International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-3, Special Issue-1, April-2015
Fifth National Conference on Innovative Practice in Construction Waste Management (IPCWM'15) On 8th & 9th April, 2015
Organized by Department of CIVIL Engineering, Sri Ramakrishna Institute of Technology, Coimbatore, India

Effects of Elevated Temperature on Geopolymer Mortar

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ABSTRACT
The discovery of inorganic polymers in the form of geopolymers is a breakthrough which provides cleaner and eco-friendlier alternatives to Ordinary Portland cement. Published literature shows that using process of alkaline activation, materials rich in alumina and silica, can be transformed into a cement to function as geopolymeric material (which is basically an alumino-silicate amorphous system) to act as a binder in a way very similar to OPC. This aspect was taken up for study in the present experimental investigation and with specific aim of filling the current knowledge gap in understanding the behaviour of geopolymers under elevated temperatures. The geopolymeric mortar mixes with fly ash and GGBS as Geopolymeric Source Material (GSM) and river sand as inert filler material were prepared to examine the refractory properties of geopolymer binders. Alkali Activator Solution (AAS) was made from a mixture of sodium hydroxide solution (having molarity of 5) and sodium silicate solution (with molar ratio SiO_2/Na_2O being 2.1). Parameters like weight loss and compressive strength were studied after the specimens were subjected to different temperatures i.e. 200^0C, 400^0C, 600^0C and 800^0C. The results of the geopolymer mortar were compared with the addition of ceramic additive.

Keywords
Geopolymer, high temperature, compressive strength, fly ash, GGBS, mortar

1. INTRODUCTION
Cement Concrete has emerged as the most important and essential building material in the world. This is partly due to the fact that concrete is produced from natural materials available in all parts of the globe, and partly due to the fact that concrete is a versatile material, giving architectural freedom. The "embodied energy" of Portland cement is a very high quantity. A tonne of Portland Cement production involves emission of about a tonne of CO_2, a greenhouse gas. More than 7% of world CO_2 production is attributed towards production of Portland Cement.

Therefore, the Portland cement industry does not fit the contemporary desirable picture of a sustainable industry. There is an urgent need to find an alternate to Portland Cement in order to make the construction industry eco-friendly. However, the new binder material should also possess satisfactory strength and durability characteristics which are comparable, preferably superior to those "conventional concretes" based on Portland cement.

A new binder material, known as "geopolymer" was first introduced by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure. He utilized silica (SiO_2) and alumina (Al_2O_3) available in the specially processed clay (metakaolin) to get inorganic polymeric system of alumino-silicates. Unlike ordinary Portland cement, geopolymers do not need calcium-silicate-hydrate(C-S-H) gel for matrix formation and strength, but utilize the polycondensation of silica and alumina precursors to achieve required strength level.

Two main constituents of geopolymers are: geopolymer source materials (GSMs) and alkaline activator liquids. The GSMs should be alumino- silicate based and rich in both silicon (Si) and aluminium (Al) and thus, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc. can form GSMs. The Alkaline Activator Solution is a mixture of sodium or potassium hydroxide, sodium or potassium silicate and water. Though it is good at strength and other properties compared to the ordinary Portland cement concrete, its behaviour under high temperatures is still unknown.

Many of the researchers have been studying the effects of high temperature on geopolymer concrete. It is very important to study the effects of this material under high temperature as it is a new material. In this study, the effects of high temperature on geopolymer mortar with 100% fly ash, 100% GGBS and 50% fly ash and 50% GGBS as geopolymeric source materials were studied and the results were compared with the addition of ceramic additive.

2. MATERIALS AND SPECIMEN PREPARATION

2.1 Materials
The source materials used in this study are low calcium class F Fly ash and Ground Granulated Blast furnace Slag. The chemical and physical properties of the source materials were given in table 1.River sand was used in this study as fine aggregate. The alkali activator solution used in this study consists of 10% sodium hydroxide solids, 50% distilled water and 40% sodium silicate solution. The sodium silicate solution with Na2O/SiO2 ratio=2 was used in this study. The sodium hydroxide solution was prepared to molarity of 5M. Zirconium dioxide (ZrO_2) was used as a ceramic additive by 2% of weight of the source material.

2.2 Specimen Preparation
Geopolymer mortar was prepared by mixing source material with river sand in proportion 1:2. The solution was mixed one day prior to the casting. Liquids to solids ratio used in this study are 0.45. The source materials and aggregates were dry mixed initially in a

digital mortar mixer for 3min and the alkali activated solution was added to the mix and allowed to mix thoroughly for 7min. The mix was then cast into 50mmX100mm disposable plastic moulds compacted in 3 layers and vibrated. Specimens with 2% ZrO_2 were also cast in the same manner.

Table 1. chemical composition of source materials

Chemical composition	Fly Ash (class F)	GGBS
CaO	1.3	40.3
SiO2	60.3	43.4
Al2O3	25.5	12.5
Na2O	0.4	0.9
K2O	0.8	0.6
MgO	0.8	1.5
Fe2O3	7.8	0.3
Loss on Ignition (LOI)	1.4	2.1
Specific Gravity	2.21	2.91

2.3 Curing Regime

Geopolymer specimens cast were left for curing at ambient temperature for 24hrs after which they were cured for 60^0C for 24hrs in a hot air oven. The specimens were demoulded after the curing regime and were allowed to cool to room temperature.

2.4 High Temperature Regime

At the age of three days, geopolymer specimens were exposed to temperatures of 200^0C, 400^0C, 600^0C, 800^0C in a high temperature furnace of maximum capacity 1400^0C at a gradual incremental rate of 5^0C/min. After the target temperature was attained, it was maintained for 1hr and then the specimens were allowed to room temperature in the furnace. Meanwhile, the specimens left at ambient temperature were left undisturbed.

