International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 04 | Apr -2017 www.irjet.net p-ISSN: 2395-0072

FACTORS AFFECTING COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE-A REVIEW

Ajay Sharma[1], Juned Ahmad[2]

[1] *PG Student, Structural Engineering, Integral University, Uttar Pradesh, India*
[2]*Assistant professor, Department Of Civil Engineering, Integral University, Uttar Pradesh, India*

Abstract - *The production of cement not only consumes huge amount of the natural resources i.e. limestone and fossils fuel but also produces almost 5 to 7% of the total production of carbon dioxide which causes green-house effect. So it is very essential to replace the ordinary Portland cement by the other binder which have the same or better properties than OPC. Geopolymer concrete is innovative green concrete in which binding properties are developed by the interaction of source material or by-product that is rich in silica and alumina i.e. Fly Ash, Ground granulated blast furnace slag (GGBS), Rice husk with alkaline solution of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate. A by-product of coal like fly ash obtained from the thermal power plant reacting with alkaline solution produces aluminosilicate gel that acts as the binding material for the concrete. It utilises a large amount of industrial waste materials such as fly ash and slag and also reduce the emission of carbon dioxide gases so it is eco-friendly and help to sustainable development. The main objective of this review to put the light on the constituents as well as various factors that can affect the compressive strength of geopolymer concrete. This paper also deals with the various application, economical and environmental benefits of geopolymer concrete.*

Key Words: **Geopolymer concrete, Fly-ash, GGBS, Alkaline solution, Compressive strength, Environmental benefits**

.

1. INTRODUCTION

Day by day the construction activities increases due to the urbanization of developing countries. Concrete consist of high strength, better durability and other important properties which make it suitable for construction, so the demand of concrete is more as a construction material next to water globally, which significantly increased the demand of Portland cement i.e. main constituent of concrete. In the production of Portland cement large amount of carbon dioxide emits to the atmosphere. Therefore the rate of production of carbon dioxide released to the atmosphere is also increasing. The global production of cement is estimated nearby 2.8 billion tones according to recent industry data. In each ton of cement production approximately 94.76 ×106 Joules is spent, resulting into carbon dioxide emission, estimated to be nearly 5 to 7% of the total production of carbon dioxide so the concrete industries have to be find the other alternative binder [1].

Fly ash is the waste material of coal based thermal power plant, available at high scale. According to one survey the total production of fly ash in the world is about 780 Million tons per year after 2010. In India more than 100 million tons of fly ash is produced annually, out of which 17 – 20 % fly ash is utilized either in concrete as a part replacement of cement or workability improving admixture or in stabilization of soil. There are environmental benefits in reducing the use of Portland cement in concrete, and using a cementitious material, such as fly ash, silica fume, ground granulated blast furnace slag, metakeoline, rice husk ash, etc. as a partial substitute [2].

The concept of geopolymer concrete was first introduced by a French scientist Joseph Davidovits who proposed alkaline liquid as an activator to be used to react with some source material rich in silicon and aluminium, such as industry and agro waste products like fly ash, ground granulated blast furnace slage or rice husk ash to produce geopolymer mortar which act as binder. Geopolymer is incorporated by mixing aluminosilicate-reactive material with strong alkaline solutions, such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate or potassium silicate. Since the chemical reaction that happens in this case is a polymerization process,so he select term 'Geopolymer' to represent these binders. Fly ash is the most common and very cheap source material for making geopolymers. Normally, good high-strength geopolymers can be made from class F fly ash. The concrete made with such industrial wastes is eco-friendly and hence called as "Green concrete". Therefore the replacement of cement by fly ash is possible up to certain extent. For complete replacement of cement by fly ash and to achieve higher strength within a short period of time, alkaline activating solution is important for dissolving of Si and Al atoms to form geopolymer precursors and finally alumino-silicate material. Geopolymer concrete is a new material in which cement is totally replaced by the pozzolanic materials that is rich in Silicon (Si) and Aluminium (Al) like fly ash. It is activated by highly alkaline liquids to produce the binder which binds the aggregates in concrete when subjected to elevated temperature.

