A Review on Strength Properties of Concrete with Partial Replacement of Cement by GGBS

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Abstract— Countries like India and China are facing problem of pollution due to large construction works in recent times. Ordinary Portland cement which is used in Concrete releases plethora of carbon dioxide (CO_2) in atmosphere during manufacturing. This leads to increase of level of greenhouse gases and hence contributes in global warming. Material like Geo polymer concrete is best alternative for this problem .Concrete is the most versatile, indispensable and widely used building material, of which cement is an integral constituent. From the time immemorial, Portland cement has been used as binder in concrete construction. However, the production of the cement is not eco-friendly and consumes enormous amount of energy which ultimately leads to the depletion of the fossil fuel reserve. In addition to this, it emits noxious greenhouse gases which are harmful for the biosphere.. This paper presents an experimental study of compressive and flexural strength of concrete prepared with Ordinary Portland Cement, partially replaced by ground granulated blast furnace slag in different proportions varying from 0% to 50% of GGBS Concrete.

Key words: Cement, Natural Sand, GGBS & Aggregate, Portland Cement, Geo Polymer

I. Introduction

In present time, Concrete is largest used manmade material in world. After watermost used material is cement concrete. Thousands tonnes of concrete is produced every year in construction industries. On an average every year three tons of concrete are consumed by each person on the planet. Concrete is a vital construction material that will be continuing in application far into the future. India, USA and China account for nearly half the world's demand. Concrete is used globally to build buildings, roads, runways, bridges and dams. This is due to the fact that concrete is produced from locally available materials such as cement, sand and aggregate. Cement is indispensable for construction activity, so it is strongly linked to the world economy. Cement making is rising by 2.5% annually, and is expected to growth from about 2.5 billion tons in 2006 to 3.7-4.4 billion tons by 2050. Ordinary Portland cement (OPC) is used as binding material in concrete. Two major problems are associated with the production of cement. First is that in the manufacturing of OPC fresh material such as lime stone, clay and other natural resources are required. To yield 1 ton of cement about 1.6 tons of fresh material are needed and time taken in formation of the lime stone, clay and minerals is far lengthier than the rate at humans use it.

On the other side the demand of concrete is increasing day by day. It is reported that the requirement of cement in India is likely to touch about 550 million tons by 2020 with a shortfall of 230 million tones i.e. 58 % shortage. Second is that in the production of OPC enormous amount of Carbon di Oxide (CO_2) released. It is state that in the manufacturing of 1 ton OPC about 1 ton CO_2 released. This tremendous amount of CO_2 released in environment which causes rise in CO_2 level in environment, which causes global warming.

The cement industry contributes about 5-6 % of total global carbon dioxide emissions.

On the other side, the abundance and availability of waste materials such as fly ash (FA), ground granulated blast furnace slag (GGBS), red mud and rice husk ash (RHA) worldwide create opportunity to utilize these by-product of different industries, as partial replacement for OPC in concrete. The utilization of industrial and agricultural by-products as the replacement or as the additional cementitious material has had a constructive effect in minimizing greenhouse gas emissions. Each year millions of tons of industrial wastes are produced and most of these wastes are unutilized. Increasing anxiety about the ecological significances of waste disposal has led researchers to investigate the consumption of the wastes as potential construction materials. By using these waste materials we can minimize the emission of CO_2 in environment and can also solve the problem of waste disposal.

GGBS had used in OPC concrete from long period to replace cement. An experimental study conducted to find the optimum usage of GGBS in concrete for maximum strength; it was observed that the strength of concrete increased with increase in GGBS content. Compressive strength increased up to optimum inclusion of GGBS, after this optimum value strength decreased. The optimum level of GGBS content was about 55-59% of total binder content (A. Oner and S. Akyuz 2007). For complete replacement of OPC in normal concrete, the new technology Geo Polymer concrete (GPC) is a promising technique. Geo-polymer is considered as the new generation cement after lime and Ordinary Portland cement. In geo-polymer concrete pozzolans such as ground granulated blast furnace slag and fly ash may be activated by using alkaline solution to form a binder and hence completely replace the use of OPC in concrete. In this technique, the alkalinity of the activator liquid can be low to mild or high. In contrast to OPC, principal binder in geopolymer concrete are not calcium silicate hydrates (CSH) gel, the role of binder is presumed by an alumino-silicate polymeric gel, formed by the tetra hedrally bonded silicon and aluminum with oxygen atoms shared in between.

