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Effect of Seasonal Weather on the Properties of Geopolymer Mortar

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Abstract

Despite proven to exhibit excellent mechanical properties, fresh geopolymer paste is highly viscous and displays low workability, which has become a major obstacle for it to be widely accepted for larger structural application. For cast-in-place applications, geopolymer concrete requires to be cured at ambient temperatures. Temperature and humidity varies in different seasons. The humidity variation has been found to have influence on the occurrence of white efflorescence on geopolymer samples. However, effects of temperature on efflorescence have received little attention, although temperature effects on strength are well-known. This paper will investigate the effect of a change in seasonal temperature on the properties of geopolymer mortars. The investigated properties include workability, compressive strength and efflorescence. Mini slump tests method will be carried out to determine the effect of adding extra water and commercially available superplasticisers (SP) on the flowability of geopolymer mortar. From the obtained test results, it was found that SIKA Visco Crete PC HRF – 2 has achieved the highest relative slump as compared to the reference mix RM8. Regarding strength development, it was observed those samples cured in hot (summer) conditions are more desirable to cure geopolymer mortar. Also, specimens cured under lower temperature curing conditions and low in humidity had formed white efflorescence after 7 days curing period, and rapid growth was observed over the period of 28 days curing cycle.

***Keywords**:* Fly-ash, Geopolymer mortar, Seasonal weather, Workability, Compressive strength.

1. INTRODUCTION

Among the heavy consumer of natural resources and emitter of carbon dioxide (CO_2) into the atmosphere, the cement industry is one of the leading culprit of anthropogenic climate change emissions. World-wide, the production of cement contributes at least 5-7% of CO_2 emission (Turner and Collins (2013) and Kajaste and Hurme (2016), whereas, in Australia, production of cement accounts for approximately 1.3% of CO_2 emission Williams, McLellan et al. (2011).Thus, to tackle the presented situation, one suitable solution is to utilise fly ash based geopolymer concrete (GPC) that has proved to totally replace the usage of cement in the concrete industry Nuruddin and Malkawi et al. (2016).

According to research conducted by Albitar and Visintin et al. (2015) confirms that GPC exhibits excellent compressive strength, suffers very low drying shrinkage, resistance to sulphate attack and good acid resistance. However, fresh geopolymer concrete is very cohesive and displays poor workability Jindal et al. (2017). Nonetheless, to improve the workability, research conducted by Nematollahi, Sanjayan et.al (20114) observed that the addition of superplasticizer had a positive effect and increased the flowability of the geopolymer paste. Due to high alkality, superplasticizer does not work in fresh geopolymers as effectively as in fresh cement pastes. One potential solution is to add superplasticizer with extra water to improve its performance. Furthermore, another issue that has been overlooked in the research community is the occurrence of white efflorescence, and its effect on the properties of GPC cured at lower ambient temperatures. Research conducted by Zhang, Yang et al.

(2016) revealed that sample cured at room temperature of 20±5°C exhibited rapid occurrence of white efflorescence when exposed to humid conditions and efflorescence had a negative impact on compressive strength. However, there is very limited information about the subsequent occurrence of efflorescence and its effect on GPC when subject to a lower temperature during winter season and effect of a rapid change in humidity. Therefore, the aim of this study is to investigate the effect of the change in seasonal weather (temperature and humidity) on the properties of geopolymer and occurrence of white efflorescence and its influences on the properties of geopolymer mortar. Also, to investigate the effect of adding extra water and commercially available superplasticisers has on the flowability of the GPC mortar.

2. EXPERIMENTAL PROGRAM

2.1. Dry components

2.1.1. Supplementary cementitous material

The primary binder used for geopolymer mortar for the purpose of this research is fly ash. Also, grounded blasted furnace slag (GBFS) was utilised as an additive for fly ash based GPC.
The fly ash used is a low calcium Class-F fly ash obtained from Coal Power Plant in Queensland, Australia. The grounded slag used is provided by Australian Builders. The binder ratio of 90% fly ash content and 10 % slag was used. The chemical composition of fly ash and slag is presented in Table 1.

Table 1. Chemical composition of Fly Ash and Slag.