Geopolymers are member of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that results in a three-dimensional polymeric chain a ring structure consisting of Si-O-Al-O bonds as follow:

$$M_n [-(SiO_2)_z-AlO_2]_n . wH_2O$$

Where: M = the alkaline element or cation such as potassium, sodium or calcium

n = the degree of polycondensation or polymerisation

z = 1, 2, 3 or higher

The schematic formation of geopolymer material can be shown as described by equations (1) and (2).

n(Si_2O_5, Al_2O_2) + 2nSiO_2 + 4nH_2O +NaOH/KOH
(Si-Al materials) |
|
Na^+, K^+ + n$(OH)_3$-Si-O-Al--O-Si-$(OH)_3$
|
$(OH)_2$
(Geopolymer precursor) ------------------[1]

n$(OH)_3$-Si-O-Al--O-Si-$(OH)_3$ + NaOH/KOH
| |
$(OH)_2$ |
(Na^+, K^+)-(-Si-O-Al--O-Si-O-) + 4nH_2O
| | |
O O O
(Geopolymer Backbone) -------------------[2]

From the above equation, it is clear that, water is not involved in the chemical reaction of Geopolymer concrete and water is released during the chemical reaction that occurs in the formation of geopolymers. It provides only the workability to the mixture during handling [3].

2. MATERIALS

There are two main constituents of geopolymers, namely the source materials and the alkaline liquids.

2.1 Source materials

By-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. could be used as source materials because these are rich in silica and alumina which is necessary for geopolymer concrete. Fly ash is a by-product of burning pulverized coal in an electrical generating station. Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite). Class C Fly ash produced from the burning of younger lignite or sub bituminous coal and having more than 20% lime (CaO). In addition to having pozzolanic properties, also has some self-cementing properties and does not require an activator. The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash and having less than 10% lime (CaO). This fly ash is pozzolanic in nature, and require some activator. . GGBS is a byproduct as it is produced during extraction of iron from ore. Silica fume, Containing silica, silicone or silicone-or micro-alloys produced by the production of a product by itself. SF is an amorphous solid high silica content with.

2.2 Alkaline solution

The common materials used as alkaline solution in producing fly ash-based geopolymers are sodium silicate and potassium hydroxide or sodium hydroxide.
Generally NaOH is available in market in pellets or flakes form with 96% to 98% purity where the cost of the product depends on the purity of the material. The solution of NaOH was formed by dissolving it in water with different molarity. It is recommended that the NaOH solution should be made 24 hours before casting and should be used with 36 hours of mixing the pellets with water as after that it is converted to semi-solid state.

Sodium Silicate (Na_2SiO_3) is also known as water-glass which is available in the market in gel form and also in the solid form. The ratio of silicon dioxide (SiO_2) and sodium oxide (Na_2O) in sodium silicate gel highly affect the strength of geopolymer concrete. Mainly it is seen that a ratio ranging from 2 to 2.5 gives a satisfactory result.

Usually the sodium silicate which in the form of gel mixed with sodium or potassium hydroxide to produce the alkaline solution. The alkaline solution is prepared a day before it is mixed with fly ash. Then, the materials are mixed together with fine aggregate and coarse aggregate to form concrete and curing process is done.

3. MIXING, CASTING AND CURING OF GEOPOLYMER CONCRETE SPECIMENS

Casting of GPC specimens are very much similar to that of OPC concrete specimens. The alkaline liquid-to-fly ash ratio by mass, water-to- geopolymer solids ratio by mass, the wet-mixing time, the heat-curing temperature, and the heat - curing time are selected as parameters. The mass of combined aggregates may be taken to be between 75% and 80% of the mass of geopolymer concrete. In the laboratory, the fly ash and the aggregates is first mixed together in dry state 2-3 minutes to get homogeneous mix. The alkaline solutions which were made one day before is mixed with the super plasticizer and the extra water, if any. This liquid component are added to the mixed aggregate and the mixing continued usually for another 10 - 15 minutes so that binding paste covered all the aggregates and mixture become homogeneous and uniform in colour. The fresh concrete could be handled up to 120 minutes without any sign of setting without any degradation in the compressive strength.

After the mixing is done the mix is filled in the moulds in three layers with required compaction same as the usual methods used in the case of Portland cement concrete and the specimens are kept on a vibrating table so that to minimize amount of voids. The fresh fly ash-based geopolymer concrete is usually cohesive. The workability of the fresh concrete is measured by means of the conventional slump test.

