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Effect of sodium silicate as activator on the fresh and hardened properties of cement-slag blended paste

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Abstract. Ground granulated blast-furnace slag (GGBS) is commonly used as partial cement replacement in concrete production. Although the use of GGBS has many advantages, it possesses a lower initial hydration rate that leads to lower early strength. Therefore, an attempt to use sodium silicate to activate the GGBS was carried out to promote the early strength of cement-GGBS blended paste. Based on experimental results, incorporation of 5 and 10% of sodium silicate slightly reduced the flowability and final setting time of blended paste. For hardened properties, the addition of sodium silicate reduced the strength at early age until 28 days. The modulus of elasticity of activated paste with sodium silicate was lower at early age, however at 28 days the result was comparable with the control specimen. The addition of sodium silicate decreased the ultrasonic pulse velocity (UPV) value at early age, however, at 28 days, 5% sodium silicate specimen had a higher UPV value than the control specimen. The different trend between UPV test and compressive strength test was suggested due to the inhomogeneous structure of activated blended paste that had a different mechanism during destructive test (compressive strength test) and non-destructive test (UPV test).

1. Introduction

Portland cement is one of the important components in concrete production. However, the production of cement generates carbon dioxide of 0.7 to 0.9 metric tons per metric ton of cement, it is around 5 percent of global greenhouse gas emissions [1]. One of few ways to reduce the carbon dioxide emissions from the cement production is to use some alternative raw materials that contain carbonates such as slag.

Ground granulated blast-furnace slag (GGBS) is obtained from the residue and solid waste from iron-steel metallurgic industry. GGBS has cementitious behavior (reacts with water) and pozzolanic behavior (reacts with calcium hydroxide, CH) [2]. Due to its nature that is latently hydraulic, it can be used more than 50% replacement of OPC. Not only reducing the carbon dioxide emission from cement production, but the utilization of GGBS in concrete also offers additional benefits in concrete performance, such as higher strength at later ages, and higher durability. The use of GGBS can also reduce the cost of concrete production and solve the industrial byproduct waste disposal problem [3].

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Although the use of GGBS has many advantages, it possesses a low initial hydration when mixed with water. The hydration of GGBS when mixed with OPC depends on the breakdown and dissolution of the glassy GGBS structure by hydroxyl ions released during cement hydration. GGBS reacts with CH from cement hydration to form addition calcium silicate hydrates (C-S-H). Due to its lower hydration rate, the use of slag causes the strength to be low at early age. To solve this problem, GGBS can be activated chemically by using alkaline activator to improve the early age strength. At moderate alkaline pH levels, GGBS is reactive, thus can be used with a greater range of activators in addition to the hydroxides and silicates [4]. A suitable alkaline activator combined with GGBS can develop high strength mechanical properties and improve the durability. Alkaline activator and pozzolanic materials as low-cost products can be considered to be used in the future to solve the present ecological problem [5]. This paper discusses the mechanical properties of cement-GGBS blended paste activated by sodium silicate.

2. Experimental program

2.1. Materials

Experimental study was carried out to find out the effects of sodium silicate as chemical activator on cement-GGBS blended paste. Type I Portland cement produced by Taiwan Cement Co. Ltd was used as the control specimen. GGBS Grade 120 in accordance to ASTM C989 was used as partial cement replacement. The physical and chemical properties of cement and GGBS are shown in table 1.

Sodium silicate type 3 from Fong Xiang Industrial, Co. Ltd was used as alkaline activator with SiO2 25.72 wt.%, Na2O 8.63 wt.%. The specific gravity and pH value of sodium silicate were 1.38 and 11.66, respectively.

Table 1. Physical and chemical compositions of cement and GGI	3S.
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	LOI	SiO ₂	Al_2O_3	Fe ₂ O ₃	CaO	MgO	SO ₃	Specific
	(wt.%)	(wt.%)	(wt.%)	(wt.%)	(wt.%)	(wt.%)	(wt.%)	gravity
Portland Cement	1.79	20.87	5.06	3.16	63.32	3.36	2.45	3.15
GGBS	0.25	33.39	14.39	0.19	41.08	7.22	0.11	2.88

2.2. Mixture proportions

The mixture proportion for different pastes is shown in table 2. GGBFS was used as partial replacement of cement in different amount: 0, 10, 30, and 50 wt.% of cement. The mixing water amount was chosen at water-to-binder ratio (w/b) 0.4. For alkali-activated paste with sodium silicate, the amount of GGBS was fixed at 50% replacement of cement, because at 28 days, the strength of paste incorporating 50% GGBS was equivalent with the strength of Portland cement paste. In this study, the amount of sodium silicate was 5 and 10 wt.% of mixing water.

	PC	GGBS	Water	Sodium silicate
Control	1394	0	558	0
G10	1249	139	555	0
G30	964	413	551	0
G50	683	683	546	0
SS5	683	683	519	27
	PC	GGBS	Water	Sodium silicate

Table 2. Paste mixture proportions (Units: kg/m^3).

