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Optimization of Cost and Energy Using Alkali Activated Alumino Silicates

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Abstract - Up to now, economic and ecological achievements has been carried out mainly after the development of material. At that point of time, however there is only small degree of freedom to change the composition or process to optimize the materials.The need to reduce the global warming has encouraged researchers to search for sustainable building materials. Cement, most consumed product in the construction, contributes nearly 7% of the global carbon dioxide emission. One ton of cement production emits one ton of carbon dioxide. Geopolymer concrete (GPC) was prepared using byproducts of industry.It is an excellent alternative construction material to the existing plain cement concrete.In this study fly ash, GGBS is used as alternative to cement.The effect of curing methodology on strength of fly ash-GGBS based geopolymer concrete has also been evaluated. Cost comparison and sustainability studies are conducted on both Ordinary concrete and coal ash concrete. It resembles that geopolymer concrete can be prepared at economicallywith that of OPC concrete and it also offer great reduction in carbon dioxide emissions.

Keywords: Geopolymer concrete, Sustainability, coal ash concrete, by product

I. INTRODUCTION

Concrete is the second most used material in the world. Ordinary Portland cement has been used traditionally as a binding material for preparation of concrete. Theworld-wide consumption of concrete was believed to rise exponentially primarily driven by theinfrastructural development taking place in China and India. Concrete is considered as the most versatile and widely used construction material in view of its wide ranging performance, suitability, applicability, and cost effectiveness. Normally, conventional concrete is associated with Portland cement, which is one of the main ingredients. Production of one ton of Portland cement requires about 2.8 tons of raw materials, including fuel and other materials. As a result of de-carbonation of lime, manufacturing of one ton of cement generates about one ton greenhouse gases. It is also energy intensive and consumes significant amount of natural resources, leading to depletion of the same in due course of time. At present, efforts have been made to promote the use of pozzolans to practically replace Portland cement. In view of this, there is a need to develop sustainable alternatives to conventional cement utilizing the cementitious properties of industrial byproducts such as fly ash.

Further, environmentally compatible disposal of waste materials by appropriate technologies is of increasing concern and imposes interesting technical challenges. Construction industry is the one where bulk utilization of waste materials can be effectively done without any compromise on quality or performance. It has been established that fly ash can replace cement partially. However, efforts are on to replace Portland cement completely by synthesizing alternative binder by alkali activation of many marginal materials such as fly ash which is rich in silica and alumina. Such an effort leads to dual goals of utilizing the marginal materials advantageously rather than just disposal and conservation of resources for sustainable development. The amorphous to crystalline reaction products resulting from the synthesis of alkalialumino-silicates and high alkaline solution is generically known as “Geo-Polymer”.Geopolymer is an excellent alternative which transform industrial waste products like GGBS and The amorphous to semi-crystalline three dimensional silico-aluminate structures materials which were used as source materials undergoes The final properties of geopolymer concrete is influenced by large number of factors like curing temperature, water content, alkali concentration, initial solids content, silicate and aluminate ratio, pH and others [4].Research into fly ash based geopolymer concrete have found that it has higher high compressive strength, low drying shrinkage, low creep and good resistance against acid and sulphate attacks [5]. Geopolymer concrete cured at ambient temperature can be developed using a combination of coal ash and GGBS. Alkali activation of GGBS results in precipitation of Calcium-Silicate-Hydrate(CSH) gel for geopolymer concrete at 27^{o}C while if cured at 60^{o}C a combination of calcium-silicate-hydrate(CSH) and alumino–silicate–hydrate (ASH) gel is formed[9].This study aims to synthesize geopolymer concrete using combination of fly ash and GGBS. Cost and environmental impact using embodied energy is also discussed.

II. PROPERTIES OF MATERIALS USED

The physical properties and chemical composition of materials as obtained by X-ray fluorescence (XRF) is shown in Table 1 and Table 2. Locally available sand of specific gravity 2.63 was used for the study. Coarse aggregate (12mm) is of specific gravity 2.88. OPC 53 grade cement used is of specific gravity 3.13.

