Study on Characteristic Strength of Concrete Partially Replaced by Geopolymer Aggregates

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Abstract

Huge amount of quarrying for extraction of natural aggregates has reached an alarming situation which affects the ecological balance. Also, unscientific disposal of industrial wastes is creating problems. An attempt is made to use industrial wastes such as Flyash and Ground-granulated blast-furnace slag (GGBS) for manufacturing artificial aggregates using geopolymerization technique as an alternative for natural aggregates. This study concentrates on the partial replacement of characteristic coarse aggregates with geopolymer fly ash aggregates. Factors affecting the strength of geopolymer flyash aggregates such as geopolymer solids ratio, concentration of alkali activator, and curing period were evaluated. Various ratios of Flyash and GGBS such as 90:10, 25:75, and 50:50 were mixed to make geopolymer solids. The fundamental physical properties and mechanical attributes of geopolymer fly ash aggregates are studied. The characteristic strength of partially replaced geopolymer aggregate concrete was understood. It is observed that upto 30-35% replacement of the strength can be compared to normal concrete, and after that there is a considerable decrease. By conducting Scanning Electron Microscopy (SEM), and X-Ray Diffraction (XRD analysis), micro-structural study of geopolymer fly ash aggregates is also done.

Keywords : **Flyash, geopolymerization, GGBS, SEM, XRD**

I. INTRODUCTION

Concrete is probably the most extensively used construction material in the world with about six billion tonnes being produced every year. It is only next to water in terms of per capita consumption. However, environmental sustainability is at stake, both in terms of damage caused by the extraction of raw material, and CO_2 created during cement manufacturing. Concrete would be a blessing to the environment if alternate materials are used. By using industrial byproducts as alternate materials, a new solution, that is, green concrete can be developed.

The economic, and industrial growth of a country depends on power generation. In India, the major source of power generation is from coal. 70% of power is produced using coal as fuel. Indian coal is of low calorific value and has about 30 to 45% ash content, which results in huge generation of ash in coal based thermal power stations. As per Ministry of Power, Government of India, 1800 million tonnes of coal is used which requires a large amount of land for the disposal of Flyash, which causes huge environmental issues. The Ministry of Environment & Forests (MoEF) has issued various notifications to achieve 100% utilization of Flyash to reduce these related issues [1].

Ground Granulated Blast Furnace Slag, which is a waste material from the production of iron is widely using in concrete industry as a replacement for cement, as well as aggregates for sustainable infrastructure. In this study, these two industrial by products are used for the manufacture of artificial aggregates with geopolymerization technique. In this method, geopolymers are formed when an aluminosilicate material like fly ash, metakaol in, rice husk ash, clay etc. are activated by alkaline solution [2]. Geopolymer technology can reduce approximately 80% of CO_2 emission caused by cement and aggregate industry which in turn reduces global warming [3].

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II. GEOPOLYMERIZATION

Geopolymerization can transform a wide range of waste alumino-silicate materials into building and mining materials with excellent chemical and physical properties, such as fire and acid resistance. It involves the geopolymerization process of waste aluminosilicate materials which results in the formation of alumino-silicate frameworks that are similar rock-forming minerals with excellent physical and chemical properties [1]. Thus, it gives an environmental friendly solution to disposal of hazardous waste material. The properties of geopolymer depends on Al_2O_3/SiO ratio, alkali concentration, curing temperature with curing time, water/solid ratio, and pH. Geopolymerization occurs at ambient or slightly elevated temperature when the solid aluminosilicate raw materials are mixed with alkaline activators (Na+), which form a gel phase followed by the solid binder [2]. The polymerization process involves a substantially fast chemical reaction in alkaline condition on Si-Al minerals, which results in a three-dimensional polymeric chain and ring structure consisting of Si-O- Al-O bonds

$M n [-(SiO_2) z – AlO_2] n .wH_2O$

III. MATERIALS AND METHODOLOGY

A. Flyash

Flyash is a alumino-silicate non-reactive inert particle which is a by-product from thermal power plants [4]. As per ASTM C618, flyash is classified into two types; Class F fly ash, and Class C fly ash depending upon the type of coal used from which it is obtained.

In this study, class F flyash is used for the manufacture of aggregates. Flyash was collected from Raichur Thermal power plant.

B. Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a by-product of iron and steel-making obtained by quenching molten iron slag from a blast furnace in water or steam to produce a glassy, granular product. GGBS was from JSW Steel in Bellary.

