Geopolymer Damage due to Leaching when Exposed to Water

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ABSTRACT
An investigation on the effect of water immersion on the compressive strength of geopolymer pastes was investigated. Specimen's exposure to water showed a detrimental effect on the compressive strength of the geopolymer pastes (up to 25% strength loss). It was shown that the leaching of the sodium silicate when geopolymers were immersed in water decreases the compressive strength.

INTRODUCTION
Since the invention of geopolymers, there has been advances in the literature exploring the properties of geopolymer materials on a laboratory scale [1] which has provided confidence that geopolymers can offer similar if not superior performance to Ordinary Portland Cement (OPC). Whilst the durability of geopolymers exposed to various aggressive environments have shown excellent resistance to chemical attack by chlorine (including sea water), various acids, alkali and sulphate, [1-5], others have reported that the durability of geopolymers is hindered when exposed to magnesium sulphate and sulfuric acid solutions [6].
Another durability concern is the effect of water on geopolymers, especially in relation to efflorescence and leaching. Whilst the effects of the reactivity of raw materials, alkali metal type and reaction conditions on the intensity of efflorescence and leaching of geopolymers has been reported [7-12], the literature is either scant or silent in respect to the effect on mechanical strength of geopolymer exposed to water. The effect of leaching and efflorescence on the compressive strength of geopolymer when specimens were under dry, in water contact and submerged in water for a period of up to 28 days has been studied [12]. Results indicated submerged specimens experienced strength loss postulated to be due to leaching which contributes to the restriction of the geopolymer to develop strength due to late geopolymerization whilst water contact specimens experienced strength loss due to efflorescence. This suggests that geopolymers placed in humid conditions should be given attention due to the phenomenon's in play which can effect strength loss [12]. This is partially important given that geopolymers are being considered as a possible medium for the encapsulation of radioactive and hazardous waste [13, 14] and other applications that have direct contact with water, for example, sewer pipes, bridge pillars and water waste treatment facilities. Zhang et al. [12] sighted previous works Skvara et al. [15] who reported that geopolymer mortars immersed in water exhibited lower compressive strengths than those exposed to ambient conditions. It was postulated that the leaching of sodium through diffusion of the alkali cations was attributed to this strength reduction

Resistance to water is an important durability parameter for geopolymers that needs investigation. The results presented in this study aimed to investigate and explain the effect of water exposure to cured geopolymers and their effect on compressive strength. It should be noted that the water exposure damage reported here is only applicable to the particular mixtures used. Further work of the authors is underway to obtain geopolymer mixtures which are resistant to water exposure.

EXPERIMENTAL PROGRAM

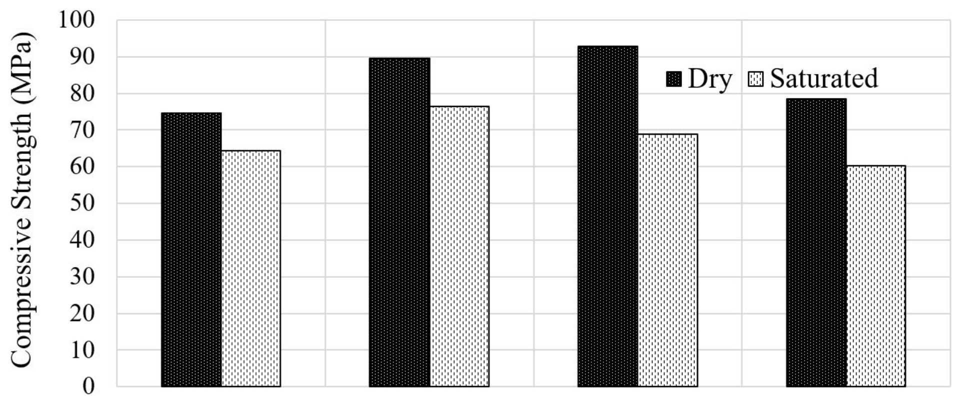
The aluminosilicate source for the geopolymer used in this study was fly ash sourced from Pozzolanic Gladstone in Queensland, Australia. Chemical composition for this fly ash has been studied by Kong and Sanjayan [16]. Alkaline activator used was a combination of sodium silicate, Na_2SiO_3 and sodium hydroxide, NaOH (molarity of 8.0M). Sodium silicate used in this experiment has a ratio of SiO_2/Na_2O of 2. Sodium hydroxide of 8.0M solution comprises 26.2% of NaOH solids and 73.8% of water [17].

All specimens had dimensions of 38 mm x 73 mm (diameter x height) and were cast in PVC moulds. The ratios of Na_2SiO_3/NaOH were 2.5, 1.75 and 1.0. Alkaline solution to fly ash ratio was kept constant at 0.4. Further specimens with 0.57 alkaline solution to fly ash ratio and 2.5 Na_2SiO_3/NaOH ratio were made to investigate the effect of saturation and dry conditions of high strength geopolymer. Ten specimens were made for each mix design, five each for the dry and saturated tests.

RESULTS AND DISCUSSION

The compressive strength results are based on five specimens from each mix apart from the Na_2SiO_3/NaOH = 1.0, Alkaline solution/fly ash = 0.4 mix which only had four specimens for the saturated state condition. In dry condition, specimens with 0.4 alkaline solution to fly ash ratio produced average compressive strength of 92.76 MPa, 89.62 MPa and 74.54 MPa for 2.5, 1.75 and 1.0 Na_2SiO_3/NaOH ratios respectively which is dependent upon the amount of Na_2O per total geopolymer mix (fly ash + alkaline solution).