SS10 683 683 492 55

2.3. Specimen preparation and testing methods

For control specimen and cement-GGBS blended specimens (G10, G30, and G50), all binders were mixed together before gradually adding the water. While for alkali-activated specimens (SS5 and SS10), all binders were mixed together, and chemical reagents sodium silicate were dissolved into mixing water and then gradually added to the mixing. All specimens were demoulded after 24 hours and were cured in curing chamber with controlled temperature of $25\pm3^{\circ}$ C with relative humidity of $75\pm10\%$.

Flowability test of paste was performed by adapting flow test from ASTM C1437 using flow table. Setting time test was conducted using Vicat needle based on ASTM C191 with *w/b* according to the mix design, which was fixed on 0.4. $50 \times 50 \times 50$ mm cubes were casted for compressive strength test based on ASTM C109. The dynamic modulus of elasticity of paste was tested by RFDA Basic (Resonant Frequency and Damping Analyzer) on $15 \times 50 \times 100$ mm prism. Ultrasonic pulse velocity (UPV) test was used to test the 100×200 mm cylinder specimens to monitor the quality of paste in accordance to ASTM C597.

3. Results and discussion

3.1. Flowability and setting time

The incorporation of GGBS did not give a significant effect to the flowability of blended paste due to the smooth and dense surface of GGBS. This comparable result had the same tendency as reported by Suresh and Nagaraju (2015) [6]. For the activated blended paste, the incorporation of sodium silicate led to the reduction of flowability for 8 and 17% reduction for SS5 and SS10, respectively, compared to that on the control specimen. This signifies the addition of activator affected the paste consistency compared with the effect by GGBS addition. It was suggested that the addition of sodium silicate led to the changes of physic-mechanical properties of paste and therefore increasing the viscosity of blended paste.

The addition of GGBS led to slightly higher initial setting time on cement-GGBS blended paste and prolonged the final setting time as shown in figure 2. The retardation of setting time was suggested due to the lower hydration rate of GGBS compared with cement hydration. While the addition of 5% and 10% of sodium silicate did not give any effect on the initial setting time and the initial setting time of activated blended pastes had a similar result with the control specimen. The addition of sodium silicate gave more influenced on the final setting time of blended paste. 5 and 10% sodium silicate reduced the final setting time for 11 and 2% of the final setting time of control specimen.



3.2. Compressive strength

The compressive strength of hardened paste was carried out at 3, 14, and 28 days. Figure 3 shows the results of compressive strength of all specimens. On the age of 3 days, the control specimen had the strength of 48.4 MPa, while the addition of GGBS led to the decrease of compressive strength. The addition of GGBS at early age increases the porosity and the size of pores because of its lower hydration rate that delay the reaction with CH to produce C-S-H [7]. The incorporation of sodium silicate however had a contrary effect from the early expectation and led to the higher decrease of compressive strength at the early age.

At 28 days, G50 had a slightly higher strength than the control specimen. This means, along with the increasing age, pozzolanic reaction of GGBS contributed on the strength development. For alkaliactivated blended paste, the addition of 5% sodium silicate led to 5% lower strength than the control specimen. 10% sodium silicate in blended paste led to the lowest strength of all specimens on 28 days, with the strength 37% lower than the strength of control specimen. The strength reduction due to the addition of sodium silicate might be due to the type of activator. The efficiency of the alkali activator is influenced by pH. Since the sodium silicate was used in this study had the pH value of 11.66, the pH 7th International Conference on Euro Asia Civil Engineering Forum

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was not high enough to produce an alkali environment. Sajedi and Razak (2010) also mentioned that sodium silicate as single type activator tended to reduce the strength. Therefore, it is suggested to combine the sodium silicate, with such as sodium hydroxide to increase the strength [8]. The internal reason for the strength reduction of alkali-activated blended paste linked to the reacted products between the activator and the binder. The sodium silicate might have affected the cement hydration, which formed a significant amount of CH and Na-substituted C-S-H, which was reported to have a lower strength than the C-S-H from pure cement hydration [9-11].

3.3. Dynamic modulus of elasticity

As shown in figure 4, at the age of 3 days, the incorporation of GGBS decreased the modulus of elasticity compared to that on the control specimen. With the increase of age, the modulus of elasticity of cement-GGBS blended specimens were similar or slightly lower compared to that on the control specimen. The results of modulus of elasticity of control specimen and cement-GGBS blended specimens were correlated with the compressive strength results.

Meanwhile, the addition of 5 and 10% of sodium silicate led to a slight increase of modulus of elasticity at the early age compared to that on G50 specimen. At the age of 28 days, the specimens with sodium silicate also had a similar or slightly higher modulus of elasticity compared to that on G50 specimen. The different tendency of modulus of elasticity of activated paste with the compressive strength was suggested due to the different mechanism of test. In this study, the dynamic modulus of elasticity was tested by non-destructive test (NDT) method by measuring the resonant frequencies and internal damping of specimens. While compressive strength was related to the growth and propagation of cracks, during the dynamic of elastic modulus test, the number of cracks in the paste remained limited [12].



