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Effect of Different Cure Conditions on the Shrinkage of Geopolymer Mortar

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ABSTRACT: *Geopolymer Mortar is a type of mortar manufactured without the addition of cement and, thus, offers specific benefits when compared to ordinary Portland cement (OPC) among which are the environmental advantages due to quite insignificant greenhouse gas emission in the process of production. We examine blended slag (GGBFS), glass powder (GP) and fly ash (FA) alkali activated mortars with steam-cure (SC) and water-cure (WC) techniques in terms of shrinkage. The results reveal that dry shrinkage strains in samples cured with water at 21 ° C appear far larger than in samples treated with steam-cure. In addition, Geopolymer shrinkage is reduced whereas the amount of fly ash elevates in the slag content of the mix.*

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I. INTRODUCTION

With the recent rapid increase in population the need for infrastructure development increased exponentially. This increased demand for new infrastructure is feeding the global demand for building materials like ordinary Portland cement (OPC) [1]. Ordinary Portland cement (OPC) has traditionally been used as the binder material in concrete, however OPC has high embodied energy, with carbon dioxide equivalent (CO2-e), the measure used to compare the emissions from various greenhouse gases based upon their global warming potential, ranging from 0.66 to 0.82 kg of CO_2 emitted for every kilogram manufactured [2]. The environmental impact of the Portland cement production (OPC) is estimated at 2 billion tons/year of CO_2 emissions, which corresponds to 8–10% of anthropogenic emissions in the world, and could reach 10–15% by 2020 [3,4].

Geopolymer, as a third generation cement, is an inorganic and eco-friendly material exhibit superior mechanical and durable performances compare to ordinary Portland cement (OPC)is regarded as an environmentally friendly substitute for Portland cement due to its very low carbon dioxide emission and low firing/ambient temperature [5,6]. Different kinds of aluminosilicate materials industrial, agricultural, and mining wastes, such as fly ash, ground granulated blast furnace slag, silica fume, and rice husk ash etc. can be utilized as precursors to prepare geopolymers [7, 8]. Alkali-activated fly ash and slag cement concrete are promising sustainable alternatives to ordinary portland cement concrete. The improved sustainability of alkali-activated concrete (AAC) is based on: (1) the beneficiation of industrial byproducts which would otherwise be landfilled, and (2) the reduction of carbon emissions associated with portland cement production [9].

Volume instability in hardened cement or concrete may occur due to carbonation, thermal effects, drying, or self-dessication. Drying and autogenous shrinkage both result from the removal of pore water from within the hardened binder. The former is due to the loss of internal water to the external environment through evaporation. The latter is due to self-dessication, i.e., the consumption of pore water by the continuing hydration reaction [10]. Alkali-activated binders have much higher shrinkage compared to cement-based mortars. This is because, unlike the Portland cement system, water does not incorporate directly in the production of aluminosilicate gel, and a small volume of water remains as interstitial water. As a result, there is a relatively large amount of water that is not chemically bound and therefore prone to evaporation. Contrary to common findings, Singh et al. found that the rate of shrinkage in their alkali-activated mortar was lower than that of OPC [11].

Shrinkage is an important engineering property of Portland cement (PC) concrete that can affect the cracking probability and thus durability of concrete by providing easy access of water and aggressive species into the interior of concrete. Shrinkage is for AAM based concrete and influenced by different factors, such as the chemical and physical properties of binder, the type and dosage of alkaline activator, and curing conditions [12,13].

II. MATERIAL AND METHODS

RilemCembureau Standard Sand was used in the preparation of the mortar. The particle size distribution of the standard sand is given in Table 2.1.

Table 2.1. The particle size distribution of the standard sand

Sieve Opening (mm)	*2.00*	*1.60*	*1.00*	*0.50*	*0.16*	*0.08*
Passing the Sieve (%)	0	9±2	33±2	67±2	87±2	98±2

Blast furnace slag (GBFS), fly ash (FA) and waste glass powder (GP) were used as binders in the mortar mixtures. The chemical and physical properties of the used binders are given in Table 2.2.

