by ASTM C 618 test report

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI	Moisture
52.06	20.54	5.50	14.07	3.29	0.57	0.94	0.69	0.10	0.01

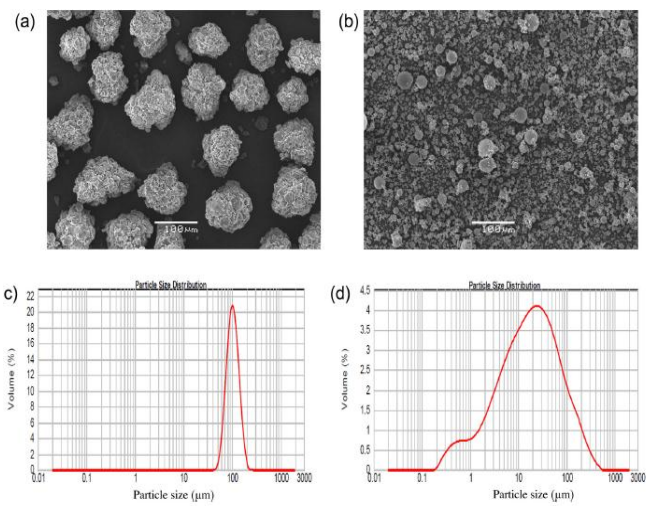

Figure 2: SEM micrograph of (a) fly ash and (b) aluminum hydroxide wasteand particle size distribution of (c) fly ash and (d) aluminum hydroxide waste.

III. METHODOLOGY

3.1 Geopolymers

Generally, geopolymers are prepared from an alkaline solution. For example, potassium hydroxide or sodium is used for dissolving silicon and aluminium atoms from raw materials of industrial waste or natural minerals. The silicate alkaline solution includesa dispersant or plasticizer, a binder, alkaline activator. The basic forms of structure

have silicon-aluminate 3D structures with cross-linked chain bonds together in the geopolymer matrix. The reaction of geopolymers was greatly shoot down at room temperature. At elevated temperatures of 42–95°C, geopolymerization is known to improve the strength of specimens.

3.2Stir casting

This has included consolidation of ceramic particulate into liquid aluminum liquefy and enabling the blend to harden. The significant thing was to make great wetting between the particulate reinforcement and the liquid aluminum composite soften. The least complex and most economically utilized procedure is known as blend throwing system or vortex strategy. The vortex method includes the introduction of pretreated clay particles into the vortex of liquid compound made by the pivoting impeller.This included consolidation of ceramic particulate into liquid aluminum liquefy and enabling the blend to harden. The significant thing was to make great wetting between the particulate reinforcement and the liquid aluminum composite soften. The least complex and most economically utilized procedure is known as blend throwing system or vortex strategy. The vortex method includes the introduction of pretreated clay particles into the vortex of liquid compound made by the pivoting impeller. It was initially created by Surappa and Rohatgi (1981) at the Indian Institute of Science, Bangalore (Lloyd, 1999). In this manner a few aluminum organizations additionally refined and changed the procedure which is at present utilized to make variety of aluminum metal matrix composites on business scale. In this strategy, after the matrix material was softened, it has been blended vivaciously to frame a vortex at the surface of the melt, and the reinforcement material was then presented along the edge of the vortex. The mixing was proceeded for two minutes before the slurry is settled.

IV. MICROSTRUCTURAL CHARACTERIZATION

4.1 Scanning electron microscopy

Micro structural characterization studies are directed on unreinforced and reinforced examples. This is proficient by utilizing checking electron magnifying lens. The composite examples were metallographically cleaned preceding examination. Characterization is done in carved conditions. Scratching has beenaccomplished utilizing Keller's reagent. Scanning electron microscope is used to obtain the SEM micrographs of composite and wear debris. The pictures are taken in both secondary electron (SE) and back scattered electron (BSE) mode as indicated by prerequisite. Minute reviews to look at the morphology, molecule measure and small scale structure were done by a JEOL 6480 LV checking electron magnifying instrument (SEM) outfitted with a vitality dispersive X-beam (EDX) indicator of Oxford information reference framework. Micrographs are taken at reasonable accelerating voltages for the most ideal determination utilizing the secondary electron imaging as appeared in Figure 3.