3. TEST RESULTS AND DISCUSSIONS

The specimens were tested for compressive strength in a compressive testing machine of 200T capacity. Weight loss was also computed after exposure to the temperature. No cracks were observed on the surface of the specimens after the exposure to temperatures of 200^0C, 400^0C, 600^0C. The surface texture of the specimens has slightly changed after the exposure to 800^0C. The weight loss was around 2%-10% after the exposure to temperatures. There was no change in color of the specimens after exposure to 200^0C, 400^0C, 600^0C. The specimens turned to slight reddish color after exposure to 800^0C.

Table 2. Mix Proportions

Mix Id	Fly ash	GGBS	Sand	AAS
GPM0	0	1	2	0.45
GPM50	0.5	0.5	2	0.45
GPM100	1	0	2	0.45

Figure 1. fresh mix

Table 3. compressive strength values with 0% ZrO_2

Mix Id	Density (kg/m3)	3daystrength(MPa)				
		RT	200^0C	400^0C	600^0C	800^0C
GPM0	2277	32	30	7.9	5.6	2.54
GPM50	2201	38	26.5	9.3	6.4	3.05
GPM100	2054	7.5	4.1	3.05	2	-

Compressive strength of the specimens without ceramic additive was given in table 3. A minimum of five specimens were tested for compressive strength at the age of 3 days. Compressive strength of specimens with ceramic additive was given in table 4.

Table 4. compressive strength values with 2% ZrO_2

Mix Id	Density (kg/m3)	3day strength (MPa)				
		RT	200^0C	400^0C	600^0C	800^0C
GPM0	2277	32	32	16.3	8.9	3.22
GPM50	2201	38	28	21.9	9.7	4.1
GPM100	2054	7.5	5	4.1	2	-

The compressive strength of the geopolymer mortar with 0% Fly ash has initially high compressive strength without any temperature exposure. With the temperature exposure, the compressive strength of the GPM0 mix specimens decreased drastically and the strength loss was about 93% at 800^0C. However, with the addition of ceramic admixture, the strength loss was 90% at 800^0C. The strength loss for the GPM50 mix was gradual with the increase of temperature and was 91% at 800^0C.

With the addition of ceramic admixture, the strength loss was only 88%. The strength loss was almost 100% for the GPM100 mix after exposure to 800^0C. Some of the specimens after exposure to temperature were shown in figure 2.

Figure 2. Specimens after exposure to800 ^{0}C with 0%ZrO_2

Figure 3. Specimens after exposure to800^{0}C with 2%ZrO_2

Figure 4. Specimens inside the furnace

The comparison of compressive strengths for all the mixes with and without ceramic additive was shown in figures 5, 6 &7.

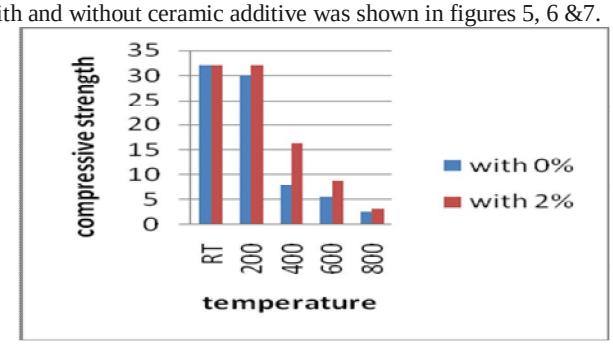

Figure 5. comparison of strength for GPM0 mix

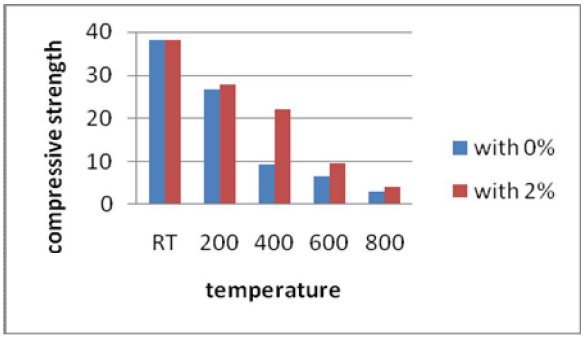

Figure 6. comparison of strength for GPM50 mix

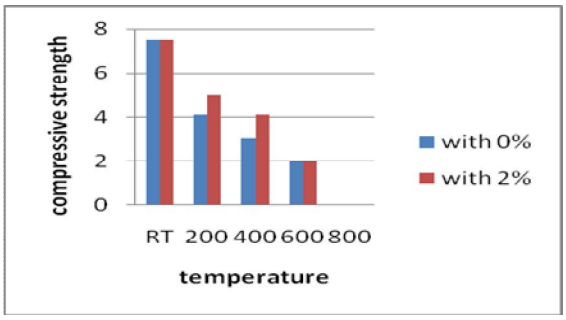

Figure 7. comparison of strength for GPM100 mix

4. CONCLUSIONS

1) The ceramic additive which was used in this study was useful in increasing the compressive strength and arresting cracks.
2) No cracks were observed on specimens after exposure to high temperatures up to 600^{0}C.
3) Cracks were observed on the specimens without ceramic additive after exposure to 800^{0}C. However, they were reduced with the help of ceramic additive.
4) Color change was observed on the specimens after the exposure to 800^{0}C.
5) Zirconium dioxide was found useful as a ceramic additive from this study.
6) Specimens with 100% fly ash as source material has no strength after exposure to 800^{0}C.
7) Curing at 60^{0}C for 24hrs was sufficient for demoulding the specimens with and without ceramic additive.

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