VOL. 4, NO. 7, SEPTEMBER 2009 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


www.arpnjournals.com

EFFECT OF WATER ABSORPTION, POROSITY AND SORPTIVITY ON DURABILITY OF GEOPOLYMER MORTARS

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ABSTRACT

An experimental program was carried out to study the effect of water absorption, apparent porosity and sorptivity on durability of fly ash based geopolymer mortar specimens in sulphuric acid solution. Low calcium Class F fly ash was activated by a mixture of NaOH and Na_2SiO_3 containing 5% to 8% Na_2O with water to fly ash ratio of 0.33.The durability of geopolymer mortar specimens was evaluated on the basis of reduction in compressive strength when exposed in 10% Sulphuric acid solution for 24 weeks. Specimens containing lesser alkali were found to possess higher apparent porosity, water absorption and water sorptivity. After 24 weeks in sulphuric acid solution, specimens still had substantial residual compressive strength ranging from 29.4% to 54.8%. Specimens with higher water absorption, porosity and water sorptivity lost more strength than those with lesser corresponding values. Results obtained in the experimental program indicate that porosity, sorptivity and water absorption of geopolymer mortar specimens influences the durability of geopolymer mortars in sulphuric acid.

Keywords: geopolymer, water absorption, porosity, sorptivity, sulphuric acid, residual strength.

1. INTRODUCTION

Over the last few decades, there has been considerable research in the field of geopolymer composites in various parts of the world. Majority of them basically deals with manufacturing process of geopolymer binder and effects of various parameters on properties of green and hardened geopolymer composites. Interest on geopolymer composites is increasing due to the fact that its manufacture, unlike cement portland cements consume no energy and has no environmental effects. On the other hand, use of waste products like fly ash, blast furnace slag etc for manufacture of geopolymers has led to tremendous surge in research in this area.

The ordinary portland cement still continues to be the most commonly used binder in infrastructure construction. Reports of earlier study with regard to its resistance to chemical attacks such as acids and sulphates indicate poor performance and hence render it unsuitable in such adverse conditions. This has been attributed to high CaO content in ordinary portland cements which readily dissolve in acids and also form gypsum and ettringite when exposed to sulphates. In the past few decades, geopolymer binders have emerged as one of the possible alternative to OPC binders due to their reported high early strength and resistance against acid and sulphate attack apart from its environmental friendliness [5].

Fly ash based geopolymers have attracted more attention since the 1990s. As a novel binder, the performance of fly ash based geopolymers is promising; especially in some aggressive situations where Portland cement concretes are vulnerable [2]. Bakharev, Sanjayan and Chen [7] conducted durability tests on alkali activated slag and found that they perform better than ordinary portland cements. Since geopolymers relies on alumina-silicate rather than calcium silicate hydrate bonds for structural integrity, they have been reported as being acid resistant. Davidovits [4] reported that metakaoline based geopolymer has very low mass loss when immersed in 5% sulphuric acid solutions. Bakharev [8] studied the resistance of geopolymer materials prepared from fly ash against 5% sulphuric acid up to 5 months exposure and concluded that geopolymer materials have better resistance than ordinary cement counterparts. Song et al [2] performed an accelerated test using 10% sulphuric acid solution for 56 days and reported its good durability. Wallah and Rangan [6] have shown that geopolymer composites possesses excellent durability properties in a study conducted to evaluate the long term properties of fly ash based geopolymers. Mechanism of corrosion of geopolymer pastes in low and high concentrations of sulphuric acid were examined by Allahverdi and Skavara [3, 4]. The absence of standard methods to evaluate the performance of cements in acid environments has led to research in different exposure conditions and procedures by various authors making it difficult to correlate the results.

The present study was conducted to assess effects of water absorption, apparent porosity and sorptivity on durability of different fly ash based geopolymer mortars in sulphuric acid in an accelerated test condition. It comprised determination of initial water absorption, apparent porosity and sorptivity prior to exposure in acid media and residual compressive strength after 24 weeks exposure in 10% sulphuric acid solution.