In geopolymer concrete, the high temperature curing is required for the polymerisation process. The required temperature may be provided either by oven curing or by steam curing. In oven curing, the specimens are wrapped by plastic sheet to prevent loss of moisture and placed in an oven for the specified period. After the curing period, the test specimens left in the moulds for at least 4-6 hours in order to avoid a major change in the environmental conditions. After de-moulding, the concrete specimens are allowed to become air-dry in the laboratory until the day of the testing.

4. PROPERTIES OF GEOPOLYMER CONCRETE

Depending on the synthesis conditions (including nature of start materials), geopolymer concrete can be made to achieve the following advantages:

- High early compressive strength gain
- Good abrasion resistance
- Rapid controllable setting and hardening
- Fire resistance (up to 1000ºC) and no emission of toxic fumes when heated.
- High level of resistance to a range of different acids and salt solutions
- Not subject to deleterious alkali-aggregate reactions
- Low shrinkage and low thermal conductivity
- Adhesion to fresh and old concrete substrate, steel, glass, ceramics
- High surface definition that replicates mould patterns
- It's impermeable like normal OPC concrete
- Bleeding free.

5. FACTORS AFFECTING COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

5.1 Fineness and Content of Fly ash

The fineness of fly ash gives a major impact on the strength of the geopolymer Concrete as the fly ash fineness plays a vital role in the activation of geopolymer concrete. An increase in the fineness increased both workability and compressive strength. It is also observed that finer particles resulted in increasing the rate of reaction needing less heating time to achieve a given strength. The mass density of geopolymer concrete increased with the increasing fly ash fineness because of more surface area with more Si-Al bond for polymerization [4, 5]. Compressive strength of geopolymer concrete increases with increase in percentage of replacement of flyash with GGBS. Flyash can be replaced by GGBS up to 28.57%, beyond that fast setting is observed [6].

5.2 Alkaline Solution to Fly ash Ratio

The higher fly ash content with a higher alkaline activator content gives a high compressive strength than the lower one. Increase in the ratio of alkaline liquid to fly ash increases the strength of concrete upto a certain limit. Beyond the limit of alkaline liquid to fly ash ratio increases compressive strength decreases. Decrease in compressive strength of geopolymer concrete is because of increases in water in the preparation of alkaline liquid and substantial increase in number of pores due to heat curing. This behavior is similar to normal concrete as water to cement ratio increases compressive strength decreases [7].

5.3 Water to Geopolymer solid Ratio

In this parameter the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of the water use in the making of the sodium hydroxide solution and the mass of extra water, if any, present in the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids used to make the sodium hydroxide solution and the mass of solids in the sodium silicate solution i.e. the mass of Na_2O & SiO_2. The compressive strength of geopolymer concrete is inversely proportional to the water-togeopolymer binder ratio similar to that of waterto- cement ratio in cement concrete. Suitable range of water-to-geopolymer binder ratio is in the range of 0.25 to 0.35. Higher ratio gives segregated mix while lower ratio gives viscous and dry mix. [8]. The concrete Mixes using additional water of 10%, 15% and 20% by mass of fly ash. Increase in water to geopolymer solids ratio results into increase of the workability of mixes but the compressive strength of geopolymer concrete reduces [9].

5.4 Concentration of NaOH

Molarity of NaOH solution plays a vital role in the strength of geopolymer concrete. With a higher concentration of NaOH solution a higher compressive strength can be achieved. The concrete specimens with molarity varies from 8M to 18M and curing at temperature for 80 0 C after testing shows that the 16M gives better strength than other molar [10]. At high NaOH concentrations, the leaching of alumina and silica was enhanced and this resulted in increased geopolymerization, and thus the strength increased. But NaOH concentration of 20 M resulted in a reduction of strength. The reduction of strength at high NaOH concentration was due to the high concentration of hydroxide ions (OH^-), which caused aluminosilicate gel precipitation at the early stage of development [11]. According to previous studies [12], it was found that 12 M

NaOH solution gives strength 1.25 times more than that of GPC with other molarities after 28 days of hot curing than others.

