Comparative Analysis of GEOPOLYMER Concrete with Conventional Concrete Using M Sand – A Review

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Abstract— World's most consumed construction material is concrete made up of cement, aggregates, water and additives as it is found to be more versatile, durable and reliable. Concrete is the second most consumed material after water, which required large quantities of Portland cement. The manufacturing process of Ordinary Portland Cement (OPC) results in destruction of the environment due to the emission of CO2 as well mining also results in unrecoverable loss to nature. The amount of carbon emissions is increasing on an alarming scale and hence, it is required to find an alternative material to the existing expensive cement-concrete. This is also a high time to think for an alternative to cement since the production of cement is the main reason for emission. There are considerable attempts which have taken place in order to replace cement other materials. Geo-polymer concrete is one of an alternative construction material which is produced by the chemical action of inorganic molecules. Fly Ash, a by-product of coal obtained from the thermal power plant is abundantly available worldwide. Fly ash which is rich with silica and alumina activated with alkaline activators form alumino silicate gel that act as the binding material for the concrete. It is an excellent alternative construction material to normal concrete without using any amount of ordinary Portland cement. Geo-polymer concrete shows a greener substitute for ordinary Portland cement concrete in some applications. This paper reviews the structural properties of Geo-polymer concrete and its applications. Hence, an attempt has been made to consolidate the research works carried out by the researchers in the area of geo-polymer concrete. The limitations of geo-polymer concrete are also presented.

Keywords: Geopolymer Concrete, Fly Ash, GGBS, M Sand, Alkaline Activator Solution, Compressive Strength, Workability

I. INTRODUCTION

Construction industry is one of the fast growing industries throughout the world. Concrete is one of the widely used construction material. The primary binder used in concrete is Ordinary Portland Cement (OPC). The worldwide production of cement is high as 2.6 billion tons per year and generates nearly 7% of carbon-di-oxide which largely contributes to environmental pollution and global warming [3]. Cement production also demands huge quantity of limestone which is seen depleting. On the other hand, there is huge quantity of fly ash produced which is aby-product produced during combustion of coal and large part of it is disposed in the landfills which affect the ground water as well as surface sources of water. Hence it is of utmost importance to use alternate pozzolan materials which will utilize waste produced as well as reduce the adverse effect of construction of environment and also improve the performance of concrete [2].

II. OVERVIEW ON GEO-POLYMER CONCRETE

Several studies have been made to address the fore said environmental concerns. The alternate pozzolan materials include fly ash, silica fume, ground granulated blast furnace slag (GGBFS), rice husk ash. French Professor Davidovits first introduced the word "Geo-polymer". Geo-polymer concrete is an alternative to conventional concrete which does not utilize cement as a binder but the binding properties is facilitated by using source materials which are rich in silica and alumina. The binding property is achieved by the reaction of alkaline solutions with the pozzolan source material [3]. The reaction between the source material and alkaline solution forms a gel known as aluminosilicate. The gel so formed binds the aggregates and other materials in concrete to form geo-polymer concrete [1].

III. LITERATURE REVIEW

A. Ukesh Praveen P and Srinivasan K (2017)

Made a review of literature pertaining to self-compacting of geo-polymer concrete and reported that the contribution of GGBS helps the self-compacting geo-polymer concrete attain high compressive strength at ambient room temperature. GGBS at ambient curing condition had more compressive strength rather than Fly ash based self-compacting geo-polymer concrete. It is recommended that sodium hydroxide and sodium silicate solutions should be prepared at least 24 hours before use.

B. Manimaran, E and Mohankumar, G (2017)

carried out an investigation on influence of sodium hydroxide concentration on the strength of fly ash based geo-polymer concrete and reported that the strength of ambient cured specimens is always less and about 95% to 97% of the hot cured concrete irrespective of the molarities of NaOH solution. Under specified concentration of NaOH, the required strength of Geo-polymer concrete can be achieved by ambient curing itself and hot curing is not at all required under laboratory condition. Hot curing may be employed in case of fabrication of precast units.

C. Patankar S.V et al. (2018)

studied effect of duration and temperature curing on compressive strength of fly ash based of geo-polymer concrete and observed while finding effect of concentration of sodium hydroxide on fly ash based geo-polymer concrete that the compressive strength of geo-polymer concrete increases with increase in the concentration of sodium hydroxide solution for all temperatures but the rate of gain of strength at and above 60∘C is not very significant.

