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Enhancement of Durability Characteristics of Geopolymer Concrete With Manufactured Sand

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ABSTRACT

Geopolymer Concrete is the concrete made without using any quantity of cement. Instead the waste material from the thermal power station called fly ash is used as the binding material. This fly ash reacts with alkaline solution like sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) and forms a gel which binds the fine and coarse aggregates. Similarly another artificial material called manufactured sand (M-Sand) is also used as the fine aggregate against the normal river sand. The durability of Geopolymer Concrete with M-sand was studied by casting cubes of size 100 x 100 x 100 mm. The cube specimens were immersed in acid, alkaline, sulphate and chloride solutions respectively. The specimens were studied at the end of 3, 7, 14, 21, 28 and 56 days. The durability of Geopolymer Concrete with manufactured sand (GPCM) was better than the normal portland cement concrete.

Key words: Fly Ash, geo polymer concrete, manufactured sand, durability.

1.0 INTRODUCTION

Construction is one of the fast growing fields worldwide. Concrete is the world's most versatile, durable and reliable construction material. Next to water, concrete is the most used material, which required large quantities of Portland cement. As per the present world statistics, every year around **4000** Million Tons of Cement is required (Wikipedia). This quantity will be increased by 25% within a span of another 10 years. Ordinary Portland cement production is the second only to the automobile as the major generator of carbon di oxide, which polluted the atmosphere. In addition to that large amount energy was also consumed for the cement production. Hence, it is inevitable to find an alternative material to the existing most expensive, most resource consuming Portland cement. Geopolymer Concrete with M- sand (GPCM) can be produced without using any quantity of ordinary Portland cement.

All the construction materials not only depend upon the strength characteristics but the durability is also one of important parameter. Durability is the property that performs satisfactorily under anticipated exposure conditions during the life span of the structure without significant deterioration. The durability of GPCM was studied by its reactions with acidic, alkaline, sulphate and chloride solutions and compared with ordinary Portland Cement Concrete (OPCC).

1.1 Geopolymer Cement

The name, Geopolymer cement was first coined by Davidovits (1994). It represents a broad range of materials characterized by networks of inorganic molecule. Geopolymer cement is a product resulting from fly ash with alkaline solution containing sodium hydroxide and sodium silicate.

1.2 Geopolymer Concrete

Geopolymer concrete consists of geopolymer cement, fine aggregate and coarse aggregate. It does not require any water for matrix bonding. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals as reported by Davidovits (1994), Anuar and *et al.* (2011) and Raijiwala and Patil (2011). In this study manufactured sand (M- sand) is used as fine aggregate.

2.0 MATERIALS

The Geopolymer concrete was prepared using the following materials:

a. Fly Ash
b. M- sand
c. Coarse aggregates
d. Sodium Hydroxide
e. Sodium Silicate

2.1 Fly Ash

Fly Ash of class F obtained from Thermal Power Station, Mettur, Tamil Nadu, South India was used in this study. The fly ash was analysed using Scan on Electronic Microscope (SEM), Energy Dispersive And Xray Technique (EDAX) and X-Ray Diffraction (XRD) analyses. The analyses confirmed the presence of Al_2O_3 and SiO_2 as predominant materials in the fly ash and the particles were spherical in shape with a specific surface of about 10µm.

2.2 M-Sand

There is a scarcity for natural sand everywhere and more over the continuous sand mining on the river beds leads to environmental problems. It is essential to find an alternative material. M-Sand is nothing but crushing of hard stone aggregates to the size of natural sand. The finest particles are removed by washing with water. The M-Sand used in this study was collected in Coimbatore, Tamil Nadu, South India. The specific gravity of M-sand was found as 2.57 by using Pychonometer and the grading was also done in the Mechanical Sieve Shaker. On comparing the Specific Gravity and Particle size distribution of M-Sand with natural sand, it was confirmed that the M-Sand shall be used as an alternative material for the natural sand.