Figure 3. Compressive strength of paste specimens.

3.4. Ultrasonic pulse velocity (UPV)

The result of ultrasonic pulse velocity (UPV) test is shown in figure 5. At early age, the incorporation of GGBS led to lower UPV results. With the increase of curing time, the utilization of GGBS, especially 50% GGBS, led to higher UPV result at 28 days. This result pointed out that partial replacement of cement with GGBS could improve the strength and quality of paste at later age.

For blended paste with sodium silicate, at the age of 3 days, the addition of 5 and 10% of sodium silicate gave a higher UPV results compare to that on G50 specimen. At the age of 28 days, the incorporation of 5% of sodium silicate gave the highest UPV value among all the specimens. The

different trend between UPV results and compressive strength of activated paste was suggested due to the inhomogeneous microstructure of the system that could transmit the frequency wave during UPV test, however, during the destructive test of compressive strength, this inhomogeneous structure led to the concentrated stress that caused the decrease of compressive strength [13].



Figure 4. Modulus of elasticity of paste specimens.

Figure 5. UPV result of paste specimens.

4. Conclusions

Based on the experimental results of the incorporation of sodium silicate on cement-GGBS blended paste, the following conclusions can be drawn.

- a) Increasing the amount of sodium silicate decreased the flowability of blended paste. The initial setting time of blended paste was not affected by the addition of sodium silicate. 5% sodium silicate led to the decrease of final setting time. However, increasing the amount of sodium silicate up to 10% did not give a significant effect on the final setting time. Uncertain trend of the addition of sodium silicate on setting time is suggested due to the changes physic-mechanical properties of blended paste.
- b) Compressive strength of blended paste incorporating sodium silicate had a lower value than the strength of control specimen at any age. It is suggested that the weak alkalinity of sodium silicate could not provide a good activation for blended paste and the reaction between cement and sodium silicate would form a significant amount of CH and Na-C-S-H that causes the reduction of strength.
- c) The addition of sodium silicate on blended paste tended to decrease the modulus of elasticity at early age. However, at 28 days, the modulus elasticity of activated paste was similar or slightly higher than that on the control specimen. The different tendency between modulus of elasticity results and compressive strength results might be due to the difference between nondestructive test and destructive test. Compressive strength is related to the propagation of cracks during the test, while the dynamic modulus of elasticity test uses a non-destructive test that the cracks in the specimens remained limited.
- d) UPV test was conducted to understand the quality of paste. The incorporation of sodium silicate decreased the UPV value compared to that on the control specimen at early age. However, at 28 days, the addition of 5% sodium silicate led to higher UPV value than the control specimen. The opposite tendency with the compressive strength is suggested due to the

inhomogeneous structure of the activated blended paste that could transmit the ultrasonic wave smoothly but decreases the strength during compressive strength test due to concentrated stress on the inhomogeneous structure.

References

- [1] Turner L K and Collins F G 2013 Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC cement concrete *Construction and Building Materials* **43** 125
- [2] Lee H-S and Wang X-Y 2016 Evaluation of compressive strength development and carbonation depth of high volume slag-blended concrete *Construction and Building Materials* **124** 45
- [3] Schneider M, Romer M, Tschudin M and Bolio H 2011 Sustainable cement production present and future *Cement and Concrete Research* **41** 642
- [4] Mangat P, Lambert P 2016 Sustainability of alkali-activated cementitious materials and geopolymers in *Sustainability of Construction Materials* 459
- [5] Kirzan D, Zivanovic B 2002 Effects of dosage and modulus of water glass on early hydration of alkali-slag cements *Cement and Concrete Research* 32(8) 1181
- [6] Suresh D, Nagaraju K 2015 Ground granulated blast slag (GGBS) in concrete a review *IOSR* Journal of Mechanical and Civil Engineering **12**(4) 76
- [7] Cyr M 2013 Influence of supplementary cementitious materials (SCMs) on concrete durability in *Eco-efficient concrete*: Woodhead Publishing Ltd 153
- [8] Sajedi F, Razak H A 2010 The effect of chemical activators on early strength of ordinary Portland cement-slag mortar *Construction and Building Materials* **24** 1944
- [9] Alexander K, Davis C 1960 Effect of alkali on the strength of Portland cement paste *Australian* J. of Applied Science **11** 146
- [10] Bakharev T, Sanjayan J G and Cheng Y-B 1999 Alkali activation of Australian slag cements *Cement and Concrete Research* 29 113
- [11] Way S and Shayan A 1989 Early yhydratio of a portland cement in water and sodium hydroxide solutions: composition of solutions and nature of solid phases Cement and Concrete Research 19 759
- [12] Smaoui N, Berube M A, Fournier B, Bissonnette B and Durand B 2005 Effects of alkali addition on the mechanical properties and durability of concrete *Cement and Concrete Research* 35 203
- [13] Djayaprabha H S, Chang T-P, Chen J-Y and Chen C-T 2017 Mechanical properties and microstructural analysis of slag based cementitious binder with calcined dolomite as an activator *Construction and Building Materials* 150 345