D. Deepa Balakrishnan S. et al (2013)

examined the properties of fly ash based geo-polymer concrete and stated that the strength gain in geo-polymer concrete is significant when heat cured for 72 hours also the strength of heat cured specimen is found to be almost equal to the corresponding strength of 90 day ambient cured specimens or almost two times as that of the 28 day strength.

E. Satpute Manesh B. et al (2012)

studied the effect of duration and temperature curing on compressive strength of fly ash based of geo-polymer concrete and reported that curing temperature and its duration are important in the activation of geo-polymer concrete. Curing time, in the range of 6 to 24 hours, produces higher compressive strength. However, the increase in strength beyond 20 hours is not significant.

F. B. V. Rangan (2008)

in his research report on Fly ash based geo-polymer concrete highlighted that longer curing time improves the polymerization process resulting in higher compressive strength. The rate of increase in strength is rapid up to 24 hours of curing time; beyond 24 hours, the gain in strength is only moderate. Therefore, heat-curing time need not be more than 24 hours for all practical applications.

G. Sandeep L. Hake et al. (2015)

made an investigation on the method of curing and found that most of researcher used only oven heat curing for geo-polymer concrete. They reported that many studied only for different curing temperature in oven curing, but only few researchers experimented with steam, membrane curing and no work was reported on accelerated curing, as well as comparison on steam, accelerated, membrane, natural land oven curing. So there is scope for research on method of curing of geo-polymer concrete.

H. Zhang H.Y. et al. (2018)

based on their experimental results on the bond behavior between geo-polymer concrete and rebar reported that Geo-polymer concrete exhibits significant temperature induced degradation in bond strength, when exposed to temperatures above 300℃ also Bond strength of geo-polymer concrete was found to decrease at the same rate as that of splitting tensile strength with temperature, but this degradation is at a higher pace than that of the compressive strength

MOLARITY

I. Manimaran E and Mohankumar G (2017)

reported while finding the influence of sodium hydroxide concentration on the strength of fly ash based geo-polymer concrete that the higher concentration of NaOH reduces the slump value and extra water is needed for workability. The equivalent characteristic strength of GPC even 3% more than that is easily obtained with the lowest molarities (8M) of NaOH both in hot and ambient curing.

J. PhoongernkhamT (2017)

investigated the effects of combinations of sodium hydroxide and sodium silicate solutions (SH, SHSS, and SS) on the strength development of fly ash and Portland cement based Geo-polymer Mortar (GM)also the GM made from SHSS solution can be used as a sustainable repair binder and its application is very attractive.

K. Patankar S.V. et al. (2018)

studied effect of various concentrations of sodium hydroxide solution in terms of molarities at solution to fly ash ratios of 0.30, 0.35, and 0.40 on workability in terms of flow in plastic state and effect of degree of heating on compressive strength. They reported that the workability as well as compressive strength of geo-polymer mortar increases with increase in concentration of sodium hydroxide solution in terms of molarities and they recommended, 13-molar solution of sodium hydroxide is recommended on the basis of workability and compressive strength.

L. Oyebisi Set al. (2018)

investigated the utilization of both corncob ash and ground granulated blast furnace slag as source materials activating with both sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) solutions in the production of geo-polymer concrete and reported that the geo-polymer concrete with 12 M sodium hydroxide shows a higher compressive strength when compared with the Portland cement concrete. Comparing with the Portland cement concrete, the optimal replacement level of both ground granulated blast furnace slag and corncob ash for optimum strength is obtained at 60% and 40% respectively.

M. Lăzărescu A et al. (2018)

investigated on the parameter affecting the mechanical property of fly ash based geo-polymer concrete while keeping the alkaline liquid to fly ash mixing ratio constant, they varied the Na2SiO3to NaOH solution ratio and the NaOH solution concentration, Results showed that by increasing the sodium silicate solution content in the mixtures, a significant increase in the compressive strength can be obtained.

USES OF FLY ASH AND OTHER INDUSTRIAL WASTES

Geo-polymer concrete doesn't use cement but uses industrials wastes like fly-ash, GGBS etc. Out of all the usable industrial wastes fly-ash is the most commonly used material.

N. Deepa Balakrishnan S et al (2013)

reported that the fly ash content is much significant when the geo-polymer concrete is cured in ambient temperature. However, the change in strength of heat cured specimen is nominal with the variation of fly ash content is varied from 395 to 425 kg per cubic meter of concrete. They reported that the fly ash geo-polymer concrete is a sustainable material for future construction works. However, design methodologies are to be developed for geo-polymer concrete prior to actual use in worksite.

