Strength, Economic and Sustainability Characteristics of Coal Ash –GGBS Based Geopolymer Concrete.

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Abstract
The need to reduce the global anthropogenic carbon dioxide has encouraged researchers to search for sustainable building materials. Cement, the second most consumed product in the world, contributes nearly 7% of the global carbon dioxide emission. Geopolymer concrete (GPC) is manufactured using industrial waste like fly ash, GGBS is considered as a more eco-friendly alternative to Ordinary Portland Cement (OPC) based concrete. The feasibility of production of geopolymer concrete using coarser bottom ash is evaluated in this study. Additionally, the effect of replacement of fly ash with bottom ash at varying percentage on strength of Geopolymer concrete is also studied. The effect of curing methodology on strength of fly ash-GGBS based geopolymer concrete has also been evaluated. Economic impact and sustainability studies were conducted on both OPC based concrete and geopolymer concrete. Comparison studies shows that geopolymer concrete can be prepared at comparable cost with that of OPC concrete while they offer huge reduction in carbon dioxide emissions.

Keywords: Geopolymer concrete, Sustainability, Green concrete, coal ash concrete, sustainability, waste materials, Cost analysis

1. Introduction

Concrete is the second most used material in the world after water. Ordinary Portland cement has been used traditionally as a binding material for preparation of concrete. Theworld-wide consumption of concrete is believed to rise exponentially primarily driven by theinfrastructural development taking place in China and India. 1 tone of carbon dioxide isestimated to be released to the atmosphere when 1 ton of ordinary Portland cement ismanufactured. Also the emission by cement manufacturing process contributes 7% to theglobal carbon dioxide emission [1]. It is important to find an alternate binder which has less carbon footprint than cement.

Geopolymer is an excellent alternative which transform industrial waste products like GGBS and fly ash into binder for concrete.The amorphous to semi-crystalline three dimensional silico-aluminate structures of the Poly(sialate) type (-Si-O-Al-O-) or of the Poly(sialate-siloxo) type (-Si-O-AI-O-Si-O-) were christened "geopolymers" by Davidovits[2].Al- Si materials which are used as source materials undergoes dissolutions, gel formation, setting and hardening stages to formgeopolymers[3]. The alumino silicate material used in this study is a combination of coal ash and ground granulated blast furnace slag (GGBS).

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 [5-8]. 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 coarser bottom ash and GGBS. Fly ash was replaced in varying percentages by bottom ash to understand the effect on compressive strength. Cost and environmental impact using embodied energy is also discussed.

2. 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. Fly ash and bottom ash are having specific gravity of 2.05.The sieve analysis result for bottom ash is given in Figure 1. 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.

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

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3
Fly Ash	53.30	29.50	10.70	7.60	1.80
Bottom Ash	56.76	21.34	5.98	2.88	0.72

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

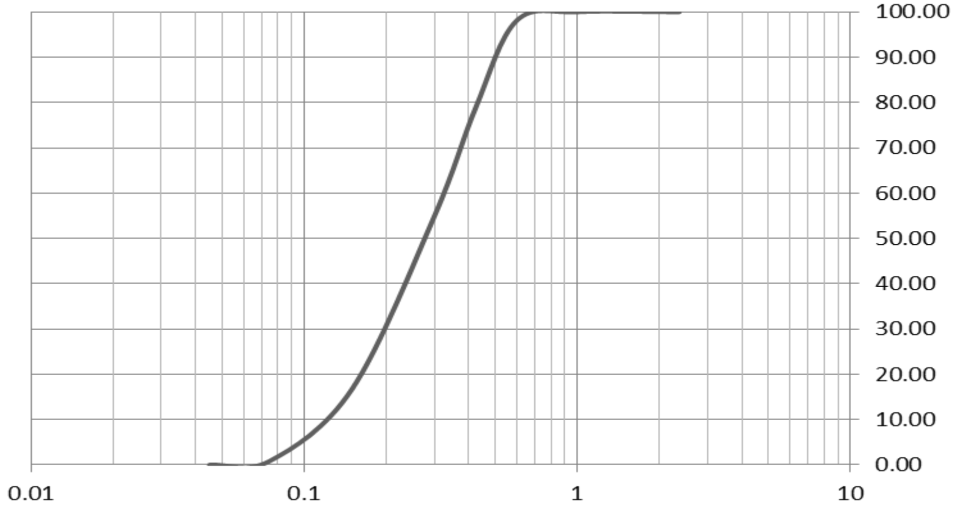

Figure 1.Particle size distribution of bottom ash.

A combination of 15 molar sodium hydroxide and sodium silicate in the ratio of 2.33 was used as solution for activation. Sodium hydroxide is of laboratory grade with purity of 97% and had a specific density of 2.13 g/cm^3. Sodium meta 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.

3. 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 and bottom ash - GGBS based geopolymer concrete mixes are manufactured separately. Additionally mixes were prepared by replacing fly ash with bottom ash in 10%, 20% and 30% replacement levels (by weight). OPC based concrete mix was designed as per IS 10262:2009[10]. Bottom ash-GGBS based geopolymer was casted assuming particles finer than 300 microns (58% by weight) takes part in the reaction and remaining replaces fine aggregate. 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 60^{o}C for 6 hours and then at 100^{o}C 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.

