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Studies on The Behaviour of Geopolymer Concrete With Manufactured Sand As Fine Aggregate When Exposed To Elevated Temperatures

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Abstract – Concrete is the most widely used construction material in the world. The production of one ton of Portland cement emits approximately one ton of carbon dioxide into the atmosphere that leads to about 7% of global warming. Geopolymer is a promising alternative binder to Portland cement, it is an innovative eco-friendly, construction material, it is produced from by-product materials such as fly ash and blast furnace slag; hence recognized as a low-emission alternative binder for concrete. On the other hand river sand is becoming scare day by day and costlier. So the manufactured sand turns out to be alternative material for river sand. The present study is to assess engineering properties of low calcium fly ash and slag based geopolymer concrete of G30 and G50 with manufactured sand as fine aggregate when it is exposed to elevated temperatures i.e. 100 ^{O}C, 200 ^{O}C, 400 ^{O}C and 600^{O}C for different duration of 1, 2, 4 and 6 hours. It is observed that conventional concrete started developing cracks at 400 °C, whereas geopolymer concrete did not show any vi sible crack up to 600°C i.e. geopolymer concrete sh ows better resistance against surface cracking when exposed to elevated temperatures.

Index Terms – Elevated Temperature,Fly Ash, Geopolymer Concrete, GGBS and Manufactured Sand

1. INTRODUCTION

Concrete is the only construction material which is used world and its consumption is second only to water. Production of cement is not only energy intensive, but also responsible for emission of carbon dioxide (CO2) in large quantity. Geopolymer is a promising alternative binder to Portland cement. It is produced mostly from by-product materials such as fly ash and blast furnace slag. The global warming is caused by the emission of greenhouse gases, such as CO_2, to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is responsible for the emission of carbon dioxide, for one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere. There are many efforts are being made to reduce the use of Portland cement in concrete by finding alternative binders to Portland cement this include the utilisation of supplementary cementing materials fly ash, granulated blast furnace slag, rice-husk ash and metakaolin. In 1972, Joseph Davidovits coined the name ''geopolymers'' to descr ibe the zeolite like polymers. Geopolymers are the alumina-silicate polymers which consist of amorphous and three dimensional structures formed from the geopolymerisation of alumina-silicate monomers in alkaline solution. Investigations have been carried out on calcined clays (e.g., metakaolin) or industrial wastes (e.g., fly ash or metallurgical slag). A reaction pathway involving the polycondensation of orthosialiate ions (hypothetical monomer) is proposed by Davidovits.the objective of this paper is to study the behavior of low calcium fly ash and slag based geopolymer concrete of G30 and G50 when it is exposed to elevated temperatures i.e. 100 ^{O}C, 200 ^{O}C, 400 ^{O}C and 600^{O}C for different duration of 1, 2, 4 and 6 hours. The loss in compressive strength and weights are evaluated and compared both controlled and geopolymer concrete of respective grade.

2. MATERIALS

2.1 Ordinary Portland Cement

In the experimental investigations, 53-grade of ordinary Portland cement is used. The cement thus procured was tested for physical properties in accordance with the IS: 4031-1968 and found to be conforming various specifications of IS 12629-1987.

2.2 Fine aggregate

Manufactured sand nothing but crushing of hard stone aggregates to the size of natural sand. The M-sand used is collected from local suppliers. The manufactured sand used was without any organic impurities and conforming to IS: 383 – 1970 [Methods of physical tests for hydraulic cement]. The M-sand was tested for its physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS: 2386 – 1963 [Methods of test for aggregate for concrete] and is shown in below Table No.1.

Table 1: Physical properties of Manufactured Sand

S.No.	Property	Method	Fine Aggregate
1	Specific gravity	Pycnometer IS:2386 part 3-1986	2.71
2	Bulk density (compact)	IS:2386 part 3-1986	1720 Kg/cum
3	Bulk density (loose)	IS:2386 part 3-1986	1663.27 Kg/cum
4	Fineness modulus	SieveAnalysis (IS:2386 Part 2-1963)	2.67
5	Bulking	IS:2386 Part 3-1986	4% wc
6	Grading		Zone –II

2.3 Coarse aggregate

The crushed angular aggregate of 20mm maximum size obtained from the local crushing plants is used as coarse aggregate in the present study. The physical properties of coarse aggregate such as specific gravity, bulk density, flakiness and elongation index are tested in accordance with IS: 2386-1963.

2.4 Fly Ash

In the present study of work, the Class F-fly ash is used, which is obtained from Vijayawada thermal power station in Andhra Pradesh.

2.5 Ground Granulated Blast Furnace Slag

Ground Granulated Blast Furnace Slag (GGBS) is a by product of the steel industry. Blast furnace slag is defined as "the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace". About 15% by mass of binders was replaced with GGBS.

2.6 Water

Water free from chemicals, oils and other forms of impurities is used for mixing of concrete as per IS: 456:2000.

