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Study of the Effect of Elevated Temperature on Alkali Activated Composites

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Abstract—*Safety against fire is one of the important aspects while considering the serviceability of a structure. Fire hazards become an unavoidable mishap in this highly energy dependent world. This paper reports the findings of an experimental study performed to compare the properties of alkali activated composite (AAC) specimens made from ground granulated blast furnace slag (GGBS) and fly ash with those of ordinary Portland cement. The activating solution used was made using sodium hydroxide flakes, sodium silicate and water at a constant percentage of Na_2O and SiO_2 both at 8%. The specimens were exposed to elevated temperatures of 300^0C, 600^0C and 900^0C. Physical change and mechanical properties were studied and comparison was made with that of ordinary Portland cement specimens. The compressive strength of ordinary Portland cement (OPC) specimens shows an increase from $40N/mm^2$ to $44N/mm^2$ when temperature was increased to 300^0C from ambient temperature then it gradually decreases. While the specimens made using fly ash shows maximum increase in compressive strength at 300^0C. However, the compressive strengths gradually drop down when the exposure temperature reached 600^0C and ordinary Portland cement samples completely crumbled at 900^0C. One of the most visible change was the change in color from grey towards reddish as temperature increases accompanied by surface cracks. Among the test specimens, composites made incorporating Groundgranulated blast furnace slag gives least physical dimensional changes. It can be concluded that alkali activated composites indicate better resistance than ordinary Portland cement counterparts at elevated temperatures.*

1. Introduction

The production of Portland cement, a main component of making concrete, contributes significant amount of greenhouse gas. The production of cement is increasing by about 3% annually [1]. The production of one ton of cement liberates about one ton of CO_2 to the atmosphere, as a result of de-carbonation of limestone in the kiln and the combustion of fossil fuels [2]. The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35 billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere [3]. Cement is also among the most energy-intensive construction materials, after aluminium and steel. Furthermore, it has been reported that the durability of ordinary Portland cement (OPC) concrete is under examination, as many concrete structures, especially those built in corrosive environments, start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life [4].

In order to produce environmentally friendly concrete, Mehta [5] suggested the use of fewer natural resources, less energy, and minimize carbon dioxide emissions. He categorized these short-term efforts as 'industrial ecology'. The long-term goal of reducing the impact of unwanted by-products of industry can be attained by lowering the rate of material consumption. Above this, human activities on earth produce solid wastes in considerable quantities of over 2500MT per year,[5] including industrial wastes, agricultural wastes and wastes from rural and urban societies. Recent technologies have shown that these materials are valuable as inorganic and organic resources and can produce various useful products. Amongst the solid wastes, the most prominent ones are fly ash, blast furnace slag, rice husk (converted into ash), silica fume and demolished construction materials.

In 1978, Davidovits[6] proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. As the chemical reaction that takes place in this case is a polymerization process, Davidovits[6,7] coined the term 'Geopolymer' to represent these binders. Geopolymers also known as AAC are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline [8, 9]. The objective of the present study isto develop AAC based on fly ash and GGBS and exposed them to elevated temperature up to 900^0C and to compare the properties with that of ordinary Portland cement paste.

2. Experimental programme

The materials used for the present experimental investigation are Ordinary Portland Cement of 43 grade,Fly Ash and GGBS. For activating solution, Sodium hydroxide pellets and Sodium silicate are used. The properties of fly ash and GGBS are presented in Table 1.

Table 1: Chemical composition of Fly ash and GGBS used (% mass)

Chemical composition	Fly ash	GGBS
SiO_2	56.01	35.01
Al_2O_3	29.8	17.13
Fe_2O_3	3.58	1.10
TiO_2	1.75	0.54
CaO	2.36	36.58
MgO	0.32	6.61
K_2O	0.73	0.62
Na_2O	0.61	0.27
SO_3	Nil	1.69
P_2O_5	0.44	Nil
LOI*	0.40	0.09

*Loss on ignition

3. Preparation of specimen

The alkaline activating solution used in the manufacture of alkali activated composites (AAC) was a mixture of sodium hydroxide solids, sodium silicate solution and water. The specimens were mixed in a non-absorbent container and later transferred into steel cube moulds of 50x50x50 mm. For the AAC specimens, thermal curing was provided in an oven for 24 hours at 80°C. The OPC specimens were water cured for 28 days. Exposure of specimens to elevated temperatures were done only after 28 days of casting. The casting of specimens in the cube moulds is shown in Figure 1. Images of some demolded specimens are presented in Figure 2.

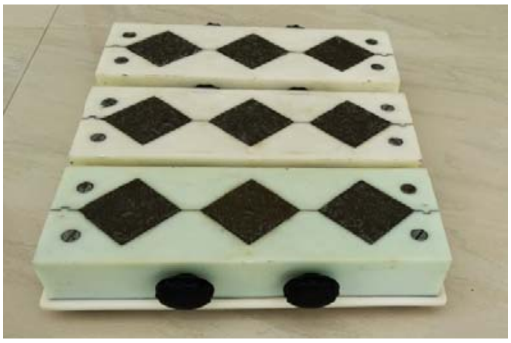

Figure 1: Specimen casted into cubes

Figure 2: Demolded specimens

4. Test conducted

The tests conducted on the unexposed specimens were for change in mass and compressive strength. The specimens were exposed to elevated temperature of 300^0C, 600^0C and 900^0C to investigate the reduction in compressive strength of specimens. Microstructural properties of specimens were studied using scanning electron microscope (SEM) and EDX. The results of the tests are reported as average of three specimens. The details of specimens are given in Table 2. PC is the cement paste specimen. FA represents AAC made using fly ash as the binder material and FAG represents AAC in which binder is formed using fly ash as binder whose 20% is substituted by GGBS.

