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# Effect of modulus and dosage of waterglass on early age shrinkage of sodium silicate activated slag paste

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ABSTRACT: In recent years, alkali-activated slag (AAS) as an alternative low-carbon emission and high strength cementitious material has received increased attention. However, high shrinkage and crack tendency of AAS limit its wider industrial applications. Although considerable researches have already been carried out on Portland cement (PC) based systems, the information and understanding on the early age shrinkage of AAS is still limited. On the other hand, early age shrinkage occurs mainly due to a high rate of water evaporation from the surface of fresh concrete. Therefore, this study seeks to explore the potential of two sodium silicate activated slag mixtures variables, namely, waterglass moduli and activator content, on moisture loss and early age shrinkage properties of AAS. A control AAS mix was formulated with water glass (silica modulus of 1.5) as an activator at the dosage of 4% ($Na_2O$ equivalent) by mass of slag and fixed water-binder ratio (w/b) of 0.4. Two mixtures with modulus of 0.75 and activator dosage of 6% were compared in this study. The most significant findings to emerge from this study is that, AAS paste with moduli of 0.75 and activator content of 4% showed lower amount of early age shrinkage. However, further study still needs to be carried out in order to establish a better understanding of the current results.
Keywords: Alkali-activated slag, Early age shrinkage, Cement Paste, Sodium Silicate, Evaporation.

## INTRODUCTION

It is widely reported that the production of portland cement (PC) contributes significant volume of $CO_2$ to the atmosphere [1]. However, PC is still the primary binder in concrete industry incur a research for more environmentally friendly cementitious materials.

Alkali-activated binder is an alternative to PC using industrial by-products containing silicate materials. The most common by-product used as binder materials is ground granulated blast furnace slag (GGBS). GGBS has been used as a cement replacement material due to its latent hydraulic properties [2]. GGBS can also react directly with water, but requires an alkali activator. Activation with sodium silicate (waterglass) has been widely known to give rise to rapid hardening and high compressive strengths [3].

Use of alkali activated slag (AAS) has several superior advantages in terms of cost and performance. However, it has higher shrinkage and cracking tendency than Portland cement concrete that prohibit its wider industrial applications. Shrinkage of AAS pastes can be 1.6 to 2.1 times greater than Portland cement (PC) [4, 5]. Under rapid drying and hot weather conditions, early age shrinkage cracks may appear in an early period ranging from placement to 24 h [6]. Such types of cracks may not endanger the present serviceability of the concrete structure but can significantly affect its durability [7]. Activation with liquid sodium silicate (waterglass) has been widely known to give rise to rapid hardening and high compressive strengths [3]. Many parameters may cause higher early age shrinkage of the AAS than that of PC. This study reports an experimental investigation on effect of the Modulus of waterglass and $Na_2O$ content for different sodium silicate activated slag pastes.

## EXPERIMENTAL PROGRAMME

### Materials and mix proportions

AAS paste samples manufactured with waterglass activated ground granulated blast furnace slag (GGBS. A control AAS mix was formulated with water glass (silica modulus of 1.5) as an activator at the dosage of 4% ($Na_2O$ equivalent) by mass of slag and fixed water-binder ratio (w/b) of 0.4. A total of three AAS mixtures were formulated with two moduli of sodium silicate (0.75, 1.5 - i.e. molar ratio between $SiO_2$ and $Na_2O$) and two alkali concentrations (4%, 6% - $Na_2O$% equivalent by the mass of slag).

### Experimental Method

The drying setup for the early age shrinkage test under a low pressure condition is shown in Figure 3. This test method can vary the relative humidity (RH) at any range of ambient temperatures. The specimen consisted of two elements: 1) a plastic mould with an inner size of $70 \times 70 \times 70$ mm3; and 2) an envelope, formed by two PVC plates (called reflecting plates) attached to a plastic sheet, to assist measuring horizontal shrinkage. Pastes of PC and AAS were cast into this envelope and positioned inside the mould. The friction between the mould and the envelope was minimized by using oil. In this way, when the specimen shrinks, the reflecting plates can be dragged along by the cement paste. The shrinkage of the paste was continuously monitored every 1 min by two laser sensors located at 45mm from the bottom. To simultaneously monitor the evaporation, the entire assembly was positioned on a digital scale inside a glass desiccator as shown in Figure 2. Using this digital scale, the weight of the sample was continuously monitored throughout the whole drying cycle. By employing a vacuum pump and a pressure regulator, the air pressure inside the desiccator was lowered to around 1700 Pa (0.5 in Hg) and controlled at this level throughout the test.