II. Review of Literatures

A. *Overview of Geopolymers*

In 1978, Joseph Davidovits coined the term geopolymer to denote a wide range of materials characterized by networks or chains of inorganic molecules. He has suggested that an alkaline activator solution could be used to react with Silicon (Si) and Aluminium (Al) present in a source material of geological origin or in by-products of several industries such as ground granulated blast furnace slag, fly ash and rice husk ash to produce binders (Davidovits 1994). These are fundamentally inorganic alumino-silicate polymers synthesized from a fast chemical reaction called „Polymerization". Due to geological origin of silicon and aluminium and polymerization reaction it is termed as geopolymer. Geopolymerization involves a chemical reaction between alumino-silicate oxide present in source material and alkali silicates of alkaline activator solution yielding a three dimensional polymeric ring structure consisting of Si-O-Al bonds. For chemical designation, this alumino-silicate based geopolymerwas named as sialate. Sialate is an abbreviation for silicon-oxo-aluminate. The sialate network consists of SiO4 and AlO4 tetrahedra linked alternatively by sharing all the oxygens (Davidovits 1994).

Davidovit has proposed empirical formula for poly sialates as Mn[-(SiO2)z-AlO2]n.wH2O, where M is a cation from alkaline activator solution such as sodium or potassium, n is a degree of polymerization, z is a number 1, 2, 3 or higher up to 32, w is the number of water molecules.

A geopolymer can take one of the three basic forms (Davidovits 1994):

- Poly (sialate), which has (-Si-O-Al-O-) as the repeating unit.
- Poly (sialate-siloxo), which has (-Si-O-Al-O-Si-O-) as the repeating unit.
- Poly (sialate-disiloxo), which has (-Si-O-Al-O-Si-O-Si-O-) as the repeating unit.

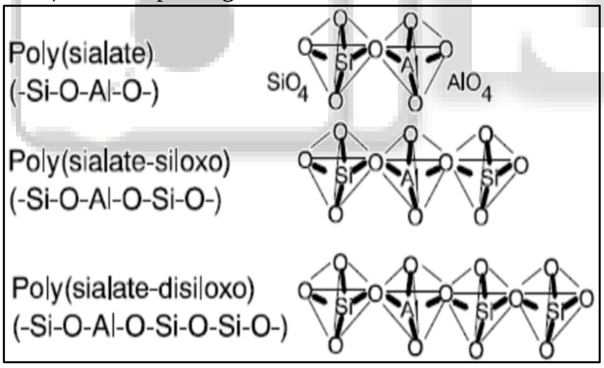

Fig. 1: D structure of Poly Sialate (Davidovits 1994)

The main criterion for developing stable geopolymer paste is that the source materials should be rich in silicon (Si) and aluminium (Al). These silicon (Si) and aluminium (Al) minerals are activated by alkaline activator solution. Alkaline activator solution is combination of alkali hydroxide (MOH) and alkali silicate (M2SiO3) is used to activate alumino-silicate materials. Generally sodium or potassium based alkaline activator solution is used to activate is used to activate silicon and aluminium ion present in source material (Lioyd N.A. and Rangan B.V. 2010). Compared to NaOH, KOH showed a superior level of alkalinity. But in actuality, it has been found that NaOH possesses greater capacity to liberate silicate and aluminate monomers.

Geopolymersare synthesized by the reaction of a solid alumino silicate powder with alkali hydroxide/alkali silicate. Under highly alkaline conditions, polymerization takes place when reactive alumino-silicates are speedily dissolved and $[SiO_4]$-and $[AlO_4]$-tetrahedral units are released in solution. The tetrahedral units are alternatively connected to polymeric precursor by sharing oxygen atom, thus forming polymeric Si–O–Al–O bonds.

The figure 2.2 shows reactions occur during geopolymerization (Davidovits 1994).

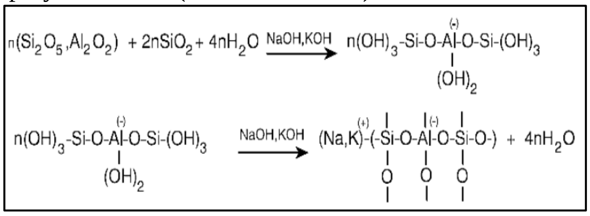

Fig. 2: Reaction during Polymerization

This process releases water that is normally consumed during dissolution. The water expelled from geopolymer during the reaction provides workability to the mixture during handling.