Figure 3: JEOL JSM-6480LV scanning electron microscope

4.2 Optical microscopy

The stir casting technique was inspected under the optical microscope instrument to decide the caste structure. A segment was cut from the castings. It is first belt pounded taken after bycleaning with various grades of emery papers. At that point they were washed and cleaned in clothes and afterward washed, dried and carved with Keller's answer and after that inspected through optical microscope.

V. PREPARATION OF GEOPOLYMER MORTAR SAMPLES

5.1 Casting of the Sample

Each geopolymer tests has been tested in 5 x 5 x 5 centimeter cubic shape and cured at 60 degree Celsius for 24 hours. The samples have been made out of alumina waste, silica squander, sodiumhydroxide, sodium silicate and sand. The ratio of alumina waste and silica waste

controlled by SiO_2/Al_2O_3 inside the aggregate sum of crude waste material (78 grams) and proportion of SiO_2/Al_2O_3 are 1, 2 and 3. Al-Fa-SiC composites are produced by differing % of fly ash (7, 11 and 17 %) by stir casting route. The alkaline activated solutions are sodium hydroxide and sodium silicate mixed in 25 ml, the proportions of $NaOH/Na_2SiO_3$ are 2, 1 and 0.5. The measure of sand in each specimen has been settled at 275 gram. The molds have been put in tight-fitting cover holders to prevent samples from oxidation with air and afterward cured at room temperature for 3 days. After demolding, the specimens were prevented from air and cured at room temperature until 7 day age. A scanning electron microscope (SEM) has been used for microstructure analysis and a universal testingmachine (UTM) for compressive strength test has been utilized. The compressive strength of geopolymer blocks is examined by ASTM C 109.

5.2 Mixing, curing and testing procedure

For making geopolymer mortar examples of different test arrangement, fly ash and alkaline activating solution to the desired extent were first combined in Hobart blender for five minutes. The sand was then gradually included and blended for an additional five minutes. The fresh mortar mix had great consistency and lustrous appearance. The crisp mortar was then filled in 50mm x 50mm x 50mm steel shape and vibrated for two minutes on vibration table to expel captured air. The samples were left undisturbed to room temperature for 120 minutes before curing in a stove at 85°C for 48 hours under atmospheric pressure and uncontrolled humidity conditions. The specimens were demoulded after cooling downto room temperature and left to air curing (drying) until tested for direct compression in a digital compression testing machine at the age of 3, 7 and 28 days. The reported compressivestrength is normal quality of three examples. Geopolymer paste specimens were prepared in similar manner with same chemical composition as that of respective mortar specimens for a particular test series. Cylindrical steel moulds of Φ25×50 mm were used to cast paste specimens. The paste specimens were used to evaluate mineralogical and microstructural characteristics of the materials by means of XRD, and SEM.

5.3 Hardness:

Hardness test was carried out on the composite specimens using Brinell hardness testing apparatus with 15 mm diameter and load of 225kg. The loading time was 40 secs. Three readings were taken for each specimen and mean value was considered.

VI. RESULTS AND DISCUSSIONS

6.1 Fly ash Analysis

Chemical composition of fly ash samples for assessing the quality of fly ash was analyzed for following inorganic compounds viz. silicon dioxide, aluminum trioxide, ferric oxide, calcium oxide, sulphur trioxide and loss on ignition (LOI) by standard methods of complexometric titration and gravimetric analysis. For the sake of easy reference fly ash from Suratgarh(TPS-1) and Kota(TPS-2) thermal power station are denoted as FA-1 and FA-2 respectively. The chemical composition of the fly ashes collected from Suratgarh and Kota thermal power stations are given in Table 2.The SEM micrograph of fly ash used in the study has been shown in the Figure 4.

