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Effects of Curing on Class-C Fly Ash based Geopolymer Bricks

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***Abstract*— Experiments have been carried out on the development of geopolymer bricks using class C fly ash. A mixture of sodium silicate and sodium hydroxide were used to prepare the bricks which were cured at room temperature, elevated temperature, water curing. The ratio of sodium silicate solution to sodium hydroxide was maintained at 2.5. The bricks were prepared with 12M of NaOH. The bricks were cured at 60ºC, 90ºC and 120ºC. The bricks were cured at room temperature for 7,14 and 28 days and water curing at the ageing of 7, 14 and 28 days. The water absorption value of fly ash based geopolymer bricks ranges between 4 and 14%. The results showed that the fly ash based geopolymer bricks exhibit increased compression strength and lower water absorption.**

***Index Terms*— Geopolymer, class – C fly ash, curing, molarity, strength**

I. INTRODUCTION

The huge demand from housing industry due to population explosion has entailed the need for sustainable building materials especially bricks. Researchers have tried to incorporate fly ash, ground granulated blast furnace slag (GGBS), lime stone dust, rice husk ash, welding flux slag and other waste products into bricks so as to improve its sustainability. An interesting area of research which has attracted interest of many scholars is Geo-polymer binder which utilizes industrial waste products to form sustainable green binders. As per TERI (2001) report, India produces more than 1400 billion bricks per year using 350 million tons of top soil by burning 24 million tons of coal thereby emitting 42 million tons of CO_2.

In India, it is estimated that by end of 2012, from the total thermal capacity of about 90 coal / lignite based Thermal Power plants, generate ash in the form of fly ash (80-90%) and bottom ash (10-20%) would be of the order of 173 Million Tons(Mt) per annum considering 38% ash content in coal as an average and at 80% Plant Load Factor (CEA 2009-10). It is further estimated that only about 51% of the ash generated found gainful utilization. Given the fact that economic growth of the Nation is generally linked to power availability and given the trend of high proportions of coal based thermal power stations (TPS), fly ash generation is likely to increase in future. It is estimated that coal ash generation will likely to grow over 200Mt by the year 2017. Unless we find more ways to utilize this industrial waste fully, in line with its output, it will greatly endanger the environment. Hence exploring the possibility of utilizing bottom ash (BA) along with Fly ash is interesting avenue for research.

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The production of burnt clay bricks requires consumption of coal leading to greenhouse gas emissions. The primary raw material used for bricks is the soil, which is often taken from prime agricultural land, causing land degradation as well as economic loss due to diversion of agricultural land. Use of traditional technologies in firing the bricks results in significant local air pollution. The burnt clay brick industry in India produces over 180 billion clay bricks annually with a strong impact on soil erosion and unprocessed emissions. At the same time, the thermal power plants in India continue to produce a huge amount of fly ash, disposal of which poses significant challenges for power plant.

Fly-ash bricks can be extensively used in all buildings constructional activities similar to that of common burnt clay bricks. The fly ash bricks are comparatively lighter in weight and stronger than common clay bricks. Since fly-ash is being accumulated as waste material in large quantity near thermal power plants and creating serious environmental pollution problems, its utilization as main raw material in the manufacture of bricks will not only create ample opportunities for its proper and useful disposal but also help in environmental pollution control to a greater extent in the surrounding areas of power plants. In view of superior quality and eco-friendly nature and government support the demand for fly ash bricks has picked up.

The geopolymerization process of an alkali-metakaolin system at different curing temperatures was studied by Muniz-Villarreal et al, and observed that curing temperature had a positive effect in the strength increase at the first days of reaction. Klabprasit et al, studied the effect of curing temperature on both compressive strength and rate of reaction of fly ash and rice husk-bark ash based geopolymer paste and observed that curing at 60ºC enhanced the higher compressive strength within early ages. Temuujin et al. in their study obtained increased compressive strength for geopolymer with mechanically activated fly ash, cured at ambient temperature. Compressive strength of ambient cured geopolymer mortar with fly ash increases with increase in ground granular blast furnace content and molarity of alkaline solution.

Water serves as a carrier of the alkali activating agent during the geopolymer hardening. Different curing conditions have been reported with different geopolymers created from different raw materials and different activators. The geopolymerization reaction of non-milled fly ash obtained from industry was extremely slow at ambient temperature which can be enhanced by curing at elevated temperature to get the optimum compressive strength from geopolymer concrete based on raw Class F fly ash. Mustafa Al Bakri et al. studied the factors influencing early age compressive strength of fly ash based polymer with different molarities of sodium hydroxide and concluded that the geopolymer paste with NaOH concentration of 12M produced maximum compressive strength.