2. MATERIALS AND METHODS

2.1 Materials

Low calcium Class F fly ash was sourced from Kolaghat Thermal Power Plant near Kolkata and it had chemical composition as listed in Table-1. 75% of

particles were smaller than 45 micron and Blaine specific surface was 380 m^2/kg. Laboratory grade Sodium hydroxide in pellet form (98 percent purity) and Sodium Silicate solution (Na_2O = 8%, SiO_2 = 26.5% and 65.5% water) with silicate modulus ~ 3.3 and a bulk density of 1410 kg/m^3 was supplied by LOBA CHEMIE Ltd. A mixture of Sodium hydroxide and Sodium silicate solution giving Na_2O in the activator mix as 5% to 8% of fly ash was used to activate the fly ash. The fine aggregate used in the geopolymer mortar was river sand having a specific gravity of 2.5 and fineness modulus of 2.65.

Table-1. Chemical composition of fly ash.

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_5	LOI*
56.01%	29.8%	3.58%	1.75%	2.36%	0.30%	0.73%	0.61%	Nil	0.44%	0.40%

2.2 Specimen preparation and test procedure

Sodium hydroxide pellets and Sodium silicate solution were mixed in required quantities so as to result in the desired Na_2O content of 5%, 6.5% and 8%. Sufficient water was added to give water to fly ash ratio in the activator solution as 0.33. Specimens had equal proportions of fly ash and sand. In a Hobart mixer, fly ash was first mixed with the activator solution for 5 minutes before sand was gradually introduced and further mixed for another 5 minutes. The geopolymer mortar mix was then transferred into 50 mm cube moulds and vibrated on a vibrating table for 2 minutes. Specimens were cured along with the moulds in an oven for a period of 48 hours at 85^{o}C and allowed to cool inside the oven before being removed to room temperature until tested. The manufacturing procedure followed was after Thakur and Ghosh [9].

To determine the water absorption of mortar specimens, three cubes from each series were oven dried at a temperature of 85^{o}C for 24 hours and its weight determined as initial weight. The samples were then immersed in water for 24 hours and its saturated surface dry weight was recorded as the final weight. Water absorption of specimens is reported as the percentage increase in weight. The temperature of 85^{o}C which is the curing temperature was selected for drying the specimens as higher temperature might cause disturbances in the microstructure of mortar specimens thereby resulting in incorrect values of water absorption. Another set of three samples were used for determination of apparent porosity. The following equation was used to find the apparent porosity.

Apparent porosity = $[(M_w-M_d)/ (M_w-M_s)]$ x100%

Where

M_w = weight of specimen after immersion in water for 48 hours

M_d = Weight of specimen after oven drying at 85^{o}C for 24 hours

M_s = weight of specimen suspended in water

Sorptivity test of specimen was conducted on specimens previously painted with waterproof enamel paint on all four sides such that only unidirectional uptake from the bottom is possible. A curve of cumulative mass gained per exposed surface area was drawn against square root of time and the slope of the linear portion was considered for determination of sorptivity.

The response of geopolymer mortars in sulphuric acid environment was studied by immersing the specimens in 10 % solution of sulphuric acid for a period of 24 weeks. The volume of acid solution was kept as four times the volume of specimens immersed and stirred every week and the solution was refreshed after 12 weeks. The effect of acid on the specimen was regularly monitored through compressive strength tests during exposure to the acid solution. A Digital compression testing machine was employed to determine the compressive strength of the specimen at regular intervals. The details of mortar specimens are given in Table-2.

Table-2. Details of geopolymer mortar specimens.

Sample ID	**Na_2O** (%)	**Water/fly ash**	**Curing temp. and duration**	**28day compressive strength** (Mpa)
GM1	5	0.33	85°C and 48 hrs	22
GM2	6.5	0.33	85°C and 48 hrs	37
GM3	8	0.33	85°C and 48 hrs	40

3. RESULTS AND DISCUSSIONS

3.1 Water absorption, apparent porosity, sorptivity and residual compressive strength

Results of water absorption, apparent porosity, sorptivity prior to exposure in sulphuric acid and residual compressive strength after 24 weeks immersion in sulphuric acid are presented in Table-3. Geopolymer mortar specimen GM3 manufactured with 8% Na_2O resulted in lesser values of water absorption, apparent porosity and sorptivity when compared to the ones produced with lesser % Na_2O as in the case of GM1 and

GM2 specimens. This may be attributed to the fact that higher alkali content in the mix gives better reactivity with the fly ash resulting in denser microstructure. GM1 specimen recorded 11.79% water absorption, 21.51% apparent porosity and 6.89×10^{-4} gm/mm^2/min$^{0.5}$ sorptivity whereas specimens of GM3 showed comparatively lower corresponding values of 6.42%, 12.54% and 3.0×10^{-4} respectively. Residual compressive strength after acid exposure was found maximum for GM3 specimen which contained 8% Na_2O.