Table 2: Composition of fly ash used as reinforcement in weight%

Components or Property	*Suratgarh Fly ash (%)*	*Kota Fly ash (%)*
Silicon dioxide (SiO_2)	58.23	56.07
Aluminium trioxide (Al_2O_3)	29.11	26.69
Ferric oxide (Fe_2O_3)	5.72	8.03
Calcium oxide (CaO)	1.3	1.2
Sulphur trioxide (SO_3)	0.67	0.18
Loss on Ignition (LOI)	0.13	0.8

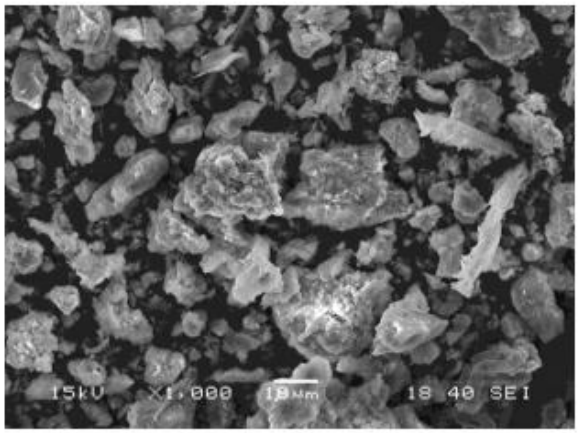

Figure 4: SEM Micrograph of fly ash used in the study

The results haveshown that porosity of specimens decreases as fly ash content increases to 16.7 weight %. Above 16.7 weight % of fly ash, the porosity of composites seems to be constant. The lowest porosity of the composites containing fly ash equal 16.7 weight % is 0.69 %, indicating specimen having high relative density. As shown in Figure 5, it can be seen that the porosity is influenced by the amount of the fly ash content and how the fly ash particles are arranged in the matrix. When the amount of fly ash is lower than 16.7 weight % the fly ash particles are well distributed in the matrix and almost every single particle is surrounded by the matrix, because fly ash particles are smaller than aluminum powders. This gives good bonding between the matrix and the particle. However, above 16.7 weight % of fly ash, some fly ashes particles are close each other forming clusters of particles leading to less bonding and interaction between matrix and the particles. In this latter case, the pores are easy to occur as indicated in Fig 5(a). The Fig 5(b)shows the bending

ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962

strength of AMC/fly ash composites as a function of fly ash content. The bending strength was measured using four point bending test. The bending strength increases from 268 MPa until 311.53 MPa or 13.97 % with increasing fly ash content from 5 weight % up to 16.7 weight %. Above 16.7 weight % of fly ash the bending strength decreases. In relation with this, it can be explained that the increase of bending strength of the composites from fly ash content of 5 to 16.7 weight % is due to the reduce of porosity in the materials as indicated in Fig 5 (a) and (b).

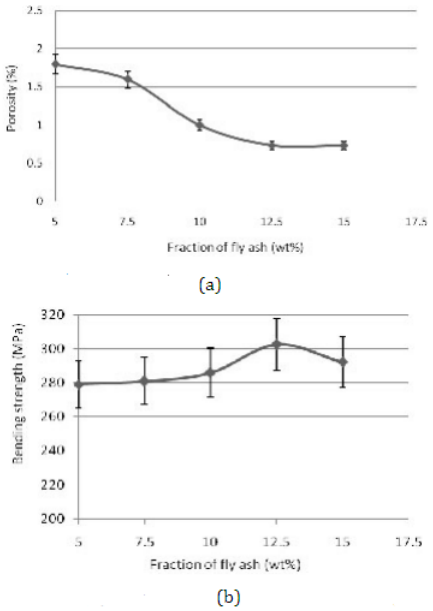

Fig 5: (a) Porosity as function of fraction of fly ash and (b)

Bending strength as function of fraction of fly ash As consequences of the hardness property, the harder material will have lower wear rate during the wear test. The wear rate of the composites decrease from 0.0142 mg/(MPa.m) until 0.0095 mg/(MPa.m) or 46.3 % with increasing fly ash content from 5 weight % up to 16.7 % wt. Above 16.7 weight % fly ash the wear rate seems to be constant . In general, this decrease of wear rate of the composites is due to fly ash (which consists of most metal oxide) has higher wear resistance compared to that of aluminum.