C. Alkaline Activators

In the geopolymerisation process, alkali activators such as sodium hydroxide and sodium silicate are added to flyash and GGBS to geopolymer paste. The ratio of sodium silicate to sodium hydroxide is maintained as 2.5 [8]. The concentration of Sodium Hydroxide plays a major role in the development of strength.

D. Geopolymer Aggregates

Flyash and GGBS were mixed in different ratios such as 90FA:10GGBS(M1), 75FA:25GGBS(M2), and 50FA:50GGBS(M3). These are considered as the geopolymer solids. Alkali activator solution is made by dissolving sodium hydroxide pellets in varying concentration which is then mixed with sodium silicate solution. Sodium hydroxide pellets have to be dissolved one day prior to mixing with geopolymer solids [7]. The ratio of geopolymer solids to liquid is kept as 0.3 [6]. They are mixed in a concrete mixer for 10 minutes by sprinkling the alkaline solution at regular intervals. The pellets which are formed were transferred to a collecting pan and kept for 24 hours green curing, and after that it was cured at 60^{o} C for 24 hours (Fig. 1).

Fig. 1. GeopolymerAggregates

IV. RESULTS AND DISCUSSION

The cured aggregates of various ratios, that is, M1, M2, M3 were cooled to room temperature. The *Aggregates Crushing test* was conducted for these aggregates. Even the concentration of Sodium Hydroxide is varied from 5M to 15M. It can be seen that as the concentration of alkali activator increases, the strength also increases. The aggregates crushing value of the geopolymer aggregates with 25GGBS:75 flyash proportion, and with 10 M sodium hydroxide were having comparable values with natural aggregates, and the aggregates with this ratio were produced for further studies.

Table I.
PHYSICAL PROPERTIES OF AGGREGATES

Properties	Natural Granite Aggregates	Geopolymer Aggregates
Shape	Angular	Cubical
Specific gravity	2.66	1.81
Bulk density (Kg/m^3)	1715	912
Water absorption (%)	1.16	9.6
Crushing value (%)	21.94	27.56

Geopolymer aggregates were manufactured in bulk quantity. A detailed study was conducted on characteristic strength of M30 grade concrete replacing natural coarse aggregates by geopolymer aggregates.