5.5 Ratio of Sodium Silicate to Sodium Hydroxide

The effect of ratio of sodium hydroxide to sodium silicate solution by mass on the compressive strength of concrete can be seen by comparing the results. For these grades the concentration of sodium silicate solution (in terms of molarity), the water content, the fly ash content and the condition of curing were kept constant. The ratio is varied from 2 to 3.5, in the increment of 0.5. The average maximum strength was obtained when the ratio was 2.5. Firstly, the cost of alkaline liquid is economical when the ratio of sodium silicate solution-to-NaOH solution is 2.5. Secondly, the test results were remarkably consistent when this ratio was 2.5 [13].

5.6 Addition of Super Plasticiser

Naphthalene sulphonate–based super plasticiser may be used to improve the workability of fresh low-calcium fly ash-based geopolymer concrete. However, the content of the super plasticiser need not be more than 2% of the mass of fly ash. Beyond this amount, the addition of super plasticiser can cause a slight reduction in the compressive strength of hardened concrete; moreover, amounts greater than 2% may be uneconomical in practice [14]

5.7 Rest Period

The term 'Rest Period' is defined by the time taken from the completion of casting of concrete specimens to the start of curing at an elevated temperature. This is very important in context to many practical applications. For instance, when the fly ash based geopolymer concrete is used in precast concrete industry, there must be sufficient time available between casting of products and sending them to the curing chamber. It has been observed that one day rest period has resulted into higher gain in compressive strength as compared to that for 0 day rest period.

5.8 Curing Hour and Curing Temperature

Cuing hour and curing temperature is very significant parameter of geopolymer concrete because it is very important for polymerization process. Longer curing time and curing hours is improved the polymerisation process resulting in development of higher compressive strength.

The curing temperature at 90ºC showed better compressive strength than 80ºC and 100ºC. Furthermore 90ºC-12 hour curing produced maximum strength when compared with 90ºC-24 hours curing. Beyond this optimum temperature, increase in the curing temperature and curing hours reduced the compressive strength of geopolymer concrete specimens. The loss in compressive strength was due to continuous moisture loss from the specimens which produced voids and resulted in strength degradation [15].

It is also observed that the rate of gain of strength increases as the duration of heating increases specifically at higher temperature. After 12 hours of temperature curing, the rate of gain of strength is not very significant specifically at 90∘C and 120∘C. But at heating temperature of 60∘C, the rate of gain of strength is constantly increasing for all curing periods. That means the strength of geopolymer concrete can be increased by increasing temperature with reduced duration of heating. But at heating temperature of 120∘C, cracks are developed on the concrete surface so the suitable temperature for making geopolymer concrete is in between 60 and 90∘C. Similarly, duration of heating in the range of 6 to 24 hours produces higher compressive strength. However, the increase in strength beyond 12 hours is not very significant [16].

The rate of gain of strength is slow at 60°C but high at 120°C. The compressive strength and split tensile strength beyond 120°C is not significant for 24 hours of curing but it is significant at 18 hrs of curing time. The compressive strength for 120°C at 6hrs and 12hrs will not be satisfactory. The rate of gain of compressive strength and split tensile strength for 60°Cis not satisfactory at 6, 12, 18 and 24hrs of curing time. The optimum strength achieved at 90°C in between 18 to 24hrs duration [17].

6. APPLICATIONS

Geopolymer concrete is a new type of concrete which needs more attention on site to be used as a compare to all OPC concrete. Geopolymer technology is most advanced in precast applications due to the relative ease in handling sensitive materials i.e. alkaline solution and the need for a controlled high-temperature curing environment required for polymerisation process. High-early strength gain is a characteristic of geopolymer concrete when dry-heat or steam cured, although ambient temperature curing is possible for geopolymer concrete. So it can be used to produce precast railway sleepers, sewer pipes, deck slabs as well as structural retrofits using geopolymer-fiber composite and other prestressed concrete building components. The early-age strength gain is a characteristic that can best be exploited in the precast industry where steam curing or heated bed curing is common practice and is used to maximize the rate of production of elements. Recently, geopolymer concrete has been tried in the production of precast box culverts with successful production in a commercial precast yard with steam curing.

Geopolymer concrete has excellent resistance to chemical attack so it is applicable in aggressive marine environments, environments with high carbon dioxide or sulphate rich soils. Similarly in highly acidic conditions, geopolymer concrete has shown to have superior acid resistance and may be suitable for applications such as mining, some manufacturing industries and sewer systems [18].