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	MgO	K_2O	SO_3	LOI
Fly Ash	52.2	24.0	13.7	3.18	0.65	1.32	0.78	0.18	1.08
Slag	32.6	13.4	0.35	43.0	0.20	5.5	0.25	3.41	0.14

2.1.2. Fine aggregates

The aggregates used for geopolymer mortar consisted of fine aggregates. The fine aggregates are Nepean River sand and are used by the local construction industry to prepare conventional mortar. For geopolymer mortar design ratio of binder to fine aggregate was 2:1.

2.2. Liquid Components

2.2.1 Alkaline Solution

The alkaline solution used to activate the binder content is a combination of sodium hydroxide (NaOH) and sodium silicate solution (Na_2SiO_3). The ratio of sodium hydroxide solution to Sodium silicate solution by mass is taken to be 2.5. The sodium silicate solution used is commercially available D-grade with SiO_2 to Na2O ratio of 2.0, that is the solution was comprised of 55.9% of water and 44.1% of sodium silicate (Na2O =14.7% and SiO_2 = 29.4%). For the purpose of this research, various NaOH concentrations are used to prepare an alkaline solution which includes 8M, 10M, 12M and 14M.

2.2.2. Superplasticisers (SPs)

A total of five commercially available superplasticisers were used to improve the workability of geopolymer concrete. To determine the most optimum SPs for geopolymer mortar various types of brands were used. Details of different SPs is provided in Table 2.

2.3. Mixture Proportions

To study the flowability of geopolymer mortar numerous mix design were prepared to incorporate different alterations such as NaOH molarity, a various brand of SPs and different combination dosage of superplasticisers and extra water. One reference mix for different NaOH concentration was prepared without the presence of SP and extra water. In addition to that, a mix design that has achieved the best relative slump value will be selected for cylinder testing. Mixture proportions are given in Table 2 and 3 for mini slump test and cylinder test, respectively.

2.4. Preparation of test specimens

To prepare the mortar, alkaline solution was prepared 24 hours before mixing. The alkaline solution was added during mortar mixing using a unique 50:50 method. Firstly, the dry component was mixed thoroughly, and 50 percent of alkaline solution was added to the mixing bowl and mixed for one minute. Followed by 50 percent of SPs into the mix and mixed for another thirty seconds. Next, rest of the alkaline solution and SPs was poured into the mixing bowl and mixed for one minute. Extra water was added at last if required and mixed for another two minutes.

2.5. Experimental Tests

2.5.1. Mini Slump Test

For mini slump test, three different sets of test were carried out to examine the flowability of the geopolymer mortar. First sets were carried out to determine the best commercially available SPs. Second test were carried out to determine the effect of SPs with extra water. Finally, the third set of test was carried out to determine the effect of extra water on the flowability of the mortar without the presence of SP.

2.5.2. Curing conditions for Compression Test

To study the effect of the change in seasonal temperature and humidity on strength development of geopolymer paste various for curing environment was adopted. To simulate realistic data, a mean maximum for hot season and a mean mini temperature for cold season were chosen for this research. Based on 21 years of past records from Bureau of Meteorology (2017), weather data for Kingswood, Sydney was studied. It was found that the average cold (winter) temperatures were 10-11 degree Celsius and the hot (summer) temperature conditions were 25-26 degree Celsius. Furthermore, to develop a high humidity curing environment, a method employed by Zhang, Yang et al. (2016) was used, where test samples were wrapped in a thin plastic sheet, submerged under water and kept at their relative cold and hot weather curing conditions until the testing day. Thus, cylinder test sample was cured under these four curing conditions.

2.6. Testing of Specimens

Mini Slump test is also known as the spread-flow test were conducted to determine the flowability of geopolymer mortar Nematollahi, Sanjayan et.al (2017). A freshly mixed mortar was poured into the cylindrical mould (top diameter of 20 cm, a bottom diameter of 38 cm and a length of 55 cm) and tampered with tamper rod. The excessive mortar was removed from the top surface and mould was lifted vertically, allowing the mortar to flow outwards in a circular pattern as shown in Figure 1. Three specimens were poured per mix design, and four perpendicular diameters on the dried mortar spread were measured as shown in Figure 2. The relative slump was calculated by the following equation:

$$\mathrm{r_p} = \left(\frac{d}{d_o}\right)^2 - 1 \qquad (1)$$

Where, $\mathrm{r_p}$ = relative slump; d = average measured diameter; d_o = bottom diameter of the cylindrical cone.