Table 2: Details of test specimen

Specimen ID	PC	FA	FAG
Cement	1000	-	-
Fly ash	-	1000	800
GGBS	-	-	200
Water/binder ratio	0.33	0.33	0.33
Na_2O (%)	-	8	8
SiO_2 (%)	-	8	8

5. Results and discussions

5.1 Change in mass

The results of the change in mass of the specimens in grams are given in Figure 3. All the specimens showed gradual decrease in mass with the increase in temperature.

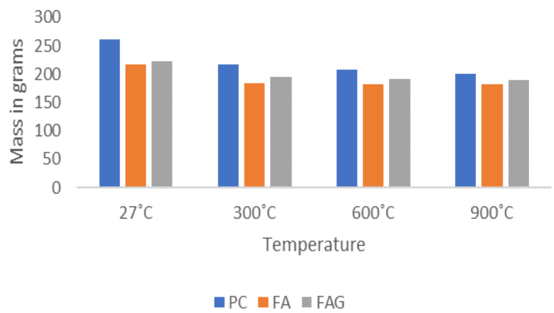

Figure 3: Change in mass of the specimens at different temperatures

5.2 Compressive strength

Compressive strength tests were conducted at 28 days at ambient temperature. Similar compressive strength test was done after exposing the specimens to elevated temperatures. The results of compressive strength of specimens are shown in Figure 4. The results reveal significant variation in the compressive strength of the specimens before exposure to elevated temperature. PC specimen gave the highest compressive strength of 40N/mm^2 in 28 days at ambient temperature. This shows that geopolymer specimen made using fly ash were able to gain strength in short time interval.

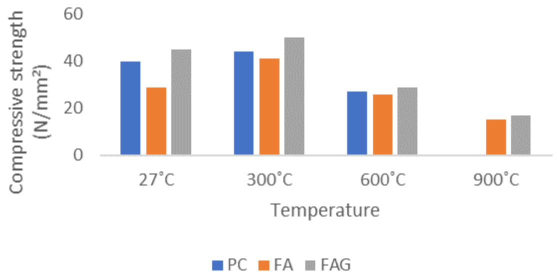

Figure 4: Compressive strength of the specimens at different temperatures

5.3 Change in surface texture at elevated temperatures

A muffle furnace was used to expose the specimens at a temperature 900^{0}C. The OPC specimen was observed to be completely crumbled such that compressive strength after elevated temperature exposure could not be performed. Photograph of specimens after exposure to elevated temperature of 900^{o}C are presented in Figure 5. Lots of cracks were noticed in the rice husk geopolymer specimens. Fly ash geopolymer specimen remained intact without visible cracks. Though PC specimen could not record any strength after exposure to elevated temperature, AAC specimens FAstill retained some amount of compressive strength.

Figure 5: Specimens after exposure at 900˚C

5.4 Ultrasonic pulse velocity test

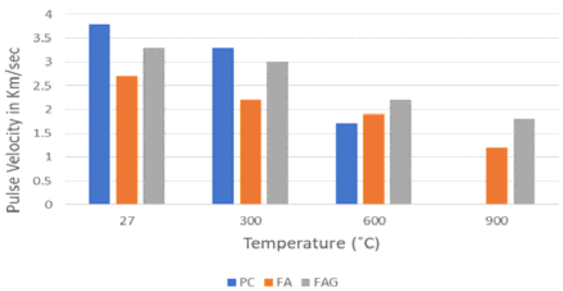

Figure 6: Pulse velocity of the specimens

Figure 6 presents the results of ultrasonic pulse velocity test. The pulse velocity of specimen PC shows the highest value upto a temperature of 300˚C. At ambient temperature, the quality of PC specimen exhibited "good" quality. As the pore structure increases with the increase in temperature, the velocity gradually deceases. PC specimens crumbled and failed to give any value at 900˚C. in the case of FAG samples, it started giving higher values of pulse velocity by 600˚C. FA samples continued to give lowest pulse velocity in all the three different temperatures except at 900˚C.

Conclusion

The present experimental study is performed to study the properties of ordinary Portland cement paste and AAC specimens prepared from GGBS and fly ash. From the results obtained, it can be concluded that the compressive strength of cement paste is comparatively higher than those of geopolymer specimens at ambient temperature. However, the strength of AAC specimen can be increased by increasing the percentage of Na_2O and SiO_2 used. Thus for AAC specimens, the strength may be increased by proper proportioning of its contents. AAC specimens has been found to be highly resistant to elevated temperature. When the cement paste specimen crumbled totally, geopolymer specimens still retained its shape and strength. From the present limited study, it can be concluded that geopolymer can be more beneficial in terms of cost as GGBS and fly ash are a waste material. AAC of desired properties can be manufactured by varying the components such as Na_2O content, SiO_2 content, etc.

Acknowledgements

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