7. ECONOMICAL BENEFITS

Low calcium fly ash based geopolymer concrete provides several economic benefits over OPC concrete. Fly ash or blast furnace slag are available very cheaply as compare to conventional cement. The constituents of alkaline solution are available at little bit high prize but the overall production cost of geopolymer concrete is 10 to 30% is less than the conventional cement concrete [18]. According to the previous analysis [19], for M30 grade of GPC concrete the cost of production is marginally (1.7%) higher than OPC concrete of the same grade whereas for M50 grade, the cost of OPC concrete is 11% higher than GPC of same grade. Hence it can be concluded that savings in cost can be attained in the production of geopolymer concretes of higher grades and lower grades with a marginal difference. In addition to the above benefits, the utilization of fly ash reduce the use of Portland cement so, the production of carbon dioxide gas to the atmosphere is also reduces and hence earn monetary benefits through carbon-credit trade. Due to having properties like good fire resistance (up to 1000ºC), low shrinkage, excellent resistance to sulfate attack, good acid resistance, the geopolymer concrete may yield additional economic benefits in the utilization in infrastructure applications [20].

8. CONTRIBUTION TOWARDS SUSTAINABLE DEVELOPMENT

Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. Due to the high demand of concrete, the production of cement is going on high scale. Therefore the rate of production of carbon dioxide released to the atmosphere is also increasing. The production of one ton of cement emits approximately one ton of carbon dioxide to the atmosphere. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO2), to the atmosphere by human activities. Among the greenhouse gases, CO2 contributes about 65% of global warming. So the climate change due to global warming and environmental protection has become major concerns. Moreover, cement production is not only highly energy-intensive, next to steel and aluminium, but also consumes significant amount of natural resources which is a major challenge for the sustainable development.

On the other hand, fly ash is the waste material of coal based thermal power plant. The output of industrial waste materials such as Fly Ash, Slags, Rice-Husk Ash etc. which can be suitably used as cement replacement materials is more than double this amount of OPC annual production but creates disposal problem. Several hectors of valuable land is required for their disposal. As fly fiery debris is light in weight and effectively flies, this makes extreme wellbeing issues like asthma, bronchitis, etc. For the sustainable development, reducing the use of Portland cement in concrete, and using a cementitious material, such as fly ash, silica fume, ground granulated blast furnace slag, metakeoline, rice husk ash, etc. as a partial substitute. With silicon and aluminium as the main constituents, fly ash has great potential as a cement replacing material in concrete.
The concrete made with such industrial wastes is eco-friendly. In this respect, the geopolymer concrete with a much lower environmental footprint shows considerable promise for application in the concrete industry. In terms of global warming, the geopolymer technology could significantly reduce the CO2 emission to the atmosphere caused by the cement industries.

9. CONCLUSIONS

This paper presented a brief overall review on geopolymer concrete with its various constituents, mixing procedure and economical and environmental benefits. Higher the fineness and content of fly ash gives a higher compressive strength because of more surface area with more Si-Al bond for polymerization. The ratio of alkaline liquid to fly ash can be taken between 0.35 to 0.45. The high content of water significantly reduce the strength of geopolymer concrete. Higher the concentration of sodium hydroxide solution gives higher strength and the optimum value of sodium silicate to sodium hydroxide is 2.5. Curing hour and curing temperature is the very important parameter as it increases, the increment in strength is remarkable. Utilization of by-product waste material in production of geopolymer concrete reduces the emission of carbon dioxide gases to the atmosphere. So it helps to sustainable development as well as make the construction economical.