Table 2.2. Physical and chemical properties of the binders used in the geopolymer mortars

	GBFS	*FA*	*GP*
SiO_2	36.7	61.81	69.72
Al_2O_3	5.2	9.54	1.02
Fe_2O_3	0.98	7.01	0.45
CaO	32.61	1.77	8.84
MgO	10.12	2.56	3.45
SO_3	0.99	0.31	0.19
K_2O	0.76	0.99	0.13
Na_2O	0.42	2.43	0.22
Specific Weight	2.81	2.39	2.56
Blaine (cm2/g)	4250	6000	5320

Sodium hydroxide (SH) and sodium silicate (SS) were used for the activation of YFC, FA and GP. The SH was in granular form and had a purity of 97%. The SH was prepared to be 16M in laboratory environment. According to the manufacturer data, the specific gravity of the SS was 1.35; the SS consisted of 8.5% Na_2O, 28.5% SiO_2 and 65% H_2O. Pure water was used in the preparation of the alkaline solutions while potable tap water was used in the preparation of the mortars.

The GP was produced from waste window glass fractures as a result of different processes. Glass fractures were first brought to the fine aggregate size (0-2 mm) by the crusher and then pulverized by ball milling for 180 minutes. The ball mill was used for 180 minutes to increase the fineness value of the blaine of the FA.

The used SH was prepared 24 hours before the experiments. For the preparation of the SH, 640 grams of NaOH was used for 1 liter of water. In all mortar mixtures, water/binder (W/B) ratio was 0.33 while aggregate/binder ratio was 1.23. For activation of the mineral additives, the activation solution was used as 40% of the amount of the binder (GBFS + FA + GP) while the plasticiser was used as %0,6 of the amount of the binder. The amount of water in the mixtures was determined by taking into account the water content in the activation solution. As the mortars were self-settling, no compression process was applied. Since the consistency of the mortars and the flow diameters were fixed, the amount of chemical additives varied. In the preparation of fresh mortars, the process steps given in Figure 2.1 were taken into consideration. In the step 1, only the mineral additives were stirred with a speed of 140 rpm for 30 seconds. In step 2, after the alkaline solutions (SH and SS) were added to the binder, the mixture stirred at low speed. In step 3, low speed stirring and high speed (285 rpm) stirring were respectively performed for 30 seconds following the addition of standard sand into the paste. In step 4, the mixture stirred at low speed and high speed for 30 seconds, respectively following the addition of the plasticizer and water. Finally, the prepared geopolymer mortar mixture was placed in the shrinkage mold in step 5. The prepared mortar mixtures were placed in 25x25x285 mm shrinkage molds. The rates of mortar mixtures are given in Table 2.3. The amount of the materials used in the mortar mixtures are given in Table 2.4.

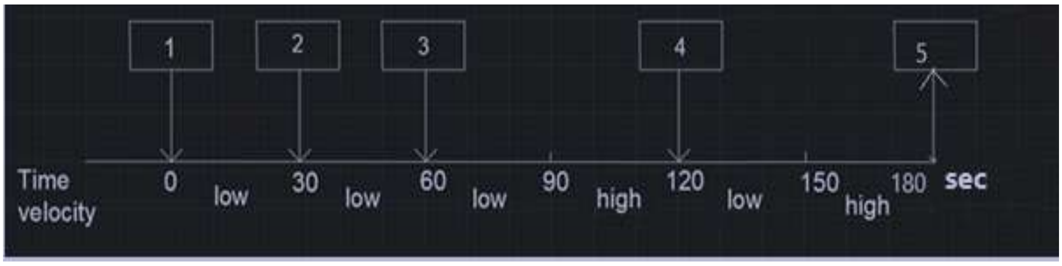

Figure 2.1. The process steps of the preparation of the mortar mixtures

Table 2.3. The mixing rates of the mortars

Mix No.	*GGBFS (%)*	*FA (%)*	*GP (%)*
S0	100	0	0
S1	90	5	5
S2	90	0	10
S3	90	10	0
S4	80	10	10
S5	70	15	15

Table 2.4. Mix design details (g)