The cylinders for compression test were prepared according to guidelines specified in standard RILEM 129-MHT (1995), where the specimen shall be cylindrical with length to diameter ratio between 3 and 4. Hence, the dimension of specimens is 30 mm diameter and 95 mm in length. Instron Universal testing machine with a 1000kN capacity was used to determine the compressive strength. The Compression test was performed in accordance with Australian Standard 1012.8.1:2014 (2006).

Figure 1. Fresh Mini Slump Test Sample.

Figure 2. Four Diameters on Dried Sample.

Table 2. Geopolymer Mix designs for Mini Slump Test.

Test Set No.	Test Objective	Mix ID	Mix Proportions (g)				NaOH (M)	SP (%)	Extra water (%)	Different SP Brands
			Fly Ash	Slag	Sand	Alkaline Solution				
Set 1	Most Effective SPs	RM8					8	0	0	N/A
		SPM1						6	0	MasterGlenium Sky 8100
		SPM2								Superplastet-F
		SPM3								MasterRheoBuild 1000
		SPM4								SIKA Visco Crete PC HRF-2
		SPM5								BASF HRL-0123
Set 2	The effect of SP and Extra water	RM10					10	0	0	N/A
		8M1					8	1	6	SIKA Visco Crete PC HRF-2
		8M2						4	6	
		8M3	270	30	150	135		3	3	
		10M1					10	1	6	
		10M2						2	9	
		10M3						1	10	
Set 3	The effect of extra water only	8EW-M1					8	0	1	N/A
		8EW-M2						0	3	
		8EW-M3						0	5	
		8EW-M4						0	6	
		8EW-M5						0	7	
		8EW-M6						0	10	

		10EW-M1					10	0	3	
		10EW-M2						0	6	
		10EW-M3						0	10	
		10EW-M4						0	11	
		10EW-M5						0	12	

Table 3. Mini Cylinder Test Specimens.

Mix ID	Mix Proportion (g)				NaOH (M)	SP and Extra water dosage (%)	Specimen Dimensions (mm)	Curing Temperature Environment
	Fly Ash	Slag	Sand	Alkaline Solution				
10M2-C	2000	220	1100	990	10	2:9	95 x 30	10-11 Celsius Degree (Cold)
10M2-CW								10-11 Celsius Degree Water Bath (High Humidity)
10M2-H								25-26 Celsius Degree (Hot)
10M2-HW								25-26 Celsius Degree Water Bath (High Humidity)

3. RESULT AND DISCUSSION

3.1. Mini Slump Test

3.1.1. Best Commercially Available Superplasticiser

To ensure consistency with all the five mixes, the dosage of SPs and concentration of NaOH in alkaline solution was kept constant. The result of the relative slump and percentage increase are presented in Figure 3. It was observed that all the SPs had a positive effect on the workability of geopolymer mortar since all the SPs had improved the flowability of mortar in comparison to reference mix RM8. Mix design SPM3 consists of SIKA Visco Crete PC HRF – 2 has achieved the highest relative slump diameter of 12.59 cm and 70 % increase in the relative slump as compared to reference mix. Therefore, SIKA Visco Crete PC HRF – 2 will be used for rest of the geopolymer mortar mix designs.

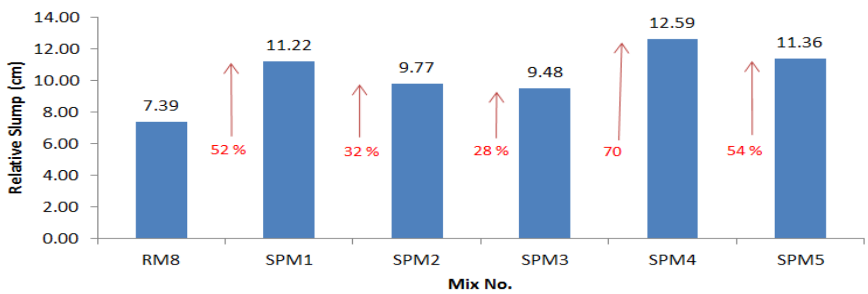

Figure 3. Relative Slump increase for most effective superplasticisers.

