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Research paper

A Study on Various Conditions of Alkali Activated Mortar Mixture for Rheological Behavior

Gun-cheol Lee1*, Dongyeop Han2, Gun-young Lee1, Soo-yeon Seo1, Seung-joe Yoon1

[1]Faculty of 1Department of Architectural Engineering, Korea National University of Transportation, Chungjusi, Korea
**Corresponding author E-mail: gclee@ut.ac.kr*
[2]Faculty of 1Department of Architectural Engineering, Gyeongsang National University, Jinjusi, Korea

Abstract

In this research, the influence of binder proportions and hardening agent conditions on fluidity of alkali activated mortar is evaluated quantitatively. According to the results, the influence of binder proportions on viscosity of alkali activated mortar was 0 to 24 Pa.s, while the influence of hardening agent on viscosity of alkali activated mortar was 0 to 52 Pa.s. Thus, in this research scope, the degree of influence on fluidity of alkali activate fiber reinforced composite can be suggested that the hardening agent proportion was higher than the binder proportion.

Keywords: *Alkali Activated, Mortar, Rheological behaviour, Consistency curve*

1. Introduction

Recently, based on the emphasized environmental issue such as global warming due to the carbon dioxide emission, in construction industry, the research regarding reducing carbon dioxide emission has been conducted continuously [1]. Especially, it is well known that the carbon dioxide emission from cement manufacturing process occupies about 8 % of the entire carbon dioxide emission in the world, and thus various research on reducing consuming cement powder is reported [2].
As a series of the research on reducing cement consuming, the effort of replacing cement powder with reactive inorganic binder from concrete is suggested and geopolymer suggested by Davidovits is a representative case[3]. An alkali activated mortar, an alumina silicate based inorganic polymer, is expected as an alternative material for cement in special applications with its features of high strength, and favorable chemical resistance which can be applicable to the coastal structures, or structures under the acid conditions[4], [5], [6], [7], [8] (Brough et al., 2002; Adam, 2009; Pacheco-Torgal et al., 2015; Choi, 2014; Yang et al., 2008).
However, the most research on geopolymer has been concentrated on improvement of mechanical properties, the research on improving workability for fresh state was not enough[9], [10].
Therefore, in this research, as the dominating factors on rheological properties of the alkali activated mortar, by controlling a binder proportion and a hardening agent proportion, the rheological properties of alkali activated mortar is evaluated quantitatively.

2. Experiment

2.1 Experimental Plan

As an experimental plan to evaluate the influence of binder and hardening agent conditions on rheological properties of alkali activated mortar is summarized in Table 1. In this research, the mixture was tested as a mortar phase, and the mortar mixture was designed to fix 0.55 of alkali activator-to-binder ratio (AA/B). For binder, blast furnace slag and fly ash was mixed with three different proportions of 100 to 0, 50 to 50, and 0 to 100. As a hardening agent, for 9 molar concentration of sodium hydroxide solution, sodium silicate solution was mixed and the proportions were five different proportions of 100 to 0, 70 to 30, 50 to 50, 30 to 70, and 0 to 100. To evaluate the fresh state mixtures' behaviors, rheological test was conducted.

Table 1: Experimental design

Experiment factor	Experiment level	
AA/B(%)	1	55
S/B(%)	1	40
Binder ratio(BS:FA)	3	100:0, 50:50, 0:100
Hardener mixture ratio (SH:SS)	5	100:0, 70:30, 50:50, 30:70, 0:100
Test conducted	3	1/2 slump flow Rheometer test
[Notes] BS : Blast Furnace Slag, FA: Fly Ash, AA/B : Alkali activated-to-binder ratio, S/B : Silica sand-to-binder ratio, SH : Sodium Hydroxide, SS : Sodium Silicate		

After the extension of the building, the gravity load on the beam located at the center of the second floor increased by 2.4 times to its capacity, and the load on the beam on the floor of the second core part increased by up to 2.6 times to its capacity due to the increase of the lateral force. The thick solid line in Figure 3 is the location of the member weakened by gravity load and lateral force. The location of the infilled walls was centered on this solid line, and the infilled wall installed in the staircase on both sides was designed to resist the lateral force, and the one installed in the direction of the shorter side of the building was to resist the gravity load.

Table 2: Mix propetions of alkali activated mortar

Hardener mixture ratio (SH:SS)	Binder ratio (BS:FA)	Unit weight(kg/m3)			
		AA	BS	FA	S
100:0, 70:30 50:50, 30:70 0:100	100:0	610	1 109	-	444
	50:50	575	522	522	418
	0:100	543	-	987	395

2.2 Materials

The physical and chemical materials used in this research are shown in Table 4 to 7. First, for the binder, blast furnace slag was obtained from "H" company in South Korea, and fly ash used was obtained from Boryung thermal power plant in South Korea. For hardening agent, sodium hydroxide and sodium silicate solutions were mixed and each solution was the general product available in South Korean market. As an aggregate of the mortar mixture, the silicate sand from Ulsan area in South Korea.