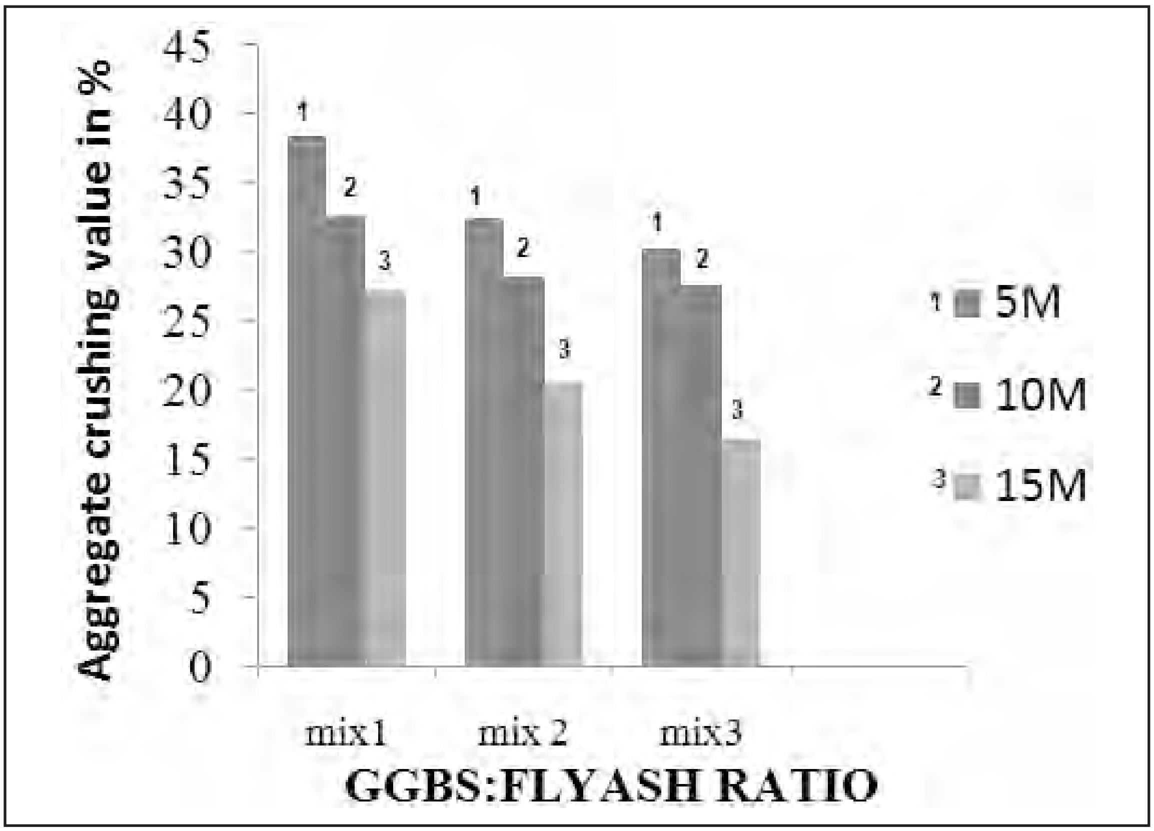

Fig. 2. Crushing Strength for Geopolymer Aggregates

The geopolymer aggregate after curing is graded by passing through 20mm sieve, and retained in 4.75mm sieve. The properties of normal aggregates and geopolymer aggregates are compared in table I. The specific gravity of geopolymer aggregates is found to be less than that of natural aggregates. Water absorption by geopolymer aggregate is higher than that of natural aggregate due to its porous nature.

The natural aggregates were replaced with a percentage varying from 25% to 50% for varying curing periods of 7,14, and 28 days. From the compressive strength values obtained, it is observed that upto 35% replacement strength is comparable with normal concrete. After 35% replacement, there is a reduction in the strength for further percentage replacement. Similar pattern is observed in the case of flexural strength also.