W/B 0.33	Materials	The Amount of Materials (kg)					
		S0	S1	S2	S3	S4	S5
Liqued	SS	64.84	64.84	64.84	64.84	64.84	64.84
	SH	98.84	98.84	98.84	98.84	98.84	98.84
	Water	103.78	103.78	103.78	103.78	103.78	103.78
	Admixure	4.86	6.48	11.35	15.19	5.53	4.72
Solid	Aggregate	1000	1000	1000	1000	1000	1000
	GGBFS	810.5	729.45	729.45	729.45	648.40	567.35
	FA	0	40.53	0	81.05	81.05	121.58
	GP	0	40.53	81.05	0	81.05	121.58

The samples were kept in laboratory conditions for 12 hours; the molded hardened mortar samples were stored in two different cure conditions as water (WC) and steam (SC). In the steam cure, the samples were kept at 85 ° C in a closed container without contacting water for 12 hours (Figure 2.2). In the water cure, the molded mortar samples were kept in the cure tank with a temperature of 20 ± 2°C until the test day. Theshrinkage properties of the mortars were determined by a digital comparator on 3, 7, 14, 21, 28, 35, 42, 56, 90 and 180th days. The mortar samples which were prepared for shrinkage and the used digital comparator are shown in Figure 2.3.

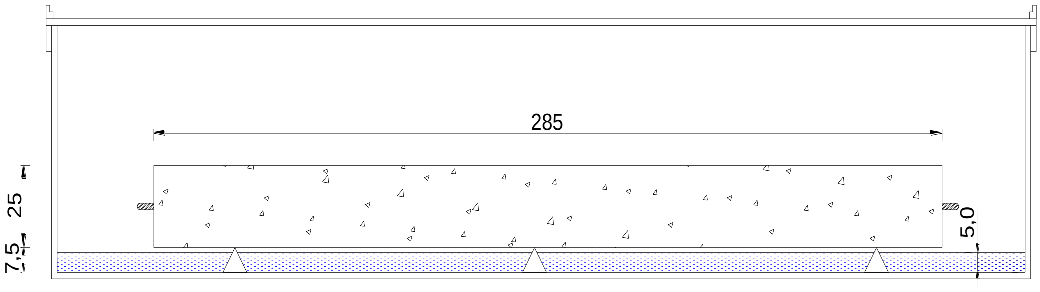

Figure 2.2. The steam cure method which was applied to the mortars

Figure 2.3. The mortar samples which were prepared for shrinkage and digital comparator

III. RESULTS AND DISCUSSION

Effect of Water Cure on Dry Shrinkage

The drying shrinkage properties of the water cure applied mortar samples are given in Figure 3.1.

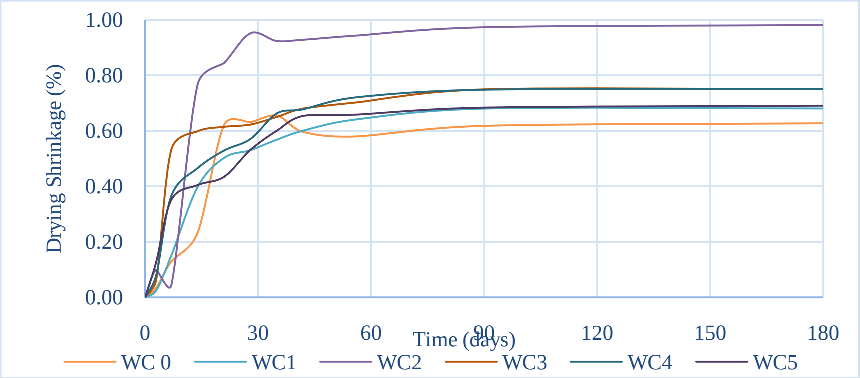

Fig. 3.1.Drying Shrinkage of WC Specimens.