10. REFERENCES

1. Bharat Bhushan Jindal et al, “Development of High Strength Fly Ash based Geopolymer Concrete with Alccofine” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320–334X.\
2. Satpute Manesh B., Wakchaure Madhukar R., Patankar Subhash V. “Effect of Duration and Temperature of Curing on Compressive Strength of Geopolymer Concrete” International Journal of Engineering and Innovative Technology (IJEIT) Volume 1, Issue 5, May 2012.
3. M. M. A. Abdullah et al., “Mechanism and Chemical Reaction of Fly AshmGeopolymer Cement- A Review” Int. J. Pure Appl. Sci. Technol., 6(1) (2011), 35-44.
4. S.S. Jamkar, Y.M. Ghugal and S.V. Patankar “Effect of Fly ash Fineness on Workability and Compressive strength

of Geopolymer Concrete" The Indian Concrete Journal APRIL 2013.
5. Subhash V. Patankar, Yuwaraj M. Ghugal and Sanjay S. Jamkar "Mix Design of Fly Ash Based Geopolymer Concrete" Advances in Structural Engineering, DOI 10.1007/978-81-322-2187-6_123, 2015.
6. Ganapati Naidu et al., "A Study on Strength Properties of Geopolymer Concrete with Addition of G.G.B.S" International Journal of Engineering Research and Development eISSN : 2278-067X, pISSN : 2278-800X, www.ijerd.com Volume 2, Issue 4 (July 2012), PP. 19-28.
7. Suresh .G. Patil , Manojkumar "FACTORS INFLUENCING COMPRESSIVE STRENGTH OFGEOPOLYMER CONCRETE" international Journal of Research in Engineering and Technology Eissn: 2319-1163 | pISSN: 2321-7308.
8. Subhash V. Patankar et al., "EFFECT OF WATER-TO-GEOPOLYMER BINDER RATIO ON THE PRODUCTION OF FLY ASH BASED GEOPOLYMER CONCRETE" International Journal of Advanced Technology in Civil Engineering, ISSN: 2231 –5721, Volume-2, Issue-1, 2013.
9. Prakash R. Vora and Urmil V. Dave "Parametric Studies on Compressive Strength of Geopolymer Concrete" Procedia Engineering 51 (2013) 210 – 219.
10. Sandeep L. Hake et al., "EFFECT OF MOLARITY ON GEOPOLYMER CONCRETE" International Journal of Advance Research in Science and Engineering, vol. 5, special issue No. 01, May 2016.
11. Pattanapong Topark-Ngarm et al, "Setting Time, Strength, and Bond of High-Calcium Fly Ash Geopolymer Concrete" American Society of Civil Engineers 10.1061/(ASCE)MT.1943-5533.0001157 2014.
12. A.Maria Rajesh et al., "Study of the Strength Geopolymer Concrete with Alkaline Solution of Varying Molarity" IOSR Journal of Engineering (IOSRJEN) ISSN (e): 2250-3021, ISSN (p): 2278-8719 Vol. 04, Issue 06 (June. 2014), ||V1|| PP 19-24.
13. Shankar H. Sanni , R. B. Khadiranaikar "PERFORMANCE OF ALKALINE SOLUTIONS ON GRADES OF GEOPOLYMER CONCRETE" International Journal of Research in Engineering and Technology, eISSN: 2319-1163 | pISSN: 2321-7308.
14. D. Hardjito and B. V. Ranga "DEVELOPMENT AND PROPERTIES OF LOW-CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE" Research Report GC 1 Faculty of Engineering Curtin University of Technology Perth, Australia, 2005.
15. Mohammed Rabbani Nagral et al, "Effect Of Curing Temperature And Curing Hours On The Properties Of Geo-Polymer Concrete" ISSN (e): 2250 – 3005 || Vol, 04 || Issue, 9 || September – 2014 ||.
16. Subhash V. Patankar et al., "Effect of Concentration of Sodium Hydroxide and Degree of Heat Curing on Fly Ash-Based Geopolymer Mortar" Indian Journal of Materials Science, Volume 2014, Article ID 938789.
17. Prof. Pradnya K. Jamdade "Effect of Temperature and Time of Curing on Strength of Flyash based Geopolymer Concrete" International Journal of Innovative Research in Science, Engineering and Technology Vol. 5, Issue 6, June 2016.
18. N A Lloyd and B V Rangan "Geopolymer Concrete with Fly Ash" Second International Conference on Sustainable Construction and Technologies June 28-June 30, 2010.
19. J.Thaarrini & S.Dhivya "Comparative Study on the Production Cost of Geopolymer and Conventional Concretes" ISSN 2278-3652 Volume 7, Number 2 (2016), pp. 117-124.
20. B. Vijaya Rangan "Geopolymer concrete for environmental protection" The Indian Concrete Journal, April 2014, Vol. 88, Issue 4, pp. 41-48, 50-59.