2.3 Coarse Aggregates

Coarse aggregates are obtained by pulverising of hard rock stones. The coarse aggregates of single size of 20 mm diameter were collected in Coimbatore, Tamil Nadu, South India.

2.4 Sodium Hydroxide Solution

Analytical grade Sodium Hydroxide (NaOH) was procured from Sigma Aldrich, Bangalore. A solution of molarity 10 was prepared in distilled water and used.

2.5 Sodium Silicate Solution

Sodium Silicate (Na_2SiO_3) solution of grade A53containing 29.4% SiO_2, 14.7 % Na_2O and 55.9 % of water was procured from Sigma Aldrich, Bangalore and used as such.

3.0 EXPERIMENTAL METHODS

Abdul Aleem and Arumairaj in 2012 had recommended a mix ratio of 1:1.5:3.3 (fly ash : fine aggregate : coarse aggregate) for the GPCM and the same mix ratio was used in preparing the GPCM cube specimens. For the OPC concrete, a mix design was carried out for M40 grade and the same was used.

3.1 Casting

Fly ash, fine aggregates (M-sand) and coarse aggregates were mixed manually in a container in the laboratory in the dry form. Alkaline solution (NaOH and Na_2SiO_3 combined together in a ratio of 2.5) to fly ash ratio of 0.35 was used. The geopolymer concrete thus prepared was placed in 100 mm cube moulds in three layers duly compacted with 25 blows of 16mm tamping rod, each layer.

3.2 Curing

Lloydand *et al.* (2009), Wallah *et al.* (2006) and Hardjito and *et al.* (2004) have concluded that geopolymer concrete did not attain any strength by water curing. They have also concluded that geopolymer concrete will harden at steam curing or hot air curing. The GPCM cubes were cured under steam curing at a temperature of 60ºC for a period of 24 hours.

3.3 Acid Resistance

The GPCM specimens were immersed separately with the 3% of the concentrated Hydrochloric Acid (HCl) and concentrated Sulphuric Acid (H_2SO_4) respectively. The weights of the specimens were found out at regular intervals such as 3, 7, 14, 21, 28 and 56 days respectively.

3.4 Alkaline Resistance

The GPCM specimens were immersed separately with the 3% of Sodium sulphate (Na_2SO_4) and 3.5% of Sodium chloride (NaCl) solution respectively. The weights of the specimens were found out at regular intervals such as 3, 7, 14, 21, 28 and 56 days respectively.

4.0 RESULTS & DISCUSSIONS

4.1 Acid Resistance

The GPCM and OPCC cube specimens immersed in hydrochloric acid and sulphuric acid solutions were periodically taken from the respective acidic solutions and the surface was wiped with dry cloth. Then the weight of the specimens were taken and compared with the initial weight of the specimen to find the percentage of loss in weight due to the acid attack. The results of GPCM were compared with OPCC which is presented in the Table 1 and Fig. 1.

The GPCM and OPCC cube specimens were immersed in the hydrochloric acid and sulphuric acid solutions respectively, and were also tested for compressive strength at the end of 28 days and 56 days. The test results are presented in the Figs. 2 and 3 respectively.

Table 1. Acid attack on GPCM and OPCC Specimens

Age in Days	% loss in weight due to Acid Attack -3 % HCl		% loss in weight due to Acid Attack -3 % H2SO4	
	GPCM	OPCC	GPCM	OPCC
0	0	0	0	0
1	0.1	0.5	0.3	0.75
3	0.2	0.8	0.4	1.1
7	0.35	1.0	0.5	1.5
14	0.38	1.2	0.6	1.8
21	0.4	1.3	0.7	1.9
28	0.45	1.5	0.9	2.05
56	0.5	1.8	1.0	2.1