Table 3: Chemical composition and physical properties of the binding materials

Binder	Density (g/㎤)	Fineness (㎠/g)	Chemical composition(%)			
			SiO2	CaO	Al2O3	MgO
BS	2.90	4 182	29.8	34.9	12.9	4.3
FA	2.26	3 450	40.0	5.3	17.0	1.3

Table 4: Physical properties of silica sand

Density (g/㎤)	Oil absorption (g/100g)	Hardness (Mohs)	Median Particle Size(㎛)
2.6	28.0	7.0	2.2

Table 5: Physical properties of sodium hydroxide

Chemical formula	Density (g/cm3)	molecular weight	Solubility(water 100g)	
			0℃	100℃
NaOH	2.13	39.997	42g	347g

Table 6: Chemical composition of sodium silicate

Chemical formula	SiO2 (%)	Na2O (%)	Fe2O3 (%)	Water insoluble fraction
Na2SiO3	28～30	9～10	under 0.03	under 0.2%

2.3 Test Methods

As a test method of the research, the mixing of alkali activated mortar was followed the mixing protocol of KS L 5109. The 1/2 slump flow test to evaluate the fluidity of the mixtures was conducted as the KS L 2476 method and measured the spread distance. The 1/2 slump test are shown in Figure 1.

To measure the consistency of the mixtures, R/S Solids typed rheometer from Brookfield was used. The spindle used was 40 mm height and 20 mm depth of vane-shape spindle. The rheological parameters were calculated using consistency curve. The consistency curve was measured by applying shear rate within the range of 0.1 to 10 s-1 with hysteresis loop method, and the down curve was used to calculate the rheological parameters of plastic viscosity and yield stress. The rheometer and shape of the spindle are shown in Figure 2.

Figure 1: 1/2 sized slump test

(a) Measurement (b) Spindle

Figure 2: Rheometer test

3. Result and Discussions

3.1 Flow Property

The results of 1/2 slump flow depending on different combinations of binders and hardening agent is shown in Figure 3. First, as a result of alkali activated mortar, depending on the binder proportions, as the portion of blast furnace slag was increased the flow distance was decreased. In the case of BS100 of binder, with the hardening agents of SH70SS30, SH30SS70, and SS100, because of the quick setting, measuring flow distance was impossible. For the binder of FA100, measuring flow distance was possible for all hardening agent conditions and relatively high flow distances were measured. It is considered that the spherical shape of fly ash particles are acted as a ball bearing among the mixture.

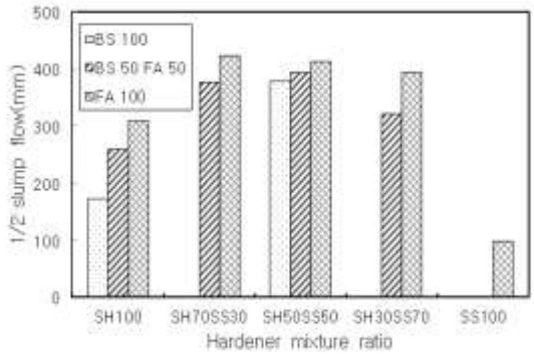
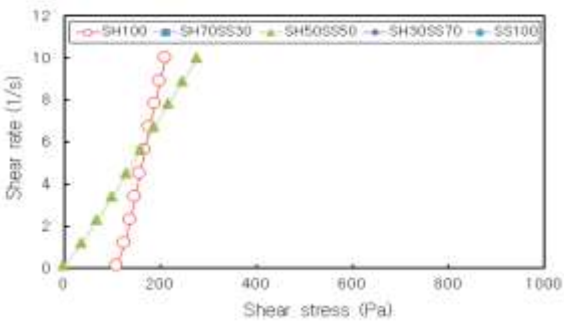
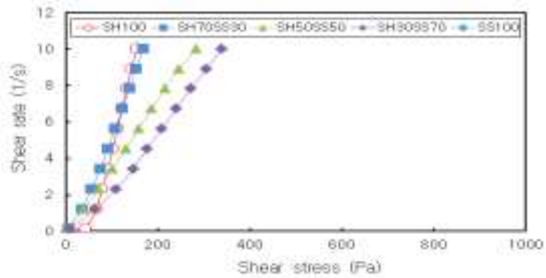


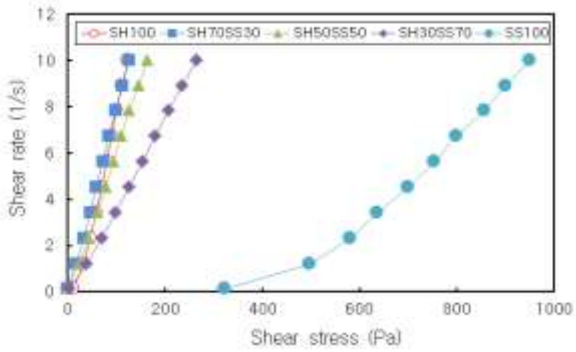
Figure 3: 1/2 slump test



(a) BS100



(b) BS50FA50



(c) FA100

Figure 4: Consistency curve of alkali-activated mortar

Depending on the hardening agent proportions, for the SS100 hardening agent of 100 % sodium silicate, quick setting of the mixture was shown when blast furnace slag was used, and when the hardening agent was SH100 of 100 % sodium hydroxide, the lowest flow distance was measured. In the case of mixed hardening agents, SH50SS50 of half and half of sodium hydroxide and sodium silicate showed the highest flow was shown.