O. B. V. Rangan (2008)

reported that heat-cured low-calcium fly ash-based geo-polymer concrete offers several economic benefits over Portland cement concrete. The price of one ton of fly ash is only a small fraction of the price of one ton of Portland cement. Therefore, after allowing for the price of alkaline liquids needed to the make the geo-polymer concrete, the

price of fly ash-based geo-polymer concrete is estimated to be about 10 to 30 percent cheaper than that of Portland cement concrete.

P. Adam A. A. et al. (2016)

investigated on the effect of lime addition on the setting time strength of ambient cured fly ash based geo-polymer concrete and reported that the setting time of the class F fly ash based geo-polymer paste can be controlled by adding a small proportion of slaked lime. The addition of lime increases the strength and decreased the setting time.

Q. Ma C. K. et al. (2018)

assessed the performance of geo-polymer concrete, both in material and structure. It was found that there are about 6 groups of geo-polymer concrete based on alumina silicate sources. They are fly ash-based, met kaolin-based, slag-based, rice husk ash-based, high calcium wood ash-based and combination of either two of the earlier mentioned alumino silicates. Among these types, fly ash-based geo-polymer concrete is the most popular and widely tested also through review of papers found that geo-polymer is suitable for structural elements. It was also found that the full scale tests are still lacking especially for non-Fly Ash based geo-polymer concrete.

R. Albitar M et al. (2017)

while evaluating the durability of geo-polymer and conventional concrete reported that Sulphuric acid has a more detrimental impact on OPC concrete with a reduction in compressive strength of 26.6% compared to 10.9% reduction of fly ash in geo-polymer concrete compressive strengths respectively.

S. Al-Majidi M. H. et al. (2016)

investigated the development of geo-polymer mortar under ambient curing temperature for in situ applications and stated that the geo-polymer mixes with increased GGBS content had considerably improved flexural and direct tensile strength, even without any heat curing treatment.

INCORPORATION OF CEMENT AS PARTIAL REPLACEMENT

Only limited work is available in the literature on incorporation of cement as partial replacement in GPC.

T. Mehta A and Siddique R (2017)

reported that the compressive strength of low-calcium fly ash based geo-polymer concrete increased with the inclusion of OPC as a replacement to fly ash up to 20% at all ages.

U. Askarian M et al. (2018)

reported that the developed one-part hybrid OPC-geo-polymer concrete could be a suitable material for on-site operation as the need for heat curing and the use of highly alkaline solutions have been eliminated. The setting time, workability, compressive strength and microstructure properties can be controlled by adjusting the OPC content and activator concentrations.

DURABILITY AND ENVIRONMENTAL CONSIDERATION& RESULTS

V. Albitar M et al. (2017)

while investigating on the durability of geo-polymer and conventional concrete reported that the OPC concrete suffers more deterioration than geo-polymer concretes due to sodium sulphate exposure with a reduction magnitude of 15.4% compared to the 13.4% reduction magnitude of fly ash geo-polymer concrete.

W. Daniel A. Salas et al. (2018)

while assessing the life cycle of geo polymer concrete reported that the production of geo polymer concrete entails a potential environmental advantage over cement concrete if sodium hydroxide is produced with solar salt while considering an electricity mix with a high share of hydropower. The global warming potential of geo-polymer concrete under these conditions is 64% lower than that of cement concrete. However, geo-polymer concrete performs worse in the ozone depletion category due to CFC emissions during the chloro-alkali process (due to the use of carbon tetrachloride), which are not present in cement production.

WATER TO GEOPOLYMER SOLID RATIO

X. Ferdous M.W. et al. (2013)

proposed a method for selecting the mix proportions of fly ash based geo-polymer concrete and their experimental results showed that the compressive strength of the fly ash based geo-polymer concrete decreased linearly with increase in the water to geo-polymer solids ratio.

Y. Sudhakarreddy K et al (2018)

reported that at 6% of replacement of cement in fly ash of geo-polymer concrete yields the better results in flexural strength of beams. They also reported that higher replacement percentage in fly ash of geo-polymer concrete increases the strength of concrete.

Z. Fan F et al. (2017)

carried out an experimental investigation on the thermo-mechanical properties of Geo-polymers prepared using a class F fly ash, KOH and Na2SiO3solutions. They reported that the compressive strength of the geo-polymer with the water/ash ratio of 0.25 and 0.3 are very close, and the residual strength of the geo-polymer matrix after 500C heating with the water/ash ratio of 0.3 is higher than that for the water/ash ratio of 0.25, which indicates that the water/ash ratio of 0.3 might be the optimal mixture ratio.