Table-3. Water absorption, porosity, sorptivity and residual compressive strength.

Specimen ID	Water absorption (%)	Apparent porosity (%)	Water sorptivity (gm/mm^2/min$^{0.5}$)	Residual compressive strength (%)
GM1	11.79	21.51	6.89×10^{-4}	29.4
GM2	9.75	18.13	5.0×10^{-4}	42.9
GM3	6.42	12.54	3.0×10^{-4}	54.8

GM1 specimens retained lowest residual strength of 29.4% and GM3 specimens still maintained strength of 54.8%. The result shows that specimens with higher alkali content suffer lesser as compared to those containing lesser alkali.

3.2 Variation of residual compressive strength with Water absorption

Residual compressive strength of specimens decreases with increase in water absorption. Variation of residual compressive strength with water absorption is shown in Figure-1. GM1 specimen which recorded a residual strength of 29.4% corresponds to maximum water absorption (11.79%) among the three series. In contrast, GM3 specimen with 6.42% water absorption retained maximum residual compressive strength of 54.8%. A polynomial trend line for the relationship curve with corresponding equation gave a value of regression coefficient (R^2) of 1.

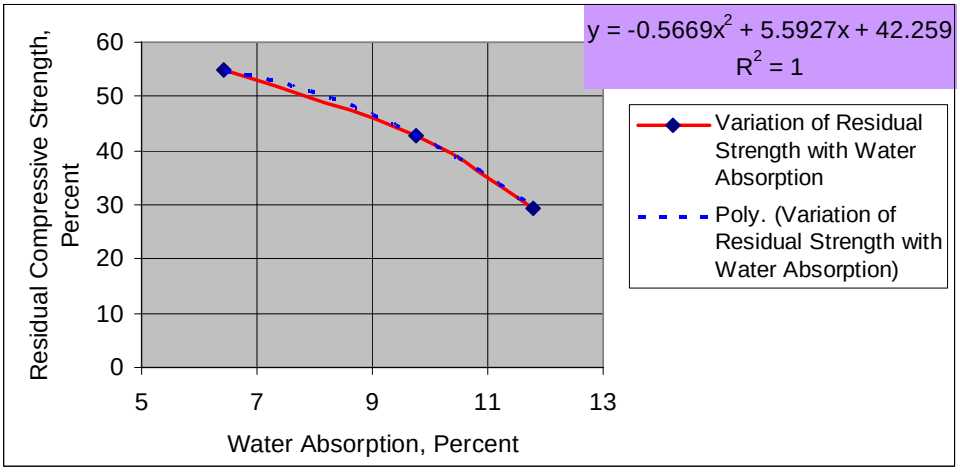

Figure-1. Relationship between residual compressive strength and water absorption.

3.3 Variation of residual compressive strength with apparent porosity

The variation of residual compressive strength with apparent porosity for different geopolymer mortar specimens after 24 weeks immersion in 10% sulphuric acid is shown in Figure-2. The relationship curve follows a similar pattern with the one representing relationship of residual compressive strength and water absorption. Specimen with minimum content of Na_2O (5%) yielded lowest residual strength and highest apparent porosity. On the contrary, GM3 specimens (8% Na_2O) showed minimum apparent porosity and maximum residual compressive strength. In the specimens with decreasing Na_2O content, residual strength after 24 weeks of exposure in sulfuric acid decreased. It could be attributed to the fact that specimen with higher porosity would allow more sulphuric acid solution to enter the geopolymer mortar specimen and hence causing greater damage. A polynomial trendline for the curve representing the relationship is shown which gave a regression coefficient of 1.