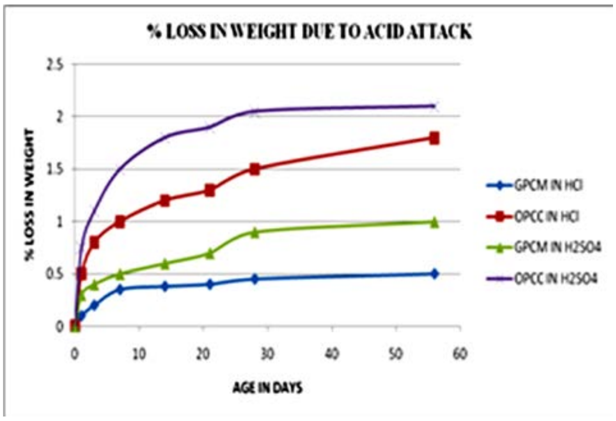

Fig. 1 Acid attack on GPCM and OPCC

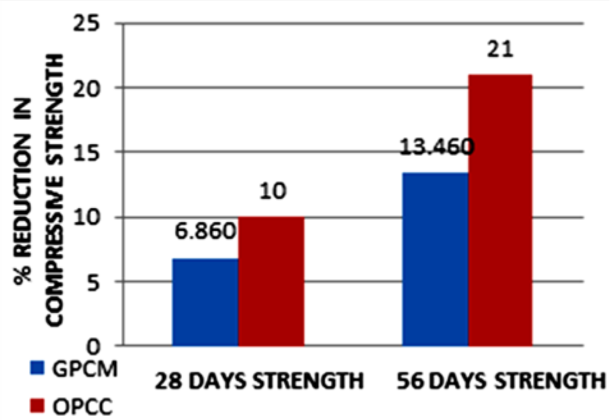

Fig. 2. Percentage of Strength reduction due to HCl Acid attack on GPCM and OPCC

Effect of hydrochloric acid

At the end of 28 days GPCM suffered a compressive strength loss of 6.86 % however it was 10% in the case of OPCC. Similarly at the end of 56 days the loss in compressive strength was 13.46 % but in OPCC it was higher up to 21%. In the OPCC, the dissolution of the calcium silicate hydrate, in the most advanced cases of acid attack, can affect the durability which in turn cause reduction in strength. The compressive strength of GPCM and OPCC due to the hydrochloric acid attack is shown in Table 2.

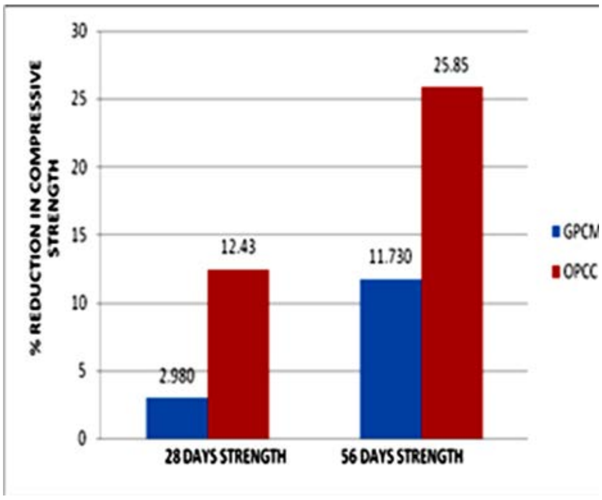

Fig. 3. Percentage of Strength reduction due to H_2SO_4 Acid attack on GPCM &OPCC

Table 2. Compressive strength of GPCM and OPCC due to hydrochloric acid attack

Specimen	Comp. strength before HCl acid attack (N/mm^2)	Compressive strength due to HCl acid attack (N/mm^2)		% reduction in strength	
		28 days	56 days	28 days	56 days
OPCC	41.00	36.90	32.40	10.00	21.00
GPCM	52.00	48.43	45.00	6.86	13.46

Effect of sulphuric acid

At the end of 28 days GPCM suffered a compressive strength loss of 2.98 % however it was 12.43% in the case of OPCC. Similarly at the end of 56 days the loss in compressive strength was 11.73% but in OPCC it was higher up to 25.85%. The compressive strength of GPCM and OPCC due to the sulphuric acid attack is shown in the Table 3.