AA. M. Mohd et al.

focused on the topic" A review on fly-ash based geo-polymer concrete without Portland cement". The study included various parameters such as curing process, compressive strength, workability, resistance against aggressive environment and behavior of geo-polymer at elevated temperature. The study concluded that fly ash based geo-polymer concrete is better than normal concrete in many aspects such as workability, exposure to aggressive environment, exposure to elevated temperature and compressive strength [1]

BB. B. Singh et al

studied the topic "Geo-polymer concrete: A review of some decent developments". The study included various parameters such as C-S-H phase effect, effect of admixtures, curing conditions, geo-polymer mortars, fresh and hardened properties of geo-polymer concrete and durability. The study concluded that geo-polymer concrete has considerable potential to be used as a construction material in several applications [2].

CC. J. Bhushan et al

studied the topic "Geo-polymer concrete: A review". The study included various parameters such as compressive strength, durability, economic benefits of geo-polymer concrete, necessity of geo-polymer concrete and application of geo-polymer concrete. The study concluded that geopolymer concrete is resistant to corrosion and fire and has high compressive and tensile strength [3].

DD. M. I. Abdul Aleem et al.

studied the topic "Geo-polymer concrete: A review". The study included various parameters such as necessity of geo-polymer concrete, constituents and properties of geo-polymer concrete, Applications and limitations of Geo-polymer concrete. The study concluded that due to high early strength, Geo-polymer concrete shall be effectively used in the precast industries, so that huge production is possible in short duration and the breakage during transportation shall also be minimized [5].

EE. Marathe S. et al.

studied the topic "Review on strength and Durability studies on Geo-polymer concrete". The study included various parameters such as constituent materials to produce geo-polymer concrete, mixing proportions and properties of geo-polymer concrete, Factors affecting strength of geo-polymer, Workability of fresh geo-polymer, Casting and curing of geo-polymer specimen, and Major hardened properties of geo-polymer concrete. The study concluded that geo-polymer concrete has significant potential as a good engineering material for the future research, as the GPC is not only environmental friendly but also possesses excellent mechanical properties [7].

IV. GEOPOLYMER CONCRETE MATERIALS

A. Fly Ash

It is a byproduct derived from combustion of coal in thermal power plants with rich silica and alumina content when used in concrete will help reduce the adverse effect on environment as a replacement of cement

B. GGBS

Acronym for ground granulated blast furnace slag is a derivative from iron and steel industry and is available in form of fine powder. Physically GGBFS can be described as glassy, granular with silicates and alumina.

C. Aggregates

Conventional fine and course aggregates of standard sizes are used in geo-polymer concrete.

D. Alkaline Solutions

Hydroxides and silicates of sodium and potassium are used. These alkaline solutions on reacting with silica and alumina from source materials such as fly ash and GGBFS will form binder material, which impart strength to concrete.

V. COMPARISON OF STRENGTH PARAMETERS

A. Compressive Strength

Marathe S. et al. focused on the topic "Review on strength and Durability studies on Geo-polymer concrete". Material constituents for geo-polymer formation, various mix proportions, strength affecting parameters, and workability of geo-polymer concrete in fresh state, casting process, and curing process were studied. The study concluded that geo-polymer concrete has significant potential as a good engineering material for the future research, as the GPC is not only environmental friendly but also possesses excellent mechanical properties [7].

B.Vijya Rangan et. al. stated that the compressive strength of geo-polymer concrete is very high when compared to normal concrete. It is about 1.5 times higher than normal concrete, for the same mix. Geo-polymer concrete also showed very good workability compared to normal concrete [16].

B. Durability

"Rangan, B.V. et al stated that Geo-polymer concrete is more resistant to heat, sulphate attack, water ingress & alkali-aggregate reaction. The role of calcium in Geo-polymer concrete made up of fly ash is very prominent since it may cause flash setting. Such structures with high durability can be adapted to marine environment [16].

"Wallah et al, explained that, fly-ash based geo-polymer concrete which is heat cured, undergoes low creep and shows very little drying shrinkage as of about 100 micro strains at the end of one year. And it shows excellent resistance to sulphate attack [17].

Chanh et al., proved that better resistance is provided by fly ash-based geo-polymer against aggressive environment. As such, this quality of resistivity can be used to construct structures which are exposed to marine environment [10].