It is evident from the above results that the fly ash is predominantly composed of SiO_2 and Al_2O_3 with small amounts of Fe_2O_3 which together account for 92.91%and 89.49% by mass of the total ash content from TPS-1 and TPS-2 respectively. For TPS-1 and TPS-2, the CaO content of fly ash has a relatively low value of 1.3 and 1.2. According to the ASTM C618, this fly ash can be classified as class F for having a less than 10% CaO content and a greater than 70% content ofSiO_2, Al_2O_3 and Fe_2O_3 altogether. The loss on ignition (LOI), a measure of unburnt carbon in the fly ash was reported to be having a low value of 0.25 and 0.6 for TPS-1 and TPS-2 respectively. These LOI values can be used as an indicator for the efficiency of the combustion chamber at the thermal power station. The values and graphs for tensile strength, compressive strength and hardness have been shown in the Figure 6 and 7. The Table 3 haslisted the values.

Table 3: Tensile strength, compressive strength and hardness as a function of fly ash (wt %)

Fly ash WT%	Tensile strength (MPa)	Compressive strength (MPa)	Hardness (BHN)
0%	319.901	484.000	50
9%	395.999	498.500	71
12%	398.999	500.260	78
15%	405.984	504.030	88

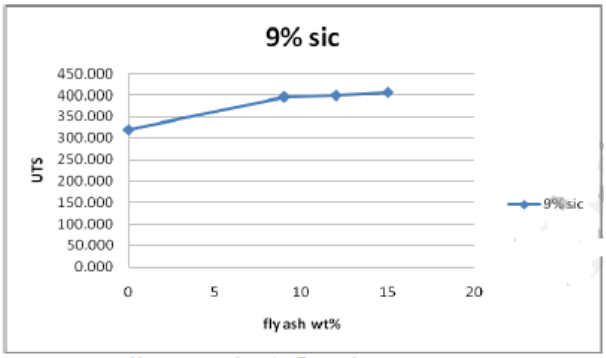

Fig 6 :Tensile strength v/s fly ash wt%

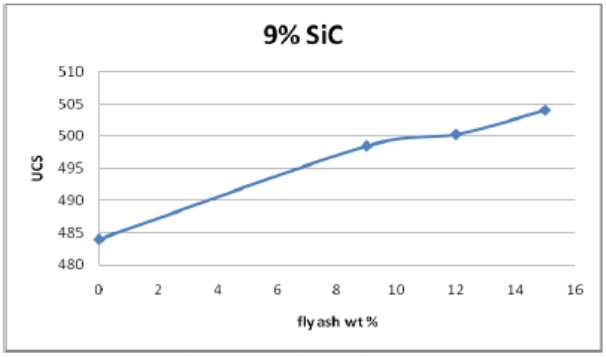

Fig 7 :Compressive strength v/s fly ash wt%

6.2 Effect of water to geopolymer solid ratio

Water content in initial mix plays a vital role in synthesis of geopolymeric material. It acts as the medium for dissolution and polymerization of Al and Si precursors. The compressive strengths of geopolymer formulations based on water to Geopolymer solid ratios varying from 0.136 to 0.369 are shown in Fig 8.

ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962

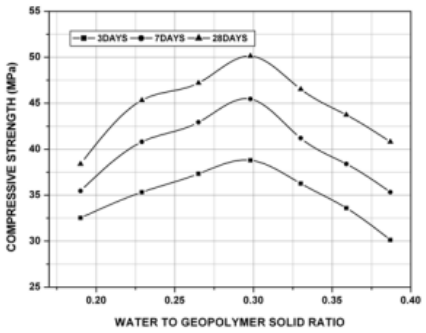

Figure 8: Water to Geopolymer solid ratio

Results indicated that lower the water content in the mix, higher was the compressive strength. Though, there are practical limitations to reducing water content of mix for desired workability. Lower water content greatly raises the viscosity of the liquid component reducingease of mixing and dispersal. The compressive strength continuously improved till water to geopolymer solid ratio of 0.27. However, further decrease in water content reduced compressive strength. It is reasonable to suggest that increasing water content beyond 3.5 will prevent the system from reaching super saturation, thus the dissolution of precursors is likely to be prolonged resulting in slow gel formation and reduction in strength.