3.1.2. Effect of Superplasticisers and Extra Water combination on Workability

From the obtained test results, it was observed that specimens had experienced a reduction of flowability in geopolymer mortar when molarity of NaOH in alkaline solution was increased. Specimens with 12M alkaline solution had very low flowability and less setting time, therefore, the mortar dried within the mini cylindrical mould right after pouring the geopolymer mortar and no flowability was observed. Similarly, the test results for specimens with 14M alkaline solution had no flowability and zero setting time because the paste had dried with the mixing bowl.

However, the test results for alkaline solution comprised of 8M and 10M of NaOH observed good flowability in geopolymer mortar. As shown in Figure 4, mix deigns 8M2 comprised of SP and EW ratio of 4:6 has achieved 14.83 cm with 101% increase in the relative slump as compared to reference mix RM8. Furthermore, for specimens comprised of a 10M alkaline solution, mix design 10M2 with SP and EW ratio of 2:9 has achieved the highest relative slump of 17.97 cm with 113 % increase in the relative slump as compared to reference mix R10M. Overall, it was observed that increasing the dosage of SP while retaining constant water dosage yield less change in the relative slump as compare to increasing water dosage and retaining constant SP dosage.

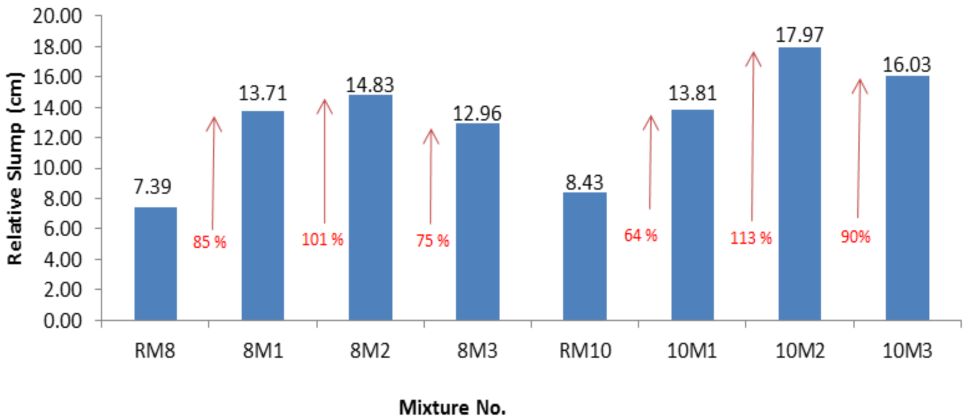

Figure 4. Relative slump increase for SP and Extra water.

3.1.3. Effect of Extra Water on Workability

The obtained test results revealed that in comparison to reference mix, the addition of extra water had a positive impact on the flowability. However, once an optimum level was achieved then increase of EW dosage had a negative impact. As seen in Figure 5, it can be observed that for 8M specimens mix design 8EW-M4 with 6 percent of extra water had achieved highest relative slump but increase in dosage of extra water had a reducing effect on the flowability. For instance, relative slump value achieved for 6% EW was 12.88 cm with 74 % increase from reference mix RM8. However, just by adding additional 1% of EW, the flowability was reduced to 31 %, that is a significant reduction of 58 %.

A similar pattern was observed for specimens comprised of a 10M alkaline solution. It was observed that upon achieving the optimum dosage of EW, there was a reduction in flowability, if higher EW dosage was added. From Figure 6, it can be seen that Mix design 10EW-M4 with 11 % of EW had the highest impact on flowability, however, by adding additional 1 % of EW, the flowability reduced. This behaviour of geopolymer mortar is new finding and has not been observed or reported previously. Furthermore, for 10M specimens, it was observed that 3 % and 6 % of EW had achieved the same relative slump value meaning having up to 6 % of EW had no significant change on the flowability and positive changes only occurred when a higher dosage of EW was added to the mix.