II. MATERIALS AND METHODS

Fly ash is primarily silicate glass containing silica, alumina, iron, and calcium. Minor constituents are magnesium, sulfur, sodium, potassium, and carbon. The XRD patterns of the raw fly ash were shown in figure 1.The main mineral Crystalline compounds are present in small amounts and large part of the structure was of amorphous content. The chemical compositions of the fly ash determined by X-Ray Fluorescence (XRF) analysis are given in Table 1. The chemical composition of the fly ash used in the experimental work is approximately equal to the maximum specified ASTM values. Hence we can define the fly ash as High calcium class C fly ash. The Scanning Electron Microscopy (SEM) image of fly ash is shown in figure 2 proved that the particle shapes of the fly ash are spherical. Sodium silicate and sodium hydroxide were chosen as a alkaline solution for the manufacturing of geopolymer bricks. The molarity of sodium hydroxide was selected as 12 M concentration. The quantity of brick is shown in Table 2.

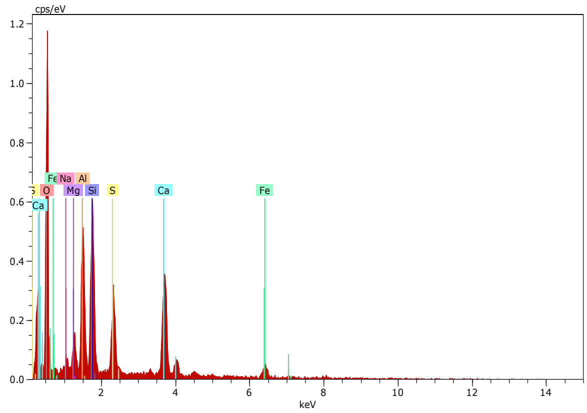

Fig 1: The XRD of fly ash

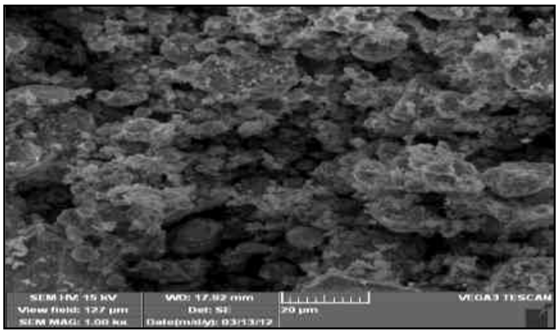

Fig 2: SEM image of fly ash

Fig 3: Geopolymer brick

Table 1: Chemical Composition of Class C flyash

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O_3	SO_3	LOI
Composition,% Tested	25.69	17.10	9.43	24.54	4.06	1.62	4.25	0.5
Specified as per ASTM	25-42	15-21	5-10	17-32	4-12.5	0.8-6.0	0.4-5.0	0.1-1.0

Table 2: Calculation for one brick

S. No.	Materials	Weight in kg
	Fly ash	2.5
	Alkaline solution	0.7
	NaOH solution	0.5
	Na_2SiO_3 solution	0.2

Sodium silicate and sodium hydroxide solution were mixed together at least one day before adding the liquid to the dry materials since heat liberation is more during polymerisation [9].Sodium hydroxide pellets of 480 gm were dissolved in a water to get 12M. Sodium silicate solution was then added with sodium hydroxide solution. After mixing of materials, the semisolid pastes were placed in 230mm x 110mm x 70mm size mould. The geopolymer bricks were shown in figure 3.The demoulded bricks were cured at three different types of curing methods namely, elevated temperature curing, room temperature curing, water curing. The bricks were cured at 60ºC, 90ºC and 120ºC. In room temperature curing method, the bricks were cured at room temperature at the ageing of 7 days, 14 days and 28 days. In water curing method, the bricks were cured in water at the ageing of 7 days, 14 days and 28 days. The cured bricks were tested under compressive strength test and water absorption test.

III. RESULTS AND DISCUSSIONS

Compressive strength

The influence of curing conditions on the compressive strength of geopolymer bricks were studied for the 12 molar concentration of NaOH. The specimens were heat cured at 60°C, 90°C and 120°C. From the figure 4, it can be seen that the compressive strength of geopolymer bricks increased with increase in curing temperature. This is due to the positive influence of curing temperature on the setting and hardening of geopolymers. The higher temperature enables greater dissolution of Si and Al ions leading to the formation of a stronger polymer chain as mentioned.