2.7 Sodium Hydroxide

Sodium Hydroxide is one of the major ingredients of geopolymer concrete. The following are the specifications of Sodium hydroxide pellets and this material is procured from the local laboratory chemical vendors in Hyderabad. Specifications are tabulated in table 2 as given by the suppliers.

Table 2: Shows Physical properties of NaOH

Molar mass	40 gm/mol
Appearance	White solid
Density	2.1 gr/cc
Melting point	318^{o}C
Boiling point	1390^{o}C
Amount of heat liberated when dissolved in water	266 cal/gr

2.8 Sodium Silicate Solution

Sodium silicate solution is a type of alkaline liquid plays an important role in the polymerisation process. This material is procured from the local laboratory chemical vendors in Hyderabad. Specifications are tabulated in table 3 as given by the suppliers.

Table 3: Properties of Na_2SiO_3 Solution

Specific gravity	1.57
Molar mass	122.06 gm/mol
Na_2O (by mass)	14.35%
SiO_2 (by mass)	30.00%
Water (by mass)	55.00%
Weight ratio (SiO_2 to Na_2O)	2.09
Molarity ratio	0.97

2.9 Super Plasticizer

Super plasticizer GLENIUM B233 of Fosroc chemical India Ltd. was used as water reducing admixture, it increases workability.

3. EXPERIMENTAL INVESTIGATION

3.1 General

The objective of this paper is to study the behavior of low calcium fly ash and slag based geopolymer concrete of G30 and G50 when it is exposed to elevated temperatures i.e. 100 ^{O}C, 200 ^{O}C, 400 ^{O}C and 600^{O}C for different duration of 1, 2, 4 and 6 hours. The cubes of size 100mm×100mm×100mm were cast and after one day rest period, half of the specimens were cured in an oven at 60°C for 24 hours and the remaining period cured in sun light until the specimens kept in muffle furnace. After 28 days, an initial weights are taken then the specimens are kept in Muffle furnace to heat at an elevated temperatures 100^{o} C, 200^{o}C, 400^{O}C and 600^{o}C for 1hr, 2hr, 4hr and 6hr. The specimens were taken out from Mufflr Furnace then final weights and residual compressive strengths were calculated.

3.2 Mixing and Casting of Geopolymer Concrete

Geopolymer concrete is prepared by using the same procedure whatever is used in the conventional concrete. In the laboratory, the fly ash and the aggregates were mixed together in dry by using a pan mixer for about two minutes, then the alkaline liquid was mixed with the super plasticizer and extra water if any. The liquid component of the mixture was then added to the dry material and the mixing continued usually for another two minutes. The fresh concrete was cast and compacted by the usual methods used in the case of conventional concrete. The workability of the fresh concrete was measured by means of the conventional slump test.

4. TEST RESULTS

4.1 Weight Loss and ResidualCompressive Strength

The weights, percentage loss of weights, compressive strengths and percentage loss of compressive strengths of controlled and geopolymer concrete specimens exposed to elevated temperatures. From the tables and graphs it is observed that as the temperature increases the percentage loss of compressive strength and weights are increased.

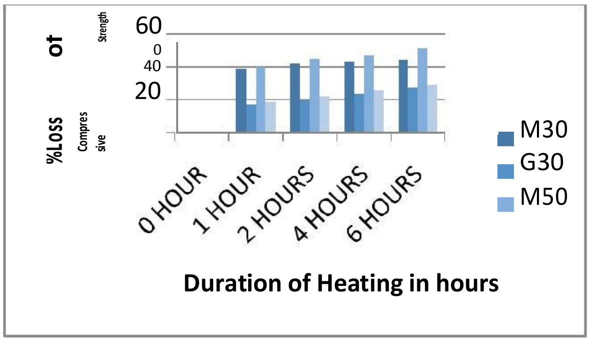

Figure 2. Shows % Loss of Compressive Strength against Duration in hours at 600° C

Table 4: Weight Loss in Percentage of Controlled (M30 & M50) & Geopolymer Concrete (G30 & G50) when Exposed to Elevated Temperatures

Te. in °C	Exposure Time in Hours	M30	% Loss	G30	% Loss	M50	% Loss	G50	% Loss
	0	2.450	0.00	2.240	0.00	2.510	0.00	2.290	0.00
	1	2.448	0.08	2.239	0.04	2.506	0.16	2.289	0.04
100	2	2.442	0.33	2.239	0.04	2.499	0.44	2.289	0.04
	4	2.426	0.98	2.238	0.09	2.482	1.12	2.288	0.09
	6	2.420	1.22	2.237	0.13	2.474	1.43	2.286	0.17
	0	2.450	0.00	2.240	0.00	2.510	0.00	2.290	0.00
	1	2.428	0.89	2.238	0.09	2.486	0.96	2.286	0.17
200	2	2.411	1.59	2.226	0.63	2.465	1.79	2.269	0.92
	4	2.401	2.00	2.218	0.98	2.455	2.19	2.254	1.57
	6	2.371	3.22	2.208	1.43	2.425	3.39	2.245	1.97
	0	2.450	0.00	2.240	0.00	2.510	0.00	2.290	0.00
	1	2.348	4.16	2.214	1.16	2.391	4.74	2.259	1.35
400	2	2.282	6.86	2.197	1.92	2.325	7.37	2.236	2.36
	4	2.263	7.63	2.177	2.81	2.305	8.17	2.217	3.19
	6	2.253	8.04	2.160	3.57	2.295	8.57	2.201	3.89
	0	2.450	0.00	2.240	0.00	2.51	0.00	2.290	0.00
	1	2.281	6.89	2.178	2.77	2.334	7.01	2.223	2.93
600	2	2.263	7.63	2.162	3.48	2.314	7.81	2.201	3.89
	4	2.233	8.86	2.143	4.33	2.285	8.96	2.176	4.98
	6	2.154	12.08	2.098	6.34	2.199	12.39	2.137	6.68