B. Base Material or Source Material

Base material for geopolymer described as material which has silicon and aluminium ion to react with alkaline activator solution. Base material may be a geological originated material or any by-product of industries such as GGBS, fly ash, RHA, sugarcane baggash etc. or it may be synthetically produced alumina and silica, metakaolin, silica fume etc. In 1979, Davidovits made fly ash based geopolymer concrete to reduce the use of OPC in concrete. Song S. et al. (2000) used GGBS as source material to study hydration of alkali activated ground granulated blast furnace slag. Combinations of GGBS and metakaolin (Cheng and Chiu 2003) and combination of fly ash and GGBS (P. Vignesh and K. Vivek 2015) have been also used as base material in earlier study. GGBS and BRHA were blended together and examined for the durability and strength properties (Venkatesan R P and Pazhani 2015). Combination of GGBS, POFA and fly ash (Islam A. et al. 2013) has been also used to study compressive strength of geopolymer mortar. Combination of GGBS and red mud can also be used as source material (Alwis Deva K.J.P. and Sakthieswaran N. 2015).

Ground granulated blast furnace slag (GGBS) is an industrial by-product resulting from rapid water cooling of molten steel. It is known to have advantageous properties for the concrete industry as it is relatively inexpensive to obtain, highly resistant to chemical attack and maintains excellent thermal properties. Major components of the slag product are SiO2, CaO, MgO and Al2O3. These components are responsible for cementitious property of slag. Slag which content glasses with a high proportion of Al2O3 and CaO react faster and yield higher compressive strength but slag with low CaO content requires an additional activator like hydrate lime, clinker, alkali hydroxide and alkali hydroxide with alkali silicate.

Slag produced from blast furnace is ground and granulated to get slag in powder form of required particles size. This ground granulated blast furnace slag is mixed with 3.5–5.5 percent (by mass) sodium hydroxide or water glass to activate silicon and aluminium ions present in GGBS. Alkali-activation yields a low-basic, highly amorphous calcium silicate hydrate (C-S-H) gel product possessing high aluminum content (Torgal F. Pacheco et al. May 2007). This product is referred as alkali activated slag.

Chemical shrinkage and porosity volumes in saturated GGBS pastes are significantly higher than in Portland cement pastes and is a legitimate concern during setting. Drying shrinkage is a direct result of hydration heat and increases with increased modulus and dosage of water glass activators. Alternatively, the increase in alkaline concentration in the paste mix increases the degree of hydration reaction and reduces pore volumes improving microstructural properties of the C-S-H product. While shrinkage in alkali activated slag pastes is more relevant than in Portland 1cement products, it maintains a much higher ultimate strength by comparison and remains a viable material for commercial use (Fernandez-Jimenez A et al 2007).

C. Curing Of Geopolymer Concrete

In geopolymer concrete three types of curing viz. ambient curing, direct sun light curing and heat curing (either by oven or by steam). When fly ash is used as binder material in geopolymer concrete heat curing or steam curing is desired. GGBS based geopolymer concrete does not need any heat curing or steam curing. Some of literature regarding curing of GGBS based geopolymer concrete given below.

There is no necessity of exposing geopolymer concrete to higher temperature to attain maximum strength if minimum 9% of fly ash is replaced by GGBS. 5 mixes were prepared by replacing the fly ash by GGBS in different proportions. Maximum strength came for mix 5 in which 28.5% fly ash is replaced with GGBS. It was observed that when this mix 5 is oven cured about 25% compressive strength decreased in compare to ambient curing (Naidu Ganapati et al. 2012).

Another study was carried out to find the suitable curing method for GGBS geopolymer concrete. Different mixes are prepared by varying the molarity of NaOH and then these mixes were cured in oven and in direct sun light. Compressive strength test was conducted at age of 3 days and 7 days. Compared to direct sun light curing, oven curing gives higher compressive strength but sun light curing is convenient for practical conditions (Supraja V et al. 2012). Figure 2.5 and 2.6 shows the effect of curing on compressive strength of geopolymer concrete at different day.

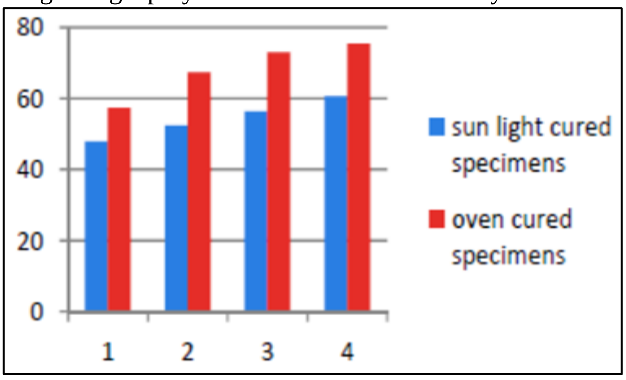

Fig. 3: Variation in the Compressive Strength at 3 days between Specimens of Oven cured and Direct Sun Light (Supraja V et al. 2012)