3.2 Consistency Curve

The influence of proportions of binder and hardening agent on consistency curve of alkali activated mortar is shown in Figure 4. As shown in the figure, depending on the binder conditions, BS100 of 100 % of blast furnace slag binder, from 0 to 277 Pa range of shear stress was measured, and in this research scope, in the cases of SH70SS30, SH30SS70, and SS100, the mixture showed quick set and thus it was impossible to execute the test. For BS50FA50 of the mixture with 50 % blast furnace slag and 50 % of fly ash, with the hardening agent of SH100 and SH30SS70, the shear stress range from 0 to 388 Pa was shown. In the case of FA100 of the mixture with 100 % of fly ash, the shear stress was measured within the range of 0 to 264 Pa, thus it was lower than the binder conditions of BS50FA50 of 0 to 124 Pa of shear stress range. From the result, it is considered that as the portion of blast furnace slag in binder is increased, shear stress was increased.

Additionally, depending on the hardening agent, the SH100 hardening agent with 100 % of sodium hydroxide showed over 11 Pa of higher shear stress than other mixtures with different hardening agent at less than 2 s-1 of low shear rate range, while at over 8 s-1 of relatively higher shear rate range, the mixtures including sodium silicate showed higher shear stress and the shear stress was decreased with increasing portion of sodium silicate.

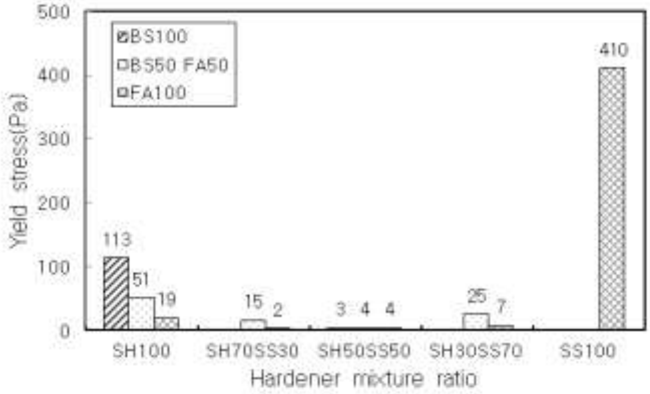
3.3 Rheological Parameters

Figure 5 shows surrender values, rheology integer that can be obtained if approximating the consistency curve calculated through the previous rheometer test to Bingham model. The yield stress of alkali activated mortar was from 2 to 410 Pa, and the highest yield stress was obtained by SH100 of 100 % of sodium silicate hardening agent. In the case of plastic viscosity, 10 to 57 Pa.s range of viscosity was obtained and the lowest plastic viscosity was obtained when SS100 of 100 % of sodium silicate hardening agent was used, and the viscosity was significantly decreased with increased portion of sodium silicate.

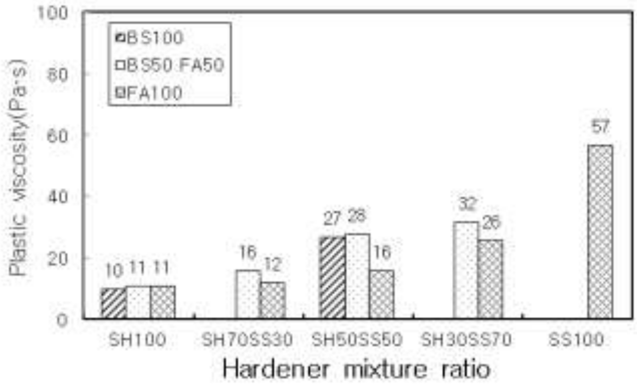
4. Conclusion

In this research, as a dominating factor on rheological properties of alkali activated mortar, the proportions of binder and hardening agent on rheological properties of fresh state alkali activated mortar was evaluated quantitatively. The conclusion can be summarized as follow:

(1) As a flow properties of alkali activated mortar depending on proportions of binder and hardening agent, as the portion of blast furnace slag was increased, the flow was decreased. For hardening agent conditions, when using the single element hardening agent of SS100 and SH100 showed the lowest flow.



(a) Yield stress



(b) Plastic viscosity

Figure 5: Rheology integer of alkali activate mortar

2) As a consistency trend, with increasing portion of sodium silicate in hardening agent, increased shear stress was shown and this tendency was emphasized with increased portion of blast furnace slag in binder.

3) The yield stress of alkali activated mortar was from 2 to 410 Pa, and the highest yield stress was obtained by SH100 of 100 % of sodium silicate hardening agent. In the case of plastic viscosity, 10 to 57 Pa.s range of viscosity was obtained and the lowest plastic viscosity was obtained when SS100 of 100 % of sodium silicate hardening agent was used, and the viscosity was significantly decreased with increased portion of sodium silicate.

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