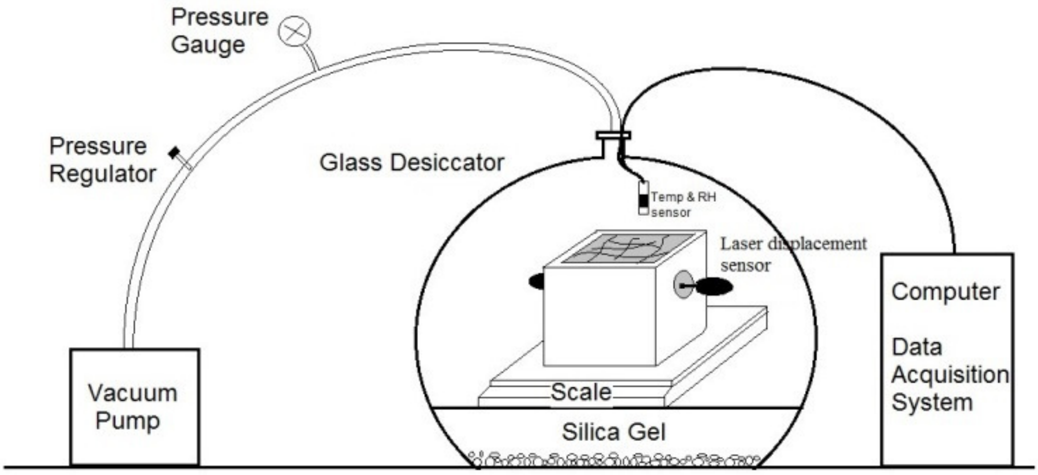



**Figure 3**- *Schematic of drying setup*

## RESULTS AND DISCUSSIONS

### Effect of $Na_2O$ content

Yang, Song [8] studied the shrinkage strain of the AAS mortar and showed it was nearly independent on the type of source materials and $Na_2O$ to source material ratio. However, Wang, Scrivener [3] mentioned that higher shrinkage strain in GGBS concrete activated by water glass due to the formation of silica gel during hydration and higher $Na_2O$ content. Hence, the influence of $Na_2O$ content on the early age shrinkage of waterglass activated paste is still controversy. Therefore, in this study, the waterglass as alkaline activator in AAS pastes was incorporated at a concentration of activation of 4% and 6% $Na_2O$ (i.e. 4% and 6% $Na_2O$ per 100g slag). Figure 4 indicate the moisture loss and shrinkage for different binder content in AAS. More alike concentration causes lower plastic viscosity and higher heat peak, therefore the evaporation rate increases. The reduction of binder content from 6% to 4% cause about 12% decrease in evaporation rate. However, influence of decreasing $Na_2O$ content is significant in early age shrinkage that content cause 15% reduction in shrinkage of AAS.