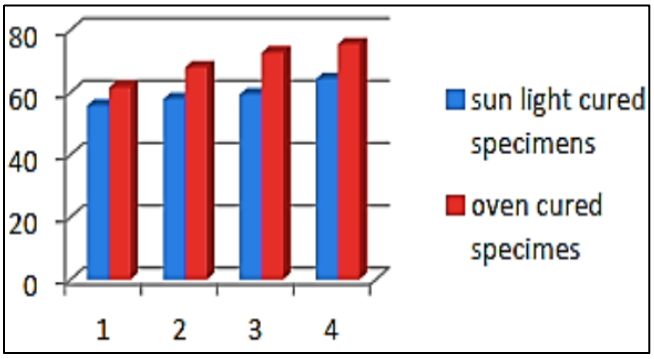

Fig. 4: Variation in the Compressive Strength at 7 days between Specimens of Oven cured and Direct Sun Light (Supraja V et al. 2012)

D. Properties of Geopolymer Concrete in Hardened State

1) Compressive Strength

Compressive strength is main mechanical properties of any type of concrete.

Compressive strength of geopolymer concrete depends on base material, alkaline activator solution and type of curing. Generally GGBS based geopolymer concrete has maximum compressive strength then fly ash based geopolymer concrete. To analyse the effect of ground granulated blast furnace slag (GGBS) on mechanical properties of low calcium fly ash based geopolymer concrete. Geopolymer concrete mixes were manufactured by replacing fly ash with GGBS in 5 different percentages. Higher percentages of GGBS (Slag) in GPC result in higher compressive strength of geopolymer concrete. 90 % of compressive strength was achieved in 14 days Naidu Ganapati et al. 2012). Table 2.1 shows the mix proportions for GPC. Table 2.2 shows the variation of compressive strength with GGBS content.

Another study to investigate the effect of ground granulated blast furnace slag (GGBS) on mechanical properties of fly ash based geopolymer concrete (GPC) was reported (Parthiban K et al 2013). He summarized the influence of the various percentages of GGBS (0-100%) on fly Ash based geopolymer concrete; the influence of the content of Alkaline Activator Solution (AAS) in the mixture of GPC on their compressive strength is analyzed at ambient temperature conditions. Maximum compressive strength was achieved at 100% replacement of fly ash with GGBS.

2) Split Tensile Strength

Tensile strength of any type concrete is a key mechanical property that is used in several design aspects of concrete structures such as those linked to beginning and propagation of cracks, shear and anchorage of reinforcing steel in concrete. To find effect of GGBS on fly ash based geopolymer concrete different mixes were casted by varying the percentage of GGBS. It was found that split tensile strength improved with rise in percentage of GGBS (Parthasarathi deb et al 2014). Figure 2.8 and 2.9 show the variation of split tensile strength with GGBS at different alkaline activator solution.

To compare the mechanical properties of conventional concrete and GGBS based geopolymer concrete a study was carried out and test results were analyzed. It has been seen from test result that split tensile strength of GGBS based geopolymer concrete was 18.23% more than the split tensile strength of conventional concrete (Murthy T.V. Srinivas et al July 2014).

3) Flexural Strength

The study investigating the effect of molarity of NaOH and GGBS on fly ash based geopolymer concrete shows that flexural strength increased with increase in molarity of NaOH and percentage of GGBS (ZendeRohit and Mamatha A. 2015). Figure 2.13 and 2.14 shows the variation of flexural strength of GPC with varying percentage of ggbs at two different molarity of sodium hydroxide at constant alkaline activator solution ratio of 2.5 and alkaline liquid to source material ratio 0.40.

III. Conclusion

This paper highlights the review of research works conducted on GGBS. From the available literature, it is observed that GGBS based GPC can be produced using technology and equipments used for the manufacturing of conventional concrete. GGBS based geopolymer concrete is very less workable. Workability of GPC mix decreased with increase of percentage of GGBS.

Applications of optimum percentage of cement replacement by GGBS can be extend up to all structural elements of a building, bridges, prestressed elements etc.

The inclusion of GGBS in concrete has several advantages like reduced heat of hydration, adequate ductility, reduction in the size of the concrete pores, improved strength at later stages, reduced primary energy usage and carbon emissions, lighter colour and better aesthetics etc.

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