Sathia et al., proved that when geo-polymer is exposed to acid solution, only 0.5% of weight is lost when compared to normal concrete immersed in 3% sulphuric acid [7].

C. Workability of fresh geo-polymer concrete

Sathia et al's study said that water also plays an important role in geo-polymer concrete as much as normal concrete. Workability can be improved by use of water in geo-polymer, but it will increase the porosity in concrete at elevated temperature due to the evaporation of water during curing process [7].

Chindaprasirt et al. discovered that the flow of mortar decreases with an increase in sodium hydroxide and sodium silicate concentration. The workable flow of geo-polymer mortar was in the range of 110 ± 5 to 135 ± 5% [12].Workability of mortar is upgraded with the addition of super plasticizer or extra water, but the use of super

plasticizer effect the strength of geo-polymer. Though, addition of extra water gives higher strength than addition of super plasticizer.

D. Economic Benefits of Geo-polymer Concrete

N A. Lloyd and B V Rangan concluded that heat-cured, low-calcium fly ash-based Geo-polymer concrete is estimated to be about 10 to 30 percent cheaper than that of Portland cement concrete. In addition, the appropriate usage of one ton of fly ash earns approximately one carbon-credit which in terms of ecological aspect makes it more economical [14].One tons of low-calcium fly ash can manufacture approximately three cubic meters of high quality fly ash-based Geo-polymer concrete. When it is utilized in infrastructure, the very little drying shrinkage, the low creep, the excellent resistance offered by geo-polymer concrete has additional economic benefits [14]. Geo-polymer concrete has many advantages as compared to the standard concretes. It has more durability than the standard concrete and requires little repair, thus saves huge amount of money to be spent on repair works and maintenance concrete based infrastructure [14].

E. Necessity of Geo-ploymer Concrete

As per the reports of international Cement Review, there is huge growth in development of infrastructure and cement usage was 3,294 million tons in 2010 which is increasing by nearly 12% per year which results in huge shortage of limestone in future. In addition to this, emission of CO2 in the atmosphere will result is global warming.

Kumar V. et al. (2005) submitted the estimate in their report that the thermal power industry is expected to produce fly ash to about 170 million tons by 2012 and 225 million tons by 2017 [3].

Lokeshappa et al. stated that the rate of utilization of fly-ash in construction field is 38%, the region where the remaining portion of the fly ash is dumped pollutes the environment. So, it is important to carry out research and undertake development for studying the structural properties of fly ash and also to utilize the industrial wastes in the construction [11].From the above study, it is understood that if geo-polymer concrete is developed, more amount of industrial wastes can be utilized in construction field with the reduction in the usage of Portland cement which will also contribute to reduce global warming [3]

F. Applications

Aleem et al. mentioned that, huge production is possible in short time if Geo-polymer Concrete can be used in the precast industries and the breakage during transportation shall also be minimized. It shall be effectively used for the beam column junction of reinforced concrete structures and infrastructure works. As a result, fly ash will be effectively used and hence no landfills are required to dump the fly ash [5].

Anuar et al, in this respect, the Geo-polymer technology proposed by Davidov, shows considerable promise for application in concrete industry as it acts as an alternative binder to the Portland cement. It can be used to produce precast railway sleepers and other pre-stressed concrete building components [15].

G. Challenges

In addition to various advantages expected from Geo-polymer concrete over ordinary Portland cement based concrete a few of the challenges may have to overcome before its practical application [3].

- Chemicals which can be harmful are used in the geo-polymer concrete.
- Bringing the base material, fly ash to the required location.
- Alkaline solutions with high cost.
- Practical difficulties in applying Steam curing / high temperature curing process.

Considerable research is being carried out to develop geo-polymer systems to overcome these technical hurdles [3].

VI. CONCLUSION

A detailed review of literature on geo-polymer concrete has been carried out and consolidated. It is found that fly-ash is the most widely used material for making geo-polymer concrete. The optimum time of curing for fly-ash based geo-polymer concrete is reported to be 20 to 24 hours. From the literature it is found that 8M to 16M sodium hydroxide solutions are often used for making GPC. Few have attempted to use lime or cement as partial replacement to fly-ash. It is reported that replacement of fly-ash with 20% of ordinary Portland cement gives higher compressive strength than geo-polymer concrete. The concept of addition of ordinary Portland cement in geo-polymer concrete is a good idea since the heat of hydration could be used for curing. The authors coin the term "Semi Geo-polymer Concrete" for geo-polymer concrete in which fly-ash is partially replaced with cement.

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