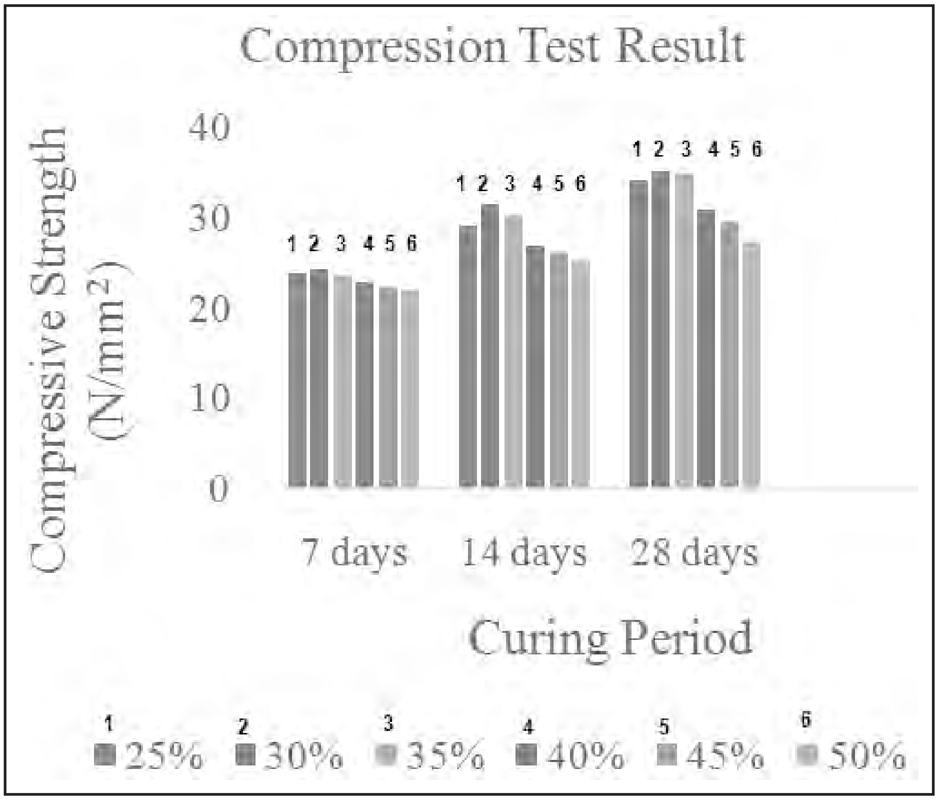

Fig. 3.Compressive Strength of Partially Replaced Concrete

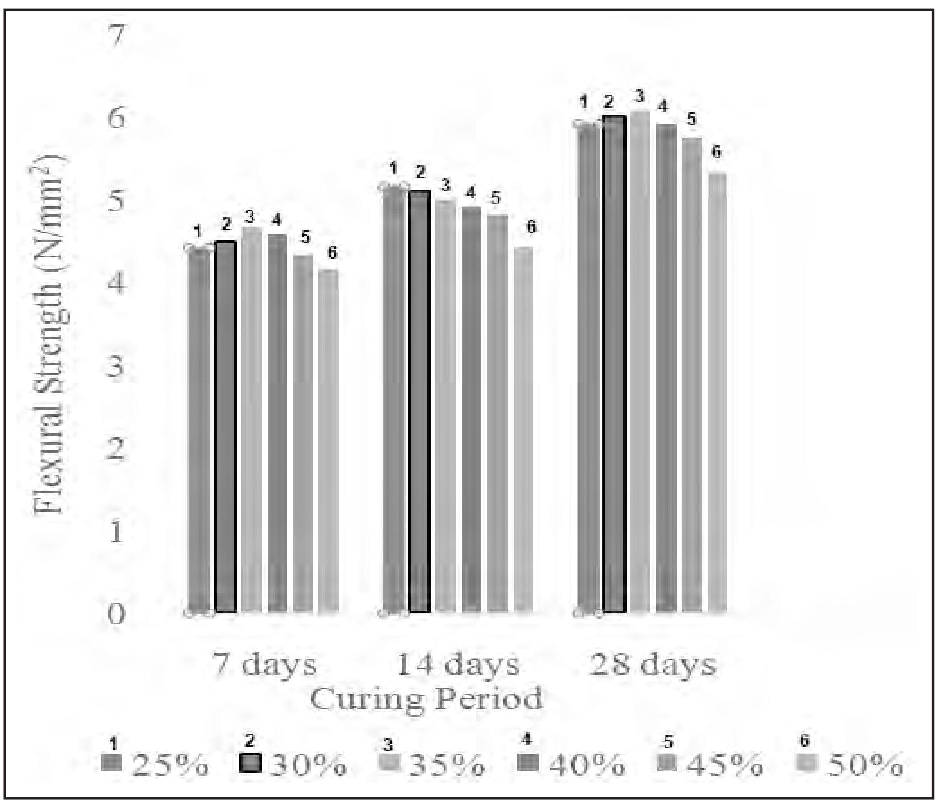

Fig. 4. Flexural Strength of Partially Replaced Concrete

V. MICROSTRUCTURAL STUDY ON GEOPOLYMER AGGREGATES

A. SEM Analysis

In Fig. 5 the incomplete geopolymerzation, as well as dense geopolymer paste in many parts can be clearly seen. The stren gth increased as more dense geopolymer structure was produced. The alkali activation of Flyash and GGBS has resulted in the formation of homogenous N-A-S-H and C-A-S-H gel [5]. The unreacted cenospheres were were also seen in the picture