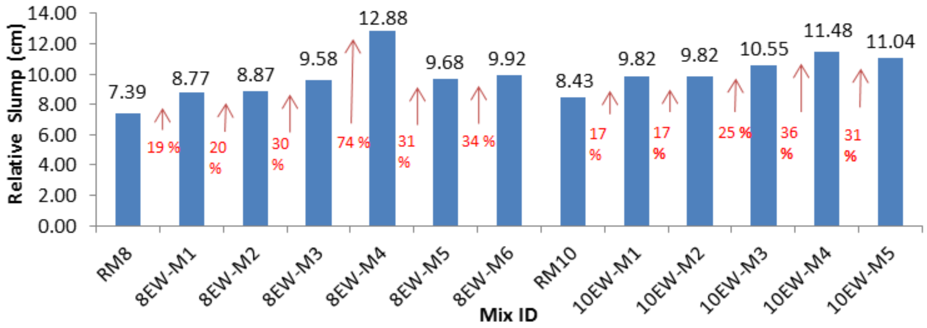

Figure 5. Relative slump increase for Extra water only.

3.2. Cylinder Compression Test

From the test results obtained, it was observed that different curing conditions based on seasonal weather changes had a great effect on the development of compressive strength and humidity also played an important role. Figure 6 illustrates the effect of temperature and humidity conditions on the strength development of geopolymer mortar. The results showed similar strength development pattern for various curing day. As expected geopolymer cylinder specimen (10M2-H) cured in for hot (summer) conditions with a temperature of 25-26 degree Celsius have developed relatively greater strength as compared to the cylinders specimens (10M2-C) cured in condition for cold (winter) temperature of 10-11 degrees Celsius. Over the curing period of 3, 7, 14, 21 and 28 days strength achieved by cylinder cured for cold weather condition was 5.4, 8.4, 12.8, 15.1 and 16.7 MPa, respectively. On the other hand, cylinders cured for hot weather conditions achieved 11.6, 22.8, 32.7, 37.6 and 40.4 MPa, respectively. Furthermore, in terms of the effect of high humidity on strength development of geopolymer mortar, it was observed that specimens cured under cold temperature had achieved the strength of 4.7, 6.6, 9.5, 10.0 and 14.6 MPa whereas for specimen cured under high humidity hot temperature had achieved strength of 9.6, 17.9, 27.2, 34.7 and 40.9 MPa. Overall, for both weather conditions, the compressive strength achieved by specimens kept under high humidity conditions was lower as compared to specimens cured in lower humidity curing conditions except for curing age of 28 days where mix 10M2-HW had achieved slightly higher strength as compare to mix 10M2-H. Nonetheless, it can be clearly seen that seasonal weather changes have a great effect on the strength development of geopolymer mortar where hot (summer) weather curing condition are more desirable as it has developed relatively high strength as compared to specimens cured under the cold (winter) weather curing conditions. Regarding strength development, it was observed that after 14 days of curing period the rate of strength increase was slower as compared to earlier curing days.

Another phenomenon that was observed for specimen (10M2-C) cured under the cold temperature at lower humidity is that cylinder specimens had formed white efflorescence after 7 days of curing period and at 28 days of curing age a larger surface area of the specimen was covered with white efflorescence as shown in Figure 7a and Figure 7b. However, specimen (10M2-CW) submerged under water did not show any occurrence of white efflorescence. Also, specimens (10M2-H and 10M2-HW) cured under hot temperature did not show any signs of efflorescence occurrence. This new finding certainly is unique since it is contrary to the findings observed by Zhang, Yang et al. (2017), where specimen submerged under water had shown efflorescence effect on the cylinder specimens and sample sealed in 25 degree Celsius exhibited a rapid development of efflorescence. Regarding strength development, the efflorescence had no impact on the compressive strength since there was no variation in strength development and a similar pattern of increase in strength was observed for all four mix specimens over the period of different curing age.