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Table 1.Chemical composition of fly ash.(By mass percentage).

Oxide	SiO_2	Al2O3	Fe2O3	CaO	SO_3
Fly Ash	53.30	29.50	10.70	7.60	1.80

Table 2.Chemical composition of GGBS.

Oxide	SiO_2	Al_2O_3	FeO	CaO	MgO	Others
Mass Percentage (%)	35.47	19.36	0.8	33.25	8.69	3.25

A combination of 15M sodium hydroxide and sodium silicate in the ratio of 2.33 was used as activation solution. Sodium hydroxide of laboratory grade with purity of 97% and had a specific density of 2.13 g/cm3. Sodium silicate also known as sodium silicate is of industrial grade with SiO_2 as 37.67% by mass and Na_2O as 35.67%. Water used for the mix is of potable quality.

III. Mix Proportions And Experimental Program

The proportions used in the mix were obtained after series of trial mixes. Various proportions used in the mix are given in Table 3. The term geopolymer solid mentioned in the table denotes all the solid particles in the binder like solids in activator solution, coal ash and GGBS.

Table 3. Various Proportions By Weight Used In The Mix

Coal ash : GGBS	Molarity of NaOH solution	Na_2SiO_3: NaOH	Activator: (Coal Ash + GGBS)	Water : Geopolymer Solid
75:25	15M	2.33	0.42	0.29

A total of five geopolymer mix was considered along with a standard OPC based M55 grade concrete (CM). Fly ash - GGBS based geopolymer concrete mix was manufactured. OPC based concrete mix was designed as per IS 10262:2009.Naphthalene sulphonate based superplasticizer was added to each mix (2% of (FA+GGBS) to improve workability.100mm cube specimens of each geopolymer concrete mix are cured at elevated temperature at 60oC for 6 hours and then at 100oC for 3 hours. Another set of specimens of each mixes are cured by air curing for 28 days. OPC based concrete is cured in both elevated and ambient temperature by respective standard practices. All specimens were casted in accordance with IS 516.

IV. Experimental Results And Discussions

The strength of geopolymer concrete using fly ash is studied and effect of replacement on the strength of fly ash–GGBS based geopolymer concrete is discussed along with cost and environmental impact analysis

1) Compressive Strength

Fly ash based geopolymer concrete attained compressive strength of 68MPa.Concrete cured at ambient temperature attained comparable strength with that of specimens cured at elevated temperatures. Thus curing at elevated temperature doesn't add much to the final strength of coal ash-GGBS based concrete.

2) Cost Analysis

Cement has a very effective hauling and transportation system in our country which makes its transportation cost less. GGBS and coal ash currently doesn't have such a system. To normalize this effect, the transportation of these materials are assumed to be in the same manner ascement. Standard freight charge from Indian Railway website is considered for this analysis. Local market price for NaOH and aggregates were considered in this study. The cost per quantity and total cost is mentioned in Table 4. Only fly ash-GGBS based concrete and OPC based concrete are used for this study.

Table 4. Cost and Energy per unit weight of materials.

Material	COST(Rs/kg)	Energy (MJ/kg)
GGBS	1.50	0.31
Fly Ash	1.00	0
Coarse Aggregate	0.43	0.10
Fine Aggregate	2.20	0.02
Water	0	0
NaOH	80.00	20.50
Sodium Silicate	10.00	5.37
Cement	7.00	4.53

The total cost of geopolymer concrete (Rs 5611.54) is 7% more than OPC based concrete (Rs 5207.65). This reduced cost is mainly due to the assumptions made for the transportation of coal ash, GGBS and sodium silicate. Without normalizing the fly ash and GGBS transportation cost, price of geopolymer based concrete will be more than twice that of OPC based concrete.