The variations of compressive strength of geopolymer bricks cured at ambient temperature were shown in figure 5. The compressive strength of ambient cured geopolymer concrete significantly increases with the age. At the same time, for the oven cured specimens both at 60°C and 90°C, the compressive strength was slightly higher and comparable with that of the bricks cured at ambient temperature. Since the brick specimens were cured in the oven without any coverage, too high a temperature causes fast evaporation of water and may lead to incomplete geopolymerization. This resulted in decrease of strength at 120° C when compared to 28 days curing at ambient temperature.

Figure 6 depicts the variation of compressive strength of geopolymer bricks cured in water. Geopolymer bricks under water curing have lower compressive strength than that under the other two conditions and the reason may be the low temperature and too much water. If too much water exists around the hydrolysis species, the polycondensation would be hindered. Additionally, reagent will leach out from surfaces of geopolymers if cured in water, which may account for the slow compressive strength development. Leaching has negative influence on the forming of strong matrix, especially when geopolymerization is slow at low temperature.

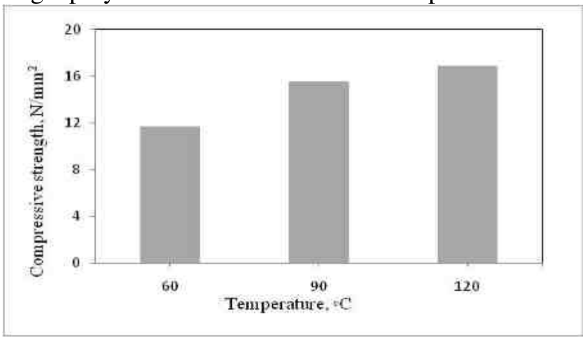

Fig 4: Compressive strength of geopolymer bricks at elevated temperature

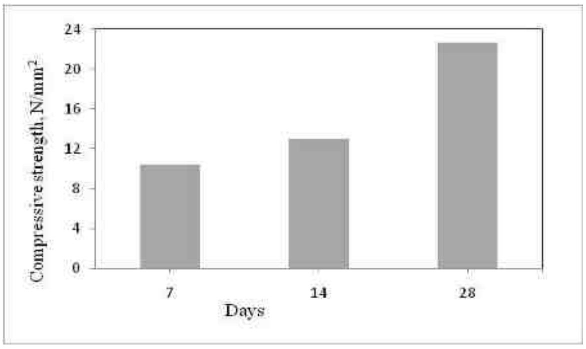

Fig 5: compressive strength of geopolymer bricks at room temperature

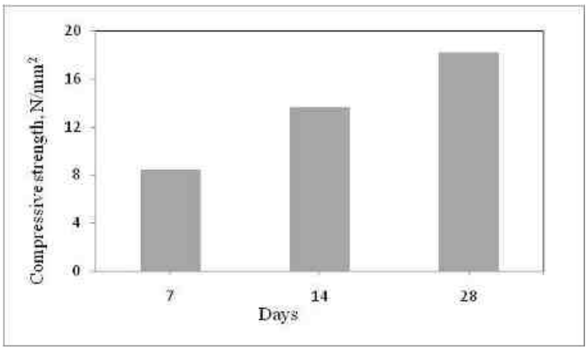

Fig 6 compressive strength of geopolymer bricks at water curing

Density

Figure 7, 8 and 9 shows the variation of density with the various curing conditions for geopolymer brick specimens prepared at 12 M NaOH concentration. Density values ranges from 1439 to 1636 kg/m^3. The density of geopolymer bricks cured under various conditions were found approximately equivalent. As the age of concrete increases, there is a slight increase in density as shown in Figure 3.Variation of density is not much significant with respect to age of concrete and type of curing.