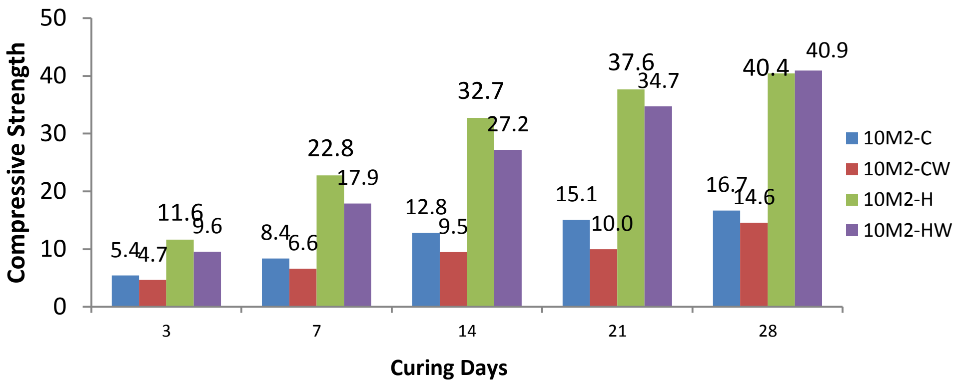

Figure 6. Mini Cylinder Compressive Strength Test Results.

(a) 7 days (b) 28 days

Figure 7. Formation of white efflorescence on specimens cured under cold conditions with low humidity.

4. CONCLUSION

Consequently, several finding from this research has provided more insight to the effect of seasonal weather on the behaviours and properties of geopolymer mortar. Finding includes: [1] SIKA Visco Crete PC HRF – 2 had the most positive effect on the flowability of geopolymer mortar out of all the other commercially available superplasticisers; [2] specimens consists of 12M and 14M alkaline solution had no flowability and zero setting time, hence the paste dried within the mixing bowl, no relative slump was observed; [3] increasing the dosage of SP, whilst retaining constant water dosage yield less change in relative slump as compare to increasing extra water dosage with constant SP dosage; [4] specimens with different morality of NaOH behaved differently and different optimum dosage of extra water had achieved highest relative slump; [5] once optimum dosage was achieved, the increasing of EW in geopolymer mortar did not increase the flowability and had negative effect as it reduced the relative slump; [6] specimens cured under cold weather conditions had formed white efflorescence after 7 days curing period, and it rapidly grows as curing age increases, however specimen submerged under water did not show any sign of efflorescence; [7] in terms of strength development, hot (summer) weather curing condition with lower humidity are more desirable as compared to cold (winter) weather curing conditions.

5. REFERENCE

Albitar, M, Visintin P, Mohamed Ali M & Drechsler M (2015). Assessing behaviour of fresh and hardened geopolymer concrete mixed with class-F fly ash, KSCE Journal of Civil Engineering, 19, no. 5, pp. 1445-55.

Bureau of Meteorology, Australia., viewed March 17 2017, < http://www.bom.gov.au/climate/data/index.shtml?bookmark=200 >

Jindal BB, Singhal D, et al, (2017). Improving compressive strength of low calcium fly ash geopolymer concrete with alccofine, Advance in concrete construction, 05, pp. 17-29.

Kajaste R, Hurme M (2016). Cement industry greenhouse gas emission – management options and abatement cost, Journal of Cleaner Production, 112, pp 4041-4052.

Nematollahi, B., Sanjayan, J., et al. (2014). Effect of superplasticizers on workability of fly ash based geopolymer, ResearchGate.

Nuruddin MF., Malkawi AB, et al(2016). Geopolymer concrete for structural use: Recent findings and limitations, International conference on Innovative research.

Standards Australia Online (2006), "Methods of testing concrete - Method for making and curing concrete - Compression and indirect tensile test specimens", AS 1012-2014, viewed 17 March 2017, SAI Global database.

Turner LK, Collins FG, (2013). Carbon dioxide equivalent (CO_2-e) emissions: a comparison between geopolymer and OPC cement concrete, Construction and Building Materials, 43, , pp 125-130.

Williams RP, McLellan BC, et al (2011). Costs and carbon emission for geopolymer pastes in comparison to ordinary portland cement, Journal of Cleaner Production, 19, pp 1080-1090.

Zhang, Z.H., Yang, T., et al., (2016). The effect of efflorescence on the mechanical properties of fly ash-based geopolymer binders, 23rd Australian Conference on the Mechanics of Structures and Material, Byron Bay, Australia, pp 107-112.

129-MHT, R., (1985). *Compressive strength for service and accident conditions.* Materials and Structures, 28(7): p. 410-414.