Higher strength losses were recorded in higher Na_2SiO_3/NaOH ratios. These results demonstrated the trend that higher strength can be achieved by using a higher Na_2SiO_3/NaOH ratio. In saturated condition, the strengths of the specimens were less than the dry condition. The saturated strengths were 68.96 MPa, 76.46 MPa and 64.40 MPa for 2.5, 1.75 and 1.0 Na_2SiO_3/NaOH ratios respectively. These are 25.66%, 14.69 and 13.60% less than the dry strengths. Figure 1 and Table 1 shows the compressive strength of geopolymers in dry and saturated conditions and their water absorption characteristics are shown in Table 2.



Na_2SiO_3/NaOH Ratio	1	1.75	2.5	2.5
Alkaline solution/Fly Ash	0.4	0.4	0.4	0.57
Strength Reduction %	13.60	14.69	25.66	23.38

Figure 1. Compressive Strengths of Dry and Saturated Geopolymer Pastes

Table 1–Compressive Strengths of Geopolymer Pastes under Dry and Saturated Conditions

		Compressive Strengths (MPa)				
Alkaline solution/FA	Na_2SiO_3/NaOH	Average Dry	STDEV	Average Saturated	STDEV	% Loss
0.4	1	74.54	2.31	64.40	4.22	13.60
0.4	1.75	89.62	3.91	76.46	1.50	14.69
0.4	2.5	92.76	2.67	68.96	4.74	25.66
0.57	2.5	78.53	4.31	60.17	5.98	23.38

Table 2 – Average Saturated Weights and Absorption Percentages of Geopolymer Pastes under Dry and Saturated Conditions

		Average Weights (g)					
Alkaline solution/FA	Na_2SiO_3/ NaOH	Average Dry	STDEV	Average Saturated	STDEV	Absorbed (%)	STDEV
0.4	1	155.80	0.16	161.58	0.15	3.73	0.05
0.4	1.75	155.40	0.51	162.06	0.48	4.28	0.15
0.4	2.5	155.04	2.80	161.78	2.89	4.34	0.26
0.57	2.5	151.76	0.59	158.98	0.38	4.74	0.18

Similar strength reductions of geopolymers due to water immersion reported in literature are shown in Figure 2. The strength reduction of the results presented in this investigation are purely from the effect of leaching.

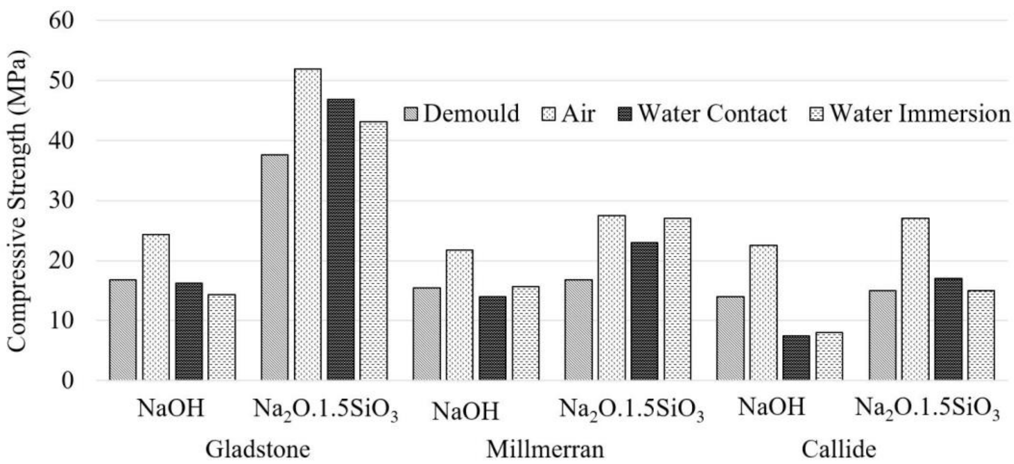


Figure 2. Compressive Strengths of Demolded Geopolymer Pastes followed by Air curing, Water Contact and Water Immersion Conditions. Modified from [12]

CONCLUSIONS

1. There is compressive strength reduction ranging from 13.60% to 25.66% for geopolymer immersed to water. Geopolymer specimens with 2.5 ratio of Na_2SiO_3/NaOH and 0.4 alkaline solution to fly ash ratio provides the highest average compressive strength of 92.76 MPa and the highest average strength reduction of 25.66%.
2. Geopolymer specimens with 1.0 ratio of Na_2SiO_3/NaOH and 0.4 alkaline solution to fly ash ratio provides the lowest average compressive strength of 74.54 MPa and the lowest average strength reduction of 13.60%.
3. Initial geopolymer strength is not the influencing factor in the strength reduction. This was proven by same strength but different Na_2SiO_3/NaOH specimens. The trend of increasing

Na_2SiO_3/NaOH with increasing strength reductions remained for the same strength specimens.

4. The strength reduction is caused by sodium silicate leaching out from specimens when immersed in water which caused strength damage. This conclusion was reached by eliminating strength as the cause of this and by measuring leached chemicals in the immersing water.
5. Strength reduction due to leaching during curing is an important consideration when developing geopolymer mixes. Some mixes seem more vulnerable to leaching than others and better understanding of this phenomenon will lead to better design of geopolymer mixes.

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