The test results indicated that GPCM showed better resistance against Hydrochloric acid and Sulphuric acid compared to OPCC specimens. The compressive strength is also not much reduced in the GPCM compared to OPCC. This may be due to the property of the Portland cement, being highly alkaline and is not resistant to the attack of strong acids. The calcium salt produced by the reaction of the sulphuric acid and calcium hydroxide is calcium sulphate which in turn causes an increased degradation due to sulphate attack. Once the durability was affected, the compressive strength was also reduced considerably. It was also observed that GPCM showed better resistance against sulphuric acid compared to hydrochloric acid attack. However, it was contradictory in the case of OPCC which shows better resistance against hydrochloric acid than sulphuric acid attack. Hence, GPCM was considered superior to OPCC.

Table 3. Compressive strength of GPCM and OPCC due to Sulphuric acid attack

Specimen	Comp. strength before H_2SO_4 acid attack (N/mm^2)	Compressive strength due to H_2SO_4 acid attack (N/mm^2)		% reduction in strength	
		28 days	56 days	28 days	56 days
OPCC	41.00	35.90	30.40	12.43	25.85
GPCM	52.00	50.45	45.90	2.98	11.73

4.2 Sulphate Attack

Sulphate attack is a chemical breakdown mechanism, where sulphate ions attack the components of the cement paste. The already immersed GPCM and OPCC cube specimens were periodically taken from the sodium sulphate solution, and the surface was wiped with dry cloth. Then the weight of the specimens were taken and compared with the initial weight of the specimen to find out the percentage of gain or loss in weight due to the sulphate attack. It was noted that the OPCC specimens were affected by sulphate attack, due to that loss in weight was observed. Interestingly, the GPCM specimens were not affected by sulphate attack and hence, no loss in weight was noted. However, there was a slight increase in the mass of specimens due to the absorption of the exposed liquid. The same effect was reported by Wallah and Rangan (2006) in their research report. The change in weight due to sulphate attack is shown in the Table 4.

Table 4. Sulphate attack on GPCM and OPCC Specimens

Age in Days	% Gain in weight due to 3% H_2SO_4	% Loss in weight due to 3% H_2SO_4
	GPCM	OPCC
0	0	0
1	2.7	3
3	3.2	3.3
7	3.5	3.6
14	3.75	3.9
21	3.85	4.2
28	3.95	4.7
56	4.0	5

The GPCM and OPCC cube specimens were immersed in the sodium sulphate and were also tested for compressive strength at the end of 28 days and 56 days. The test results are presented in the Fig. 4.

The test result indicated that GPCM showed better resistance against sulphate attack compared to OPCC specimens. The compounds responsible for sulphate attack on OPCC are water-soluble sulphate-containing salts, these new crystals occupy empty space, and as they continue to form, they cause the paste to crack, further damaging the concrete. GPCM specimens suffered a strength loss of 8.82 % at 28 days and 10.78% at 56 days of sodium sulphate attack. However, in the case of OPCC it was higher up to 27.5% in 56 days and 13.75 % in 28 days. Hence, GPCM was considered superior to OPCC with respect to the sulphate attack.