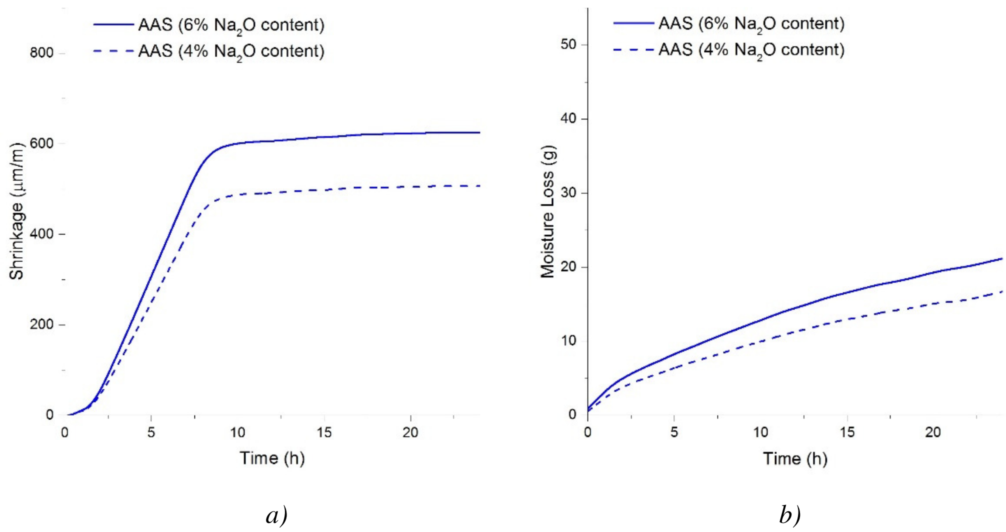
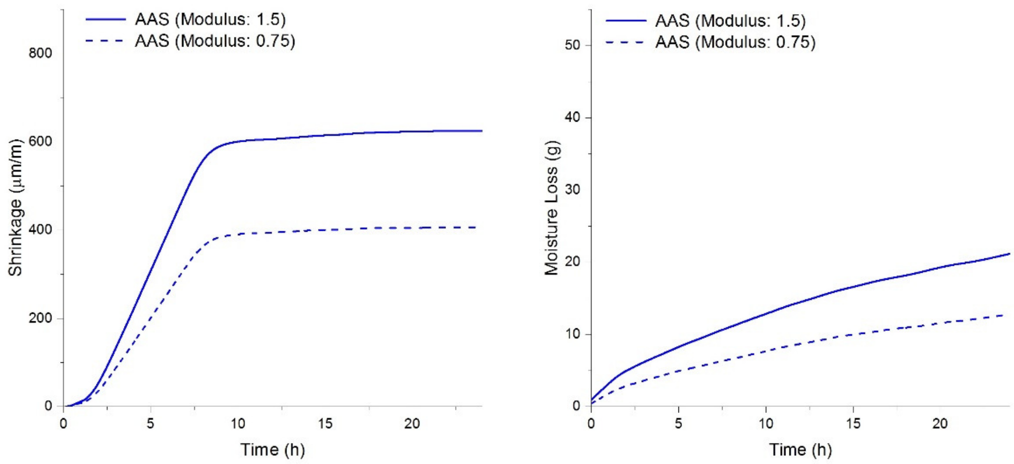



**Figure 4 -** *Effect of $Na_2O$ content on a) Shrinkage b) Moisture loss*

**Effect of Modulus of waterglass**

The effect of waterglass modulus is very similar to alkali content changes in AAS activator characteristics. Figure 5 show cumulative shrinkage and moisture loss for two different activator modulus of 0.75 and 1.5. Higher initial evaporation rate of sample with modulus of 1.5 is because of higher plastic viscosity and surface tension. The moisture loss in mixture with modulus of 1.5 is 16% higher than sample with 0.75 activator modulus. In addition, the reduction of modulus from 1.5% to 0.75% cause about 37% decrease in early age shrinkage. Therefore, activator modulus is an important parameter in shrinkage of AAS.

Some authors reported that alkali-activated slag concretes based on waterglass often undergo greater drying shrinkage due to formation of silica or silica-rich gel during hydration [9, 10]. Waterglass with a high n modulus has higher mass ratio of silica. A silica gel has a high water content and begins to shrink, expelling water from the mass. The shrinkage begins with this syneresis process, when free liquid enmeshed in the gel is spontaneously expelled. Syneresis comes to an end when the water content of the gel is still high, about 90%. On further drying, the structure of the gel continues to shrink and number of particle-to-particle bonds in the structure gradually break.




*a)* *b)*

**Figure 5 -** *Effect of modulus of waterglass on a) shrinkage b) Moisture loss*

## CONCLUSIONS

The moisture loss and early age shrinkage results can be used to differentiate characteristics of different cement pastes to obtain optimum mix design with minimal shrinkage. Parameters including water glass modulus and $Na_2O$ content have significant effects on shrinkage results of sodium silicate activated slag. The most significant findings to emerge from this study is that, AAS paste with moduli of 0.75 and activator content of 4% showed lower amount of early age shrinkage. However, further study still needs to be carried out in order to establish a better understanding of the current results.

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