6.3 Effect of sand to fly ash ratio

Filler material like sand reduces cracking and improves porosity of the composite. Its addition also reduces the quantity of binder paste making the resultant material more economical. In test series-4, sand content (sand to fly ash ratio) of the geopolymer mix was varied from 0.45 to 3.5.

6.4 Effect of Curing Temperature

The specimens with alkali content of 0.58 and silica content of 6.0 were cured for 48 hours varying curing temperatures from 55°C to 130°C under atmospheric pressure and uncontrolled humidity conditions. The effect of curing temperature on compressive strength is studied. The effect of the curing temperature on compressive strength is shown in Fig 9.

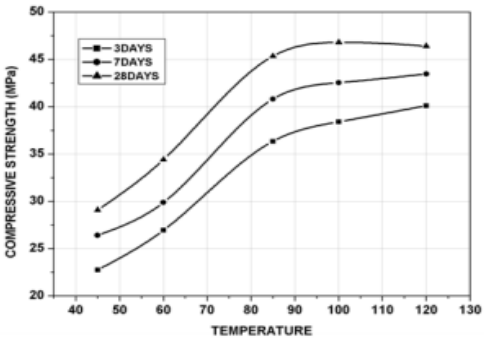

Fig 9: Curing temperature v/s compressive strength

The maximum compressive strength obtained was 46.80Mpa, for an optimum temperature of 84°C. With increase in curing temperature from 55°C to 89°C increased compressive strength almost linearly. However, no substantial improvement in strength was observed beyond 89°C.

6.5 Effect of duration of thermal curing

In this trial, test specimens with alkali content, silicate content and water to geopolymer solid ratio of 0.58, 6.0 and 0.235 respectively, were cured inuncontrolled oven humidity conditions at 89°C for a varying duration of 4 to 72 hours and under atmospheric pressure and. As curing time increases, compressive strength increases. A maximum of 39.78 Mpa compressive strength of was obtained with 48 hours of thermal curing. Further increase in curing time did not result in appreciable increase of compressive strength.

VII. CONCLUSIONS

The study was conducted to examine the fly-ash geopolymers based concrete and its applications. The study investigated various aspects of the composite mixture like compressive strength, tensile strength, hardness and so forth. Fly-ash Aluminum based geopolymer concrete is well known for its acid resistance, promising mechanical properties and fire resistance and therefore is a potential alternative construction material with comparable properties to OPC concrete. The constituents of Fly-ash Aluminum based geopolymer concrete are capable of being mixed with a relatively low alkali activating solution It can be cured in a reasonable timeunder ambient conditions. Geopolymers emit approximately 80% less CO_2 than OPC during production, making it a more environmental friendly building material. The properties of geopolymer include low shrinkage, sulphate resistance, high early strength, freeze-thaw resistance, and corrosion resistance. These high-alkali binders do not generate any alkali-aggregate reaction. Water plays important role during polycondensation, dissolution and hardening stages of geopolymerisation. The choice of curing temperature and curing time affected final compressive strength of geopolymer. Heat enhances the dissolution rate of solid aluminosilicate material and overcomes activation barrier. The geopolymer binder contains very less amount of CO_2cementious material. It does not depend on the Calcination of limestone that generates CO_2. This technology can save up to 80% of CO_2 emissions caused by the cement and aggregate industries. Due to the high early strength, Geopolymer Concrete shall be effectively used in the precast industries, so that huge production is possible in short duration of time.The study has proven that geopolymer products are no longer the hazardous waste.