As shown in Figure 3.1, a substantial drying shrinkage occurred until 42nd day. No significant change was observed in the length changes of the mortars from 42nd day. Especially, drying shrinkage was not observed in the mortars from 90th day. The highest drying shrinkage occurred in the WC2 specimen while the minimum drying shrinkage occurred in the WC0 sample. The WC0 sample contained 100% GBFS, however drying shrinkage values of the mortars increased with the use of FA and GP. In particular, 10% GP used in the WC2 sample caused a significant increase in shrinkage. The use of FA with GP provides a reduction in drying shrinkage. The WC3 and WC4 samples showed similar characteristics in terms of drying shrinkage. In the WC4 specimen, the rate of GBFS decreased; the rate of drying shrinkage decreased as a result of the use of 10% FA in spite of GP use. The combined use of GBFS, FA and GP is effective in the decreasing drying shrinkage.

Effect of Steam Cure on Drying Shrinkage

Figure 3.2 shows the drying shrinkage characteristics of the steam cure applied mortars.

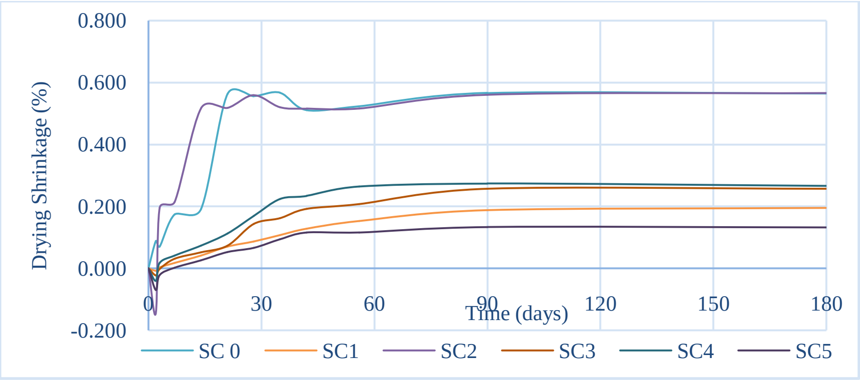

Figure 3.2.Drying Shrinkage of SC Specimens.

The steam cure applied mortars had similar characteristics with the water cure applied mortars. The drying shrinkage values increased until 42nd day while the shrinkage values were generally constant from 90th day. The most important feature that differs the steam cure from the water cure is lower drying shrinkage values. Especially, the WC2 sample having a shrinkage value of approximately 1% in water cure had a shrinkage value of approximately 0.58% in steam cure. One of the reasons for the low drying shrinkage of SC2 sample is the expansion reaction at early ages. In the 3-day period, the SC2 sample had an expansion of about 0.15%. This condition is thought to be caused by reactive SiO2 in the GP as a result of GP use with GBFS because the expansion reactions decrease in the mortar samples in which GP is used with FA. However, it is seen that the SC0 sample produced with 100% GBFS had a high shrinkage rate like SC2. The use of 15% FA and GP in steam cure notably reduced drying shrinkage.

IV. CONCLUSION

The important part of drying shrinkage in the mortars occurs until 42nd day. From the 90th day, drying shrinkage considerably decrease.

The drying shrinkage values of the two-component mixtures in which the GBFS and GP being used together are higher for both cure methods.

The shrinkage behavior is generally reduced by using FA. It is thought that GP increases drying shrinkage due to its chemical structure, but this is prevented by using FA.

The drying shrinkage of steam cure applied mortars is lower compared to water cure applied mortars because steam cure cause some expansion in the mortars at the beginning. It is thought that the expansion is caused by 10.12% MgO in the GBFS. Since steam cure accelerates chemical reactions, drying shrinkage is observed after the expansion reactions at the beginning.

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