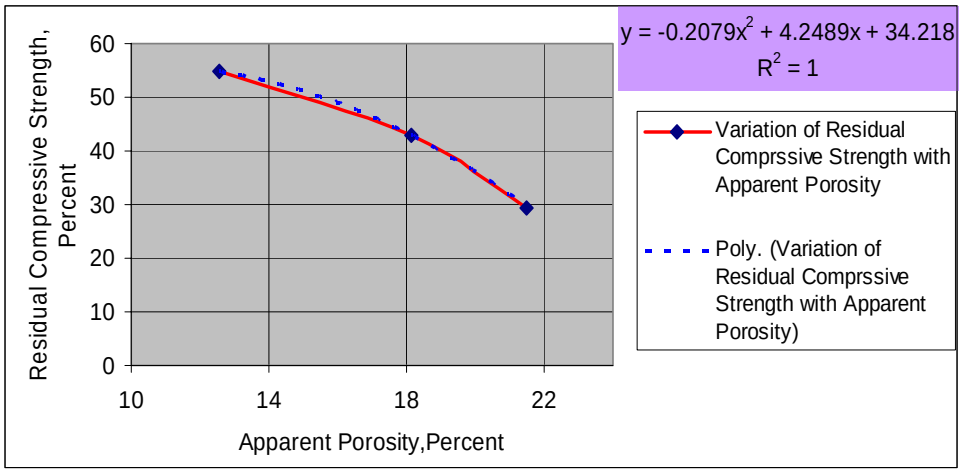

Figure-2. Relationship between residual compressive strength and porosity.

3.4 Variation of residual compressive strength with sorptivity

Relationship between residual compressive strength and water sorptivity for the specimens is shown in Figure-3. It follows a nearly straight line trend. As the water sorptivity of specimen increased from $3.0x10^{-4}$ (GM3) to $6.89x10^{-4}$ gm/mm^2/min$^{0.5}$ (GM1), the residual compressive strength reduced from 54.8 %(GM3) to 29.4 %(GM1). Earlier studies on cement concrete had shown that specimen with higher sorptivity recorded lesser durability. Some authors describe sorptivity as the measure of durability [10]. In the present study, it was noticed that specimen with higher sorptivity recorded lesser retention of compressive strength after 24 weeks immersion in sulphuric acid. A polynomial trendline drawn for the relationship showed a regression coefficient of 1 for the corresponding equation.

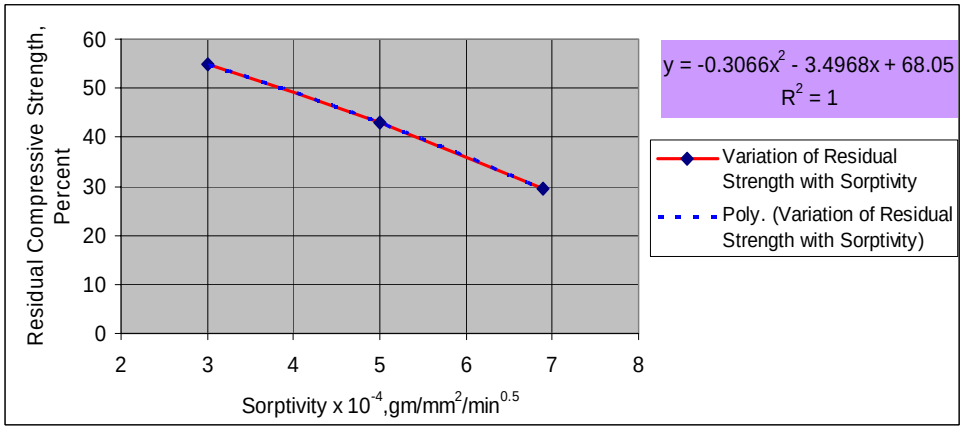

Figure-3. Relationship between residual compressive strength and sorptivity.

4. CONCLUSIONS

The following conclusions were drawn on the basis of results obtained during the experimental study:

- Geopolymer mortar specimens manufactured by activation with higher alkali content (%Na_2O) resulted in lower water absorption, apparent porosity and water sorptivity.
- Residual compressive strength after exposure in sulphuric acid had a direct relationship with alkali content. Specimens with higher alkali content recorded higher residual compressive strength.
- The relationship of residual compressive strength with water absorption, apparent porosity and water sorptivity of geopolymer mortar specimens showed similar trends; and
- Specimen with lower water absorption, porosity and sorptivity yielded higher residual compressive strength after 24 weeks exposure in sulphuric acid.

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