REFERENCES

[1] Bakharev, T. (2005). "Geopolymeric materials prepared using Class F fly ash and elevated temperature curing." Cement and Concrete Research, 35(6), 1224-1232.
[2] B. M. Mustafa Al Bakri, H. Mohammed, H. Kamarudin, I. K. Niza, and Y. Zarina, "Review on fly ash based geopolymer concrete without Portland cement," Journal of Engineering and Technology Research, vol. 3, no. 1, pp. 1–4, 2011.
[3] B. V. Rangan, D. Hardjito, S. E. Wallah, and D. M. J. Sumajouw, "Studies on fly ash-based geopolymer concrete," in Proceedings of the Geopolymer 2005 World Congress: Green Chemistry and Sustainable Development Solutions, pp. 133–137, 2005.
[4] Cheng, T.W., and Chiu, J.P. (2003). "Fire-resistant geopolymer produced by granulated blast furnace slag." Minerals Engineering, 16(3), 205-210.
[5] Davidovits, J. (2013). "Geopolymer chemistry and applications."Chapter 21 and 22, 3rd edition.Geopolymer Institute, Saint-Quentin, France. ISBN: 9782951482050.
[6] D. Hardjito, S. E. Wallah, D. M. J. Sumjouw, and B. V. Rangan, "Properties of geopolymer concrete with fly ash as source material: effect of mixture composition," in Proceedings of the 7th CANMET/ACI International Conference on Recent Advances in Concrete Technology, pp. 26–29, Las Vegas, Nev, USA, 2004.
[7] D. M. J. Sumajouw, D. Hardjito, S. E. Wallah, and B. V. Rangan, "Fly ash-based geopolymer concrete: an application for structural members," in Proceedings of the Geopolymer 2005 World Congress: Green Chemistry and Sustainable Development Solutions, pp. 149–152, 2005.
[8] Guerrieri, M. and Sanjayan, J.G. (2010). "Behavior of combined fly ash/slag based geopolymers when exposed to high temperatures." Fire and Materials, 34(4), 163- 175.
[9] Guo, X.L, Shi, H.S, and Dick, W.A. (2010). "Compressive strength and microstructural characteristics of class C fly ash geopolymer." Cement and Concrete Composites, 32(2), 142-147.
[10] Hardjito D. and Rangan B.V. 2006. Development and properties of low calcium fly ash based geopolymer concrete. Research report GC-1. Faculty of Engineering, Curtin University of Technology, Perth, Australia.
[11] J. Fongjan and L. Ludger, "Effect of high silica content materials on fly ash-based geopolymeric cement materials," in Proceedings of the Geopolymer 2005 World Congress: Green Chemistry and Sustainable Development Solutions, pp. 107–111, 2005.
[12] Kong, D.L.Y., and Sanjayan, J.G. (2010)."Effect of elevated temperatures on geopolymer paste, mortar and concrete."Cement and Concrete Research, 40(2), 334- 339.
[13] K.N.P.Prasad, M.Ramachandra, "Effect of Squeeze Pressure on The Hardness and Wear Resistance of Aluminium Fly Ash Composite Manufactured by Stir-Squeeze Casting", IJEI, 2013, vol.3, issue 4, pp.01-08.
[14] M. Uthayakumar, S. ThirumalaiKumaran, and S. Aravindan, "Dry Sliding Friction and Wear Studies of Fly Ash Reinforced AA- 6351 Metal Matrix Composites", Advances In Tribology,
[15] N. P. Rajamane and D. Sabitha, "Effect of fly ash and silica fume on alkalinity of cement mortars," The Indian Concrete Journal, vol. 79, no. 3, pp. 43–48, 2005.
[16] Palomo A., Grutzeck, M. W. and Blanco M. T. 1999. Alkali-activated fly ashes: cement for the future. Cement and Concrete Research. 29(8): 1323-1329.
[17] S. B. Suri, "Fly ash based innovative building products for construction—part-II," CE & CR, vol. 25, pp. 134–142, 2012.
[18] S.E Wallah ,B.V.Rangan (2006), Low Calcium Fly Ash Based Geopolymer Concrete: Long Term Properties, Curtin University of Technology, Perth , Australia.
[19] S. V. Patankar, S. S. Jamkar, and Y. M. Ghugal, "Effect of sodium hydroxide on flow and strength of fly ash based geopolymer mortar," Journal of Structural Engineering, vol. 39, no. 1, pp. 7–12, 2012.
[20] Thakur R.N. and Ghosh S. 2007. Fly ash based Geopolymer composite. Proceedings of 10th NCB International Seminar. New Delhi, India. pp. 443-452.
[21] Vivekanandan.P, Arunachalam.V.P, "The Experimental Analysis of Stir Casting Method on Aluminium-Fly Ash Composites", IJCET, 2013, Vol.3.
Xu H., van Deventer J.S.J. 2000. The geopolymerisation of alumino-silicate minerals, International Journal of Mineral Processing.59: 247- 266.