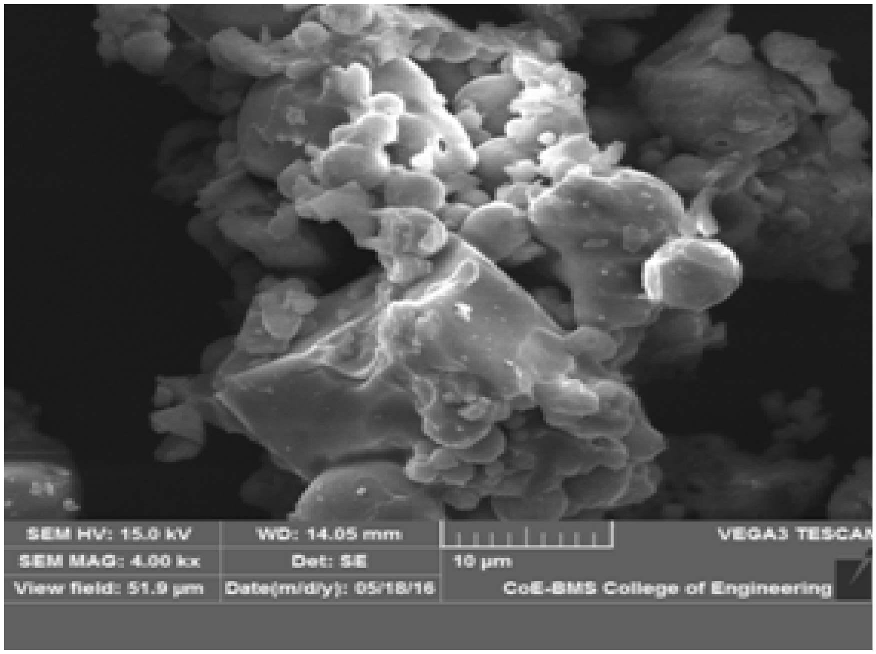

Fig. 5. SEM Image of Geopolymer Aggregates

B. XRD Analysis

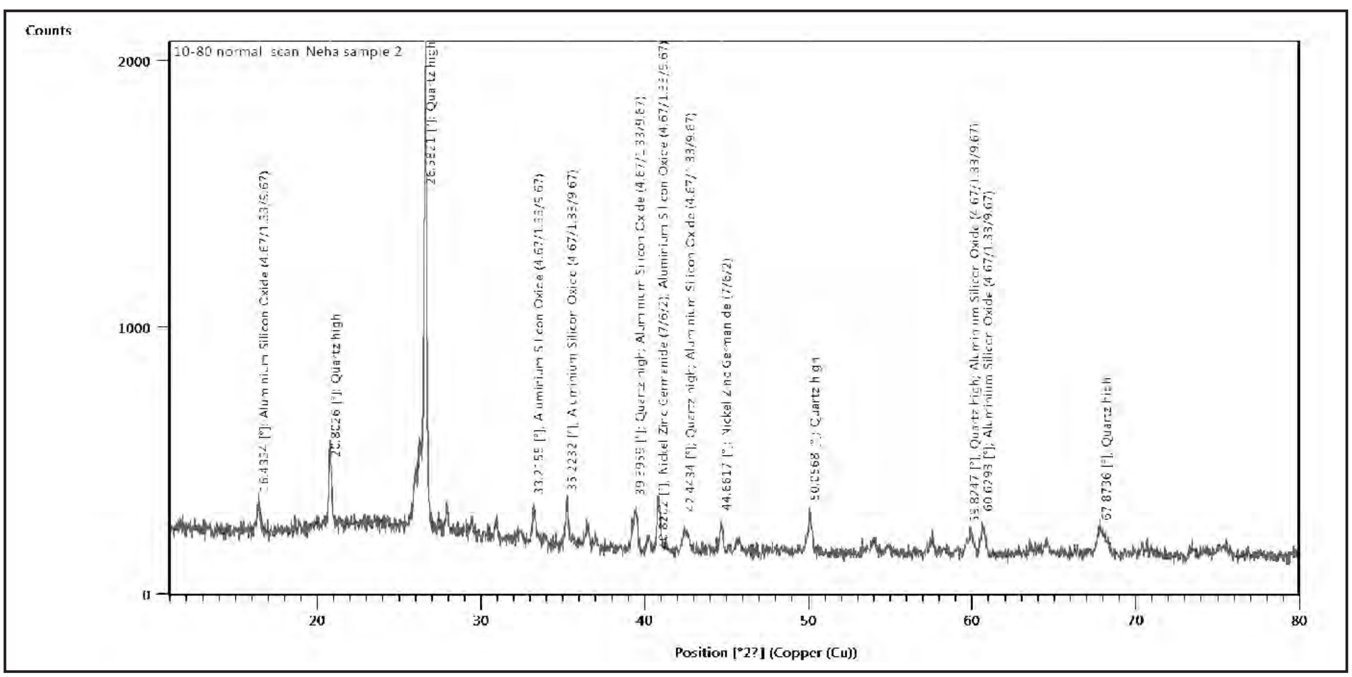

Fig. 6. XRD Graph of Geopolymer Aggregates

From the graph obtained from XRD analysis (Fig. 6), it is observed that peaks of aluminiumsilicon oxide were found at 2θ = 16° and were also very frequent when 2θ varies from 33° to 43° onwards. The existence of these crystalline peaks helps to increase the strength of the geopolymer paste.

VI. CONCLUSION

Industrial wastes such as Flyash and GGBS can be used for the manufacturing of geopolymer aggregates. Water absorption of artifical aggregates is more as compared to natural aggregates due to its porous nature. The concentration of Sodium Hydroxide has a major role in the strength development of gel. The compressive strength of geopolymer aggregate concrete is comparable with normal concrete upto 35%. There is a reduction in strength for further replacements. Similar variation is observed in the case of flexural strength also. In the microstructural SEM analysis, partial geopolymerization is seen, which affects the strength of geopolymergel. The XRD graph shows the crystalline peaks of aluminium silicate which indicate the formation of gel paste.

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