4. 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.

4.1. compressive Strength

Fly ash based geopolymer concrete attained compressive strength of 68MPa while bottom ash based concrete attained only 32MPa. The low compressive strength is due to larger particle size in bottom ash. Larger particle size reduces the dissolution of bottom ash in activator solution and hence does not take part in the reaction.

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. The experimental results are summarized in Figure 2.

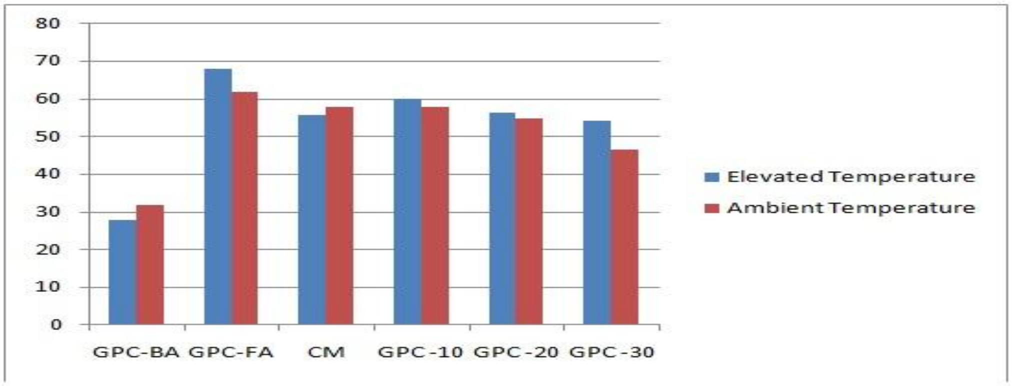

Figure 2. Average compressive strength of samples

4.2. 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 as cement. 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.

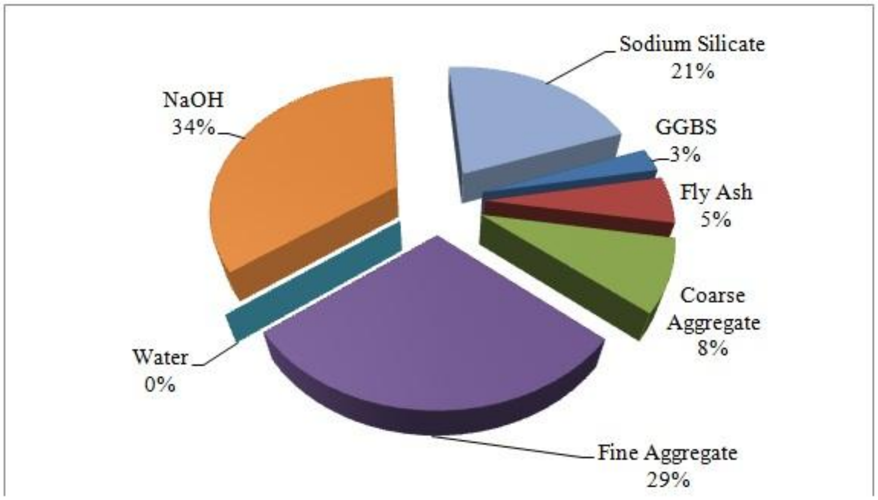

Figure 3. Cost contribution of each material to fly ash-GGBS based geopolymer concrete.

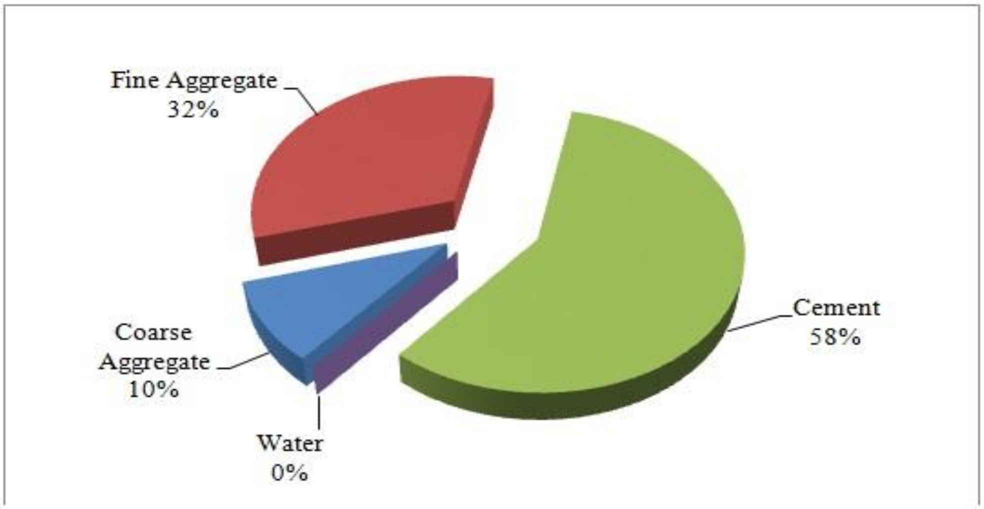

Figure 4. Cost contribution of each material to of OPC based concrete

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.