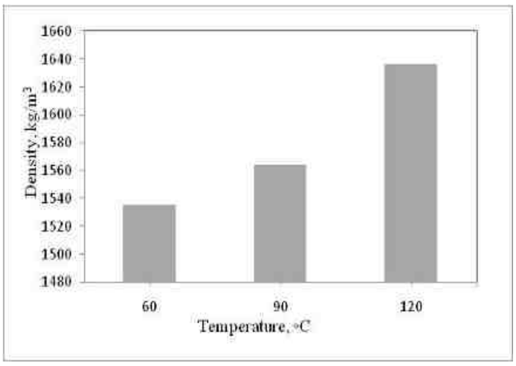

Fig 7: Density of geopolymer bricks at elevated temperature

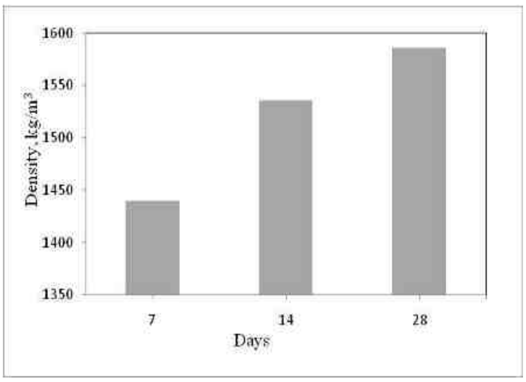

Fig 8: Density of geopolymer bricks at room temperature

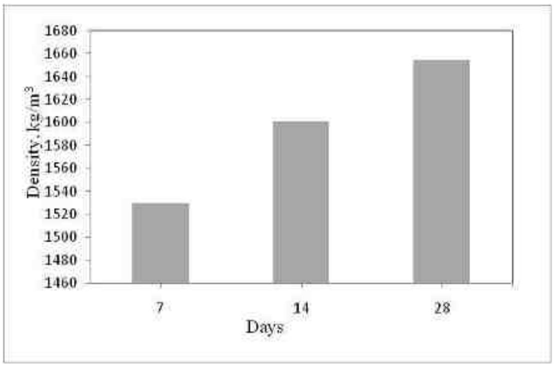

Fig 9: Density of geopolymer bricks at water curing

Water absorption

Water absorption is an important parameter for bricks. It indicates the permeability of bricks and shows the degree of reaction for fired bricks. This is also true for geopolymer bricks because higher degree of geopolymerization results in a less porous and permeable matrix.

The water absorption values of the samples cured at elevated temperature varied between 6% and 8%, while those of the samples cured at ambient temperature varied between 4 % and 10 %.

From the figure 10, the reduction in sorptivity was observed in elevated temperature curing. The finer fly ash particles produced a micro-filler effect by arresting the pores and resulted in a more compact concrete structure thereby reducing the liquid penetration property [14]. The water absorption value was higher for 7 days curing at room temperature when compared to 14 days and 28 days as can be seen in figure 11. It could be that the excessive fly ash content has affected the structural compactability of geopolymer concrete by hindering the development of a denser aluminosilicate polymer gel which enhances the capillary suction [15].

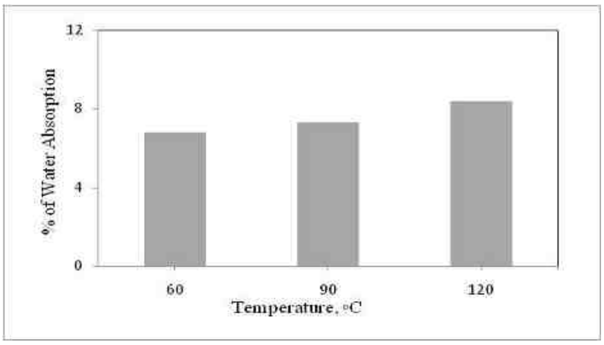

Fig 10: Water absorption of geopolymer bricks at elevated temperature

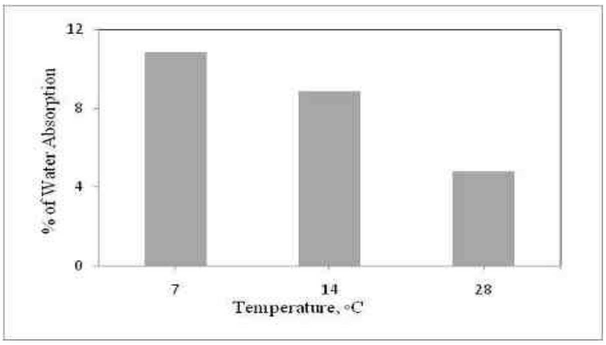

Fig 11: Water absorption of geopolymer Bricks at room temperature

Dimensionality

Dimensionality test is done according to the IS: 1077-1992. The average dimensions of the cement and geopolymer blocks obtained are given in Table 6. The dimensions of the blocks are within the limits of non-modular size specified by IS: 1077-1992.

CONCLUSION

The following broad conclusions could be drawn from this study.

- The geopolymer brick specimens prepared at 12 M NaOH concentration have higher compressive strength.
- Curing conditions plays an important role in geopolymerization reaction and thus the strength of fly ash based geopolymer bricks.
- Ambient curing method is economical and also produced high compressive strength when compared to elevated temperature curing and water curing.
- Compressive strength of geopolymer bricks under ambient temperature curing ranges from 10 to 23 N/mm^2.
- Density of geopolymer bricks ranges from 1439 to 1636 kg/m^3.
- Water absorption of geopolymer bricks was within 14% of its weight.

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