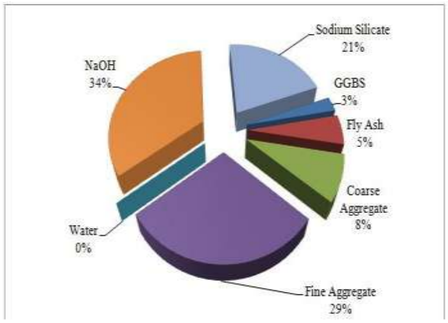

Figure 3. Cost contribution of each material to fly ash-GGBS based geopolymer concrete

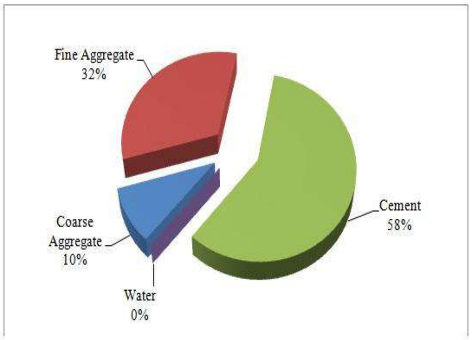

Figure 4. Cost contribution of each material to of OPC based concrete

Studies have to be made in the area of manufacturing process of sodium hydroxide so as to make its cost less. The fine aggregate cost can be minimized by using alternate materials like crusher dust. However, the impact of using such materials on the strength of concrete has to be studied.

3) Sustainability

This study considers only the embodied energy consumed in the production of basic building materials. In India 90% of the cement is manufactured by dry processes (4.2MJ/kg) and remaining by more energy intensive wet Process (7.5MJ/kg).Therefore, for cement embodied energy is taken as 4.53MJ/kg by weighted average. Fly ash and GGBS are waste products from industry. The embodied energy of fly ash is zero as collection of fly ash from flue gas is mandatory in India. GGBS will have to be grinded after quenching. Therefore embodied energy of 0.31MJ/kg (6-7% that of cement) have been considered.The embodied energy of sodium hydroxide is 20.5MJ/kg as per SPLINE LCI datasheet. The embodied energy of sodium silicate shall be taken as 5.37 MJ/kg.Embodied energy of fly- ash GGBS based geopolymer concrete is found to be 1265.73 MJ and that of OPC based concrete is calculated as 2083.33 MJ.

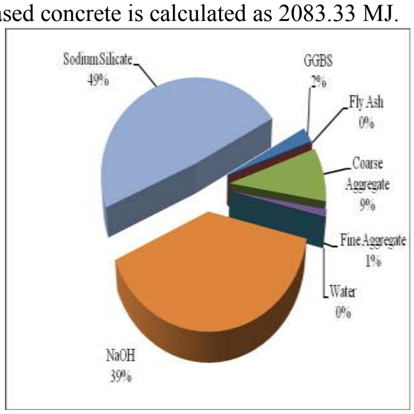

Figure 5. Embodied energy contribution of each material on fly ash-GGBS based geopolymer concrete.

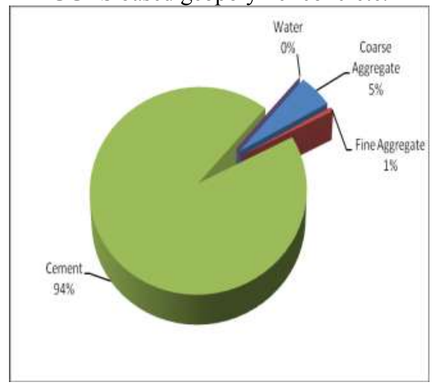

Figure 6.Embodied energy contribution of each material on OPC concrete.

V.CONCLUSION

The following are the conclusions obtained after the study

- Cost of Geopolymer concrete is probably less than OPC based concrete if transportation system for raw materials is well established.
- Strength of fly ash-GGBS based concrete is increased while cured at elevated and ambient temperature.
- The embodied energy of fly ash- GGBS based geopolymer concrete is 40 % less than that of OPC based concrete.

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