4.3. 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).(TERI 2004 and Venkatarama Reddy &Jagadish,2001[11]).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 am 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. (Fawer et al 1999)[12].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.

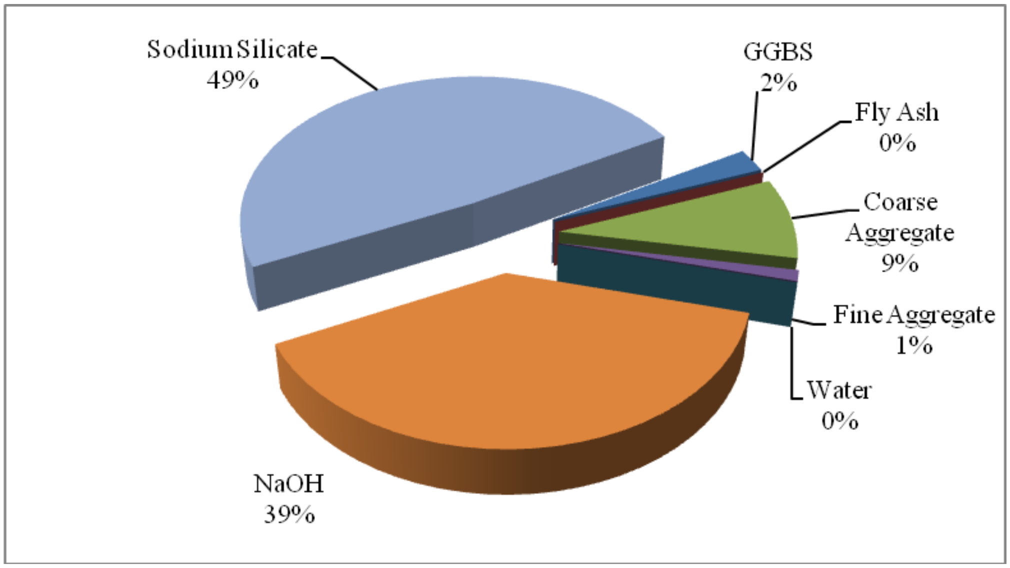

Figure 5. Embodied energy contribution of each material on fly ash-GGBS based geopolymer concrete.

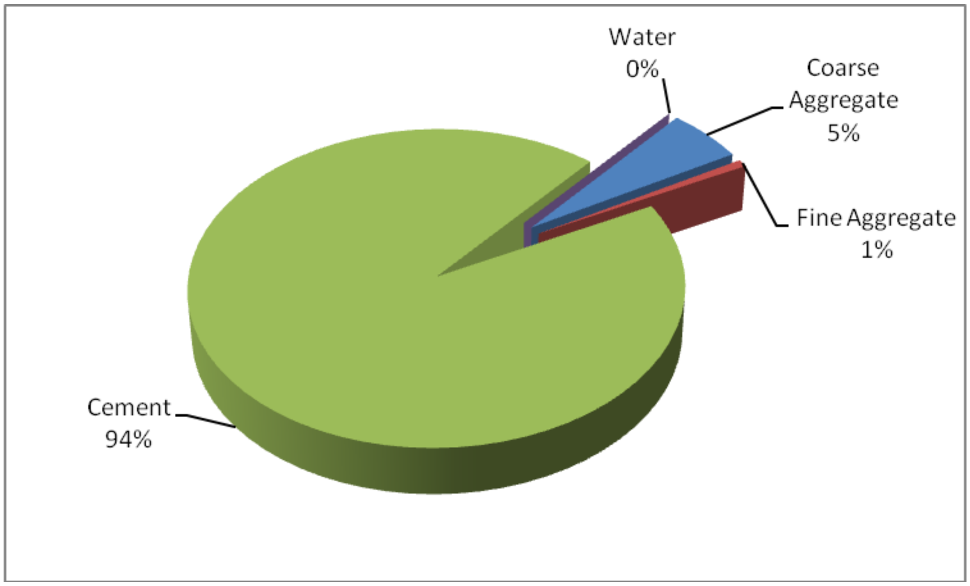

Figure 6. Embodied energy contribution of each material on OPC concrete.

The contribution of sodium silicate and sodium hydroxide to the embodied energy of geopolymer concrete is very high. Manufacturing processes of these materials for large scale production must be redesigned so as to reduce the embodied energy. High energy in sodium silicate is due to melting and drying process involved during its manufacturing.

5. Conclusion

The following are the conclusions obtained after the study

- Curing at elevated and ambient temperature will form fly ash-GGBS based concrete of comparable strengths.
- Bottom ash – GGBS based geopolymer concrete gives very low strength probably due to large particle size.
- Geopolymer concrete can be prepared at comparable cost with OPC based concrete provided transportation system for raw materials is well established.
- The embodied energy of fly ash- GGBS based geopolymer concrete is 40 % less than that of OPC based concrete.

- Sodium hydroxide (39%) and sodium silicate (49%) together contributes a lion's share to embodied energy of geopolymer concrete while in OPC cement contributes nearly 94% of the total embodied energy.

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