Table 5: Compressive Strength Loss in Percentage of Controlled (M30 & M50) & Geopolymer Concrete (G30 & G50) when Exposed to Elevated Temperatures

Te. in °C	Ex. in Hours	M30	% Loss	G30	% Loss	M50	% Loss	G50	% Loss
100	0	41.32	0.00	42.37	0.00	61.56	0.00	62.43	0.00
	1	39.41	4.62	42.43	-0.14	58.06	5.68	62.84	-0.65
	2	38.72	6.29	42.56	-0.44	57.54	6.53	64.24	-2.89
	4	38.16	7.64	43.02	-1.53	57.22	7.05	64.76	-3.73
	6	38.11	7.76	43.36	-2.33	57.12	7.21	65.36	-4.69
200	0	41.32	0.00	42.37	0.00	61.56	0.00	62.43	0.00
	1	40.02	3.14	42.12	0.59	59.34	3.60	62.17	0.41
	2	39.37	4.71	41.77	1.41	58.27	5.34	61.48	1.52
	4	38.22	7.50	40.21	5.09	57.64	6.36	60.13	3.68
	6	38.03	7.96	40.06	5.45	56.76	7.79	59.82	4.18
400	0	41.32	0.00	42.37	0.00	61.53	0.00	62.43	0.00
	1	38.81	6.07	41.02	3.18	57.16	7.14	60.13	3.68
	2	37.74	8.66	40.49	4.43	55.47	9.89	59.61	4.51
	4	36.21	12.36	39.07	7.78	54.93	10.95	58.15	6.85
	6	35.92	13.06	38.54	9.03	53.32	13.38	54.12	13.31
600	0	41.32	0.00	42.37	0.00	61.56	0.00	62.43	0.00
	1	26.60	35.62	36.32	14.27	38.14	38.04	51.65	17.26
	2	25.15	39.13	35.09	17.18	35.12	42.94	49.60	20.55
	4	24.89	39.76	33.63	20.62	33.77	45.14	47.25	24.31
	6	24.03	41.84	32.29	23.79	30.54	50.38	45.19	27.61

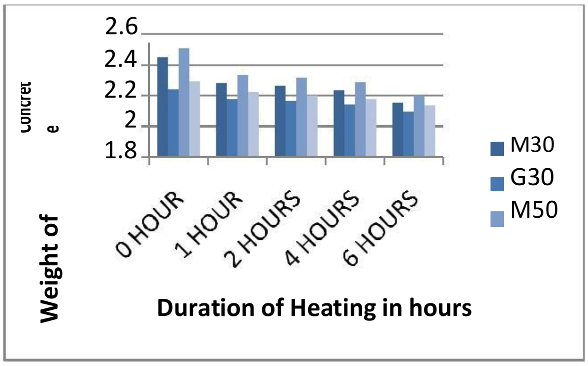

Figure 3. Shows % Loss of Weight against Duration in hours at 600° C

5. CONCLUSIONS

The following specific conclusions can be drawn from the present experimental investigation:

1. It is observed that there is a steady loss in compressive strength with an increase in temperature in geopolymer concrete whereas in controlled concrete the loss of strengths relatively more when exposed to elevated temperatures of 200ºC, 400ºC and 600ºC temperature for 1hr, 2 hrs, 4hrs and 6 hrs duration.
2. The percentage loss of compressive strength up to 400ºC is about 9.03% in geopolymer concrete and 13.38% in controlled concrete. It can be concluded that both the concretes can sustain up to this temperature.
3. It is reported that at 600ºC, there is significant loss in compressive strength and it is about 41.84% and 50.38% in M30 and M50 grades of controlled concrete respectively, whereas the strength loss is about 23.79% and 27.61% in G30 and G50 grades of geopolymer concrete respectively.
4. The percentage loss of compressive strength in M50 and G50 grades is high beyond 400ºC when compared with M30 and G30 grades. The reason may be due to high brittleness and dense micro structure of higher grade concrete.
5. It is reported that at 600ºC, there is loss in weights also and it is about 12.08% and 12.39% in M30 and M50 grades of controlled concrete respectively, whereas the strength loss is about 6.33% and 6.68% in G30 and G50 grades of geopolymer concrete respectively.

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