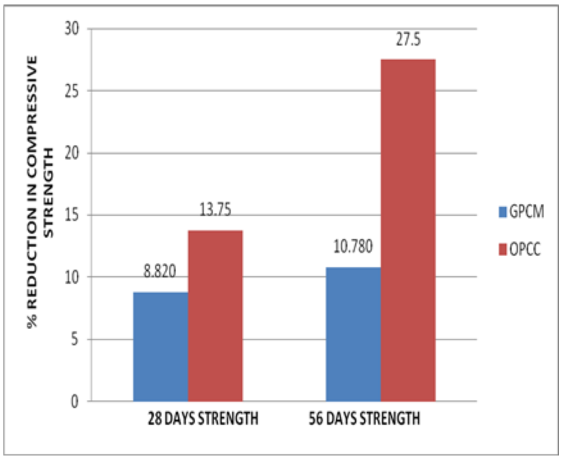

Fig. 4. Strength reduction due to Na2SO4 attack on GPCM and OPCC

4.3 Chloride Attack

The immersed GPCM and OPCC cube specimens were periodically taken from the sodium chloride solution and the surface was wiped with dry cloth. Then the weight of the specimens were taken and compared with the initial weight of the specimen to find the percentage of gain in weight due to the chloride attack. The results of GPCM were compared to the ordinary Portland cement concrete, which is presented in the Table 5.

Table 5. Chloride attack on GPCM and OPCC Specimens

Age in Days	% Gain in weight due to 3.5% NaCl	
	GPCM	OPCC
0	0	0
1	2.65	3
3	3.5	3.6
7	4	4.2
14	4.1	4.3
21	4.2	4.4
28	4.3	4.5
56	4.4	4.7

The GPCM and OPCC cube specimens were immersed in sodium chloride and were also tested for compressive strength at the end of 28 days and 56 days. The test results are presented in the Fig. 5.

The test results indicated that GPCM showed better resistance against chloride attack compared to OPCC specimens. This may be due to the better bonding of fly ash and alkaline solution compared to the possibility of voids in the ordinary Portland cement concrete. The corrosive action of chlorides is due to the formation of chloroaluminate hydrates, which causes softening of concrete. The mode of attack relies on salts and other corrosive substances, carried by moisture, being absorbed into the concrete via its pores and micro pores through capillary action. The strength loss due to chloride attack on GPCM was 10.78% in 28 days and 15.69% in 56 days. It was higher in the case of OPCC, which was 12.5% in 28 days and 36.25% in 56 days. Based on the above GPCM was considered to be superior to OPCC with respect to the chloride attack.

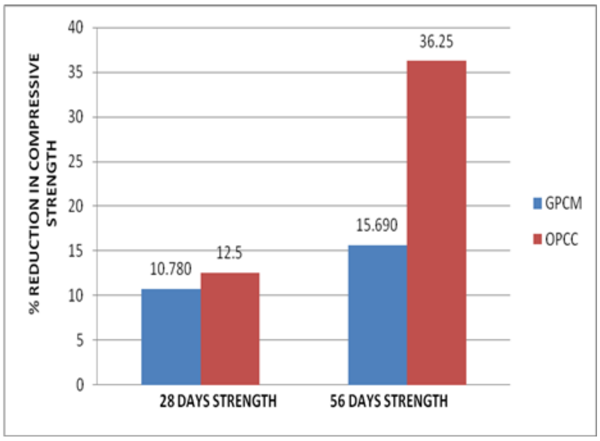

Fig. 5. Strength reduction due to NaCl attack on GPCM and OPCC

5.0 CONCLUSIONS

The experimental results revealed that the durability of GPCM was very good. For the OPCC, the acid penetrating into concrete reacted with calcium hydroxide of cement hydrated to produce gypsum and at that time the volume of solid substances increased largely, which ultimately reduced the durability of concrete. In the case of GPCM the erosion depth of concrete due to acid attack was smaller than that of plain concrete since the content of calcium hydroxide was small in fly ash. In OPCC, the mode of attack relies on salts and other corrosive substances, carried by moisture, being absorbed into the concrete via its pores and micro pores through capillary action. Based on the durability study, GPCM can be used in adverse atmospheric conditions also. GPCM can be an alternative material to the existing Ordinary Portland Cement Concrete. The GPCM can be effectively used in the prefabricated structures. Since no cement is used in the GPCM, lot of energy can be saved and pollution of atmosphere can also be reduced with reduction in the production of ordinary Portland cement. Since the fly ash can be used in an effective manner, no vacant land is required for just dumping the fly ash. As the fly ash and M-sand become the major component of GPCM environment degradation can be controlled. The use of waste materials like fly ash can add to pollution free environment.

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