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Effect of Sodium Silicate Content on Setting Time and Mechanical Properties of Multi Blend Geopolymer Mortars

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Abstract: The incorporation of industrial waste in geopolymer concrete opens new era in the construction industry because of the positive environmental impact. In this study, the effect of using sodium silicate as an activator on some fresh and hardened properties of geopolymer mortar naming, setting time, workability, density, water absorption, compressive strength, tensile strength and flexural strength were investigated. Industrial waste materials including glass powder, low calcium fly ash, granulated blast furnace slag and ceramic powder were used to prepare specimens of the geopolymer mortars. Results showed that the workability, represented by flow test and water absorption of the geopolymer mortars decreased as the content of the activator (sodium silicate) increased. Both initial and final setting time of the geopolymer mortars were found to be decreased as a response of increasing the content of the activator up to a certain content of the activator. Compressive, tensile and flexural strengths significantly increased as a result of increasing the sodium silicate.

Key words: Geopolymer mortar, sodium silicate, workability, compressive strength, flexural strength, water absorption

INTRODUCTION

Construction industry consumes about 30-40% of maim energy in the world. Cement industry is the major source of CO_2 emission. Hence, different alternatives to conventional concrete are being proposed by researchers to achieve sustainable constructions (Gupta *et al*., 2016). Geopolymer concretes have emerged as novel engineering materials with the potential to become a substantial element in an environmentally sustainable construction and building products industry (Duxson *et al*., 2007; Mo *et al*., 2016; Ng *et al*., 2012; Provis and Van Deventer, 2009; Sagoe-Crentsil, 2009; Yang *et al*., 2015). Geopolymer concrete is the result of the reaction of materials containing aluminosilicate with alkalis to produce an inorganic polymer binder. Industrial waste materials such as fly ash and blast furnace slag are commonly used as the source of aluminosilicate for the manufacture of geopolymer concrete due to the low cost and wide availability of these materials. With efficient use of other industrial by products, geopolymer binder can reduce embodied Carbon dioxide (CO_2) by up to 80%, compared to Ordinary Portland Cement (OPC) (Castel and Foster, 2015).

Alkali-activation is a technology that opens new paths for expanded use of several byproducts already, traditionally, used as mineral additives to cement such as ground Granulated Blast Furnace Slag (GBFS) from steel mills that use a blast furnace to produce pig iron (Deja, 2003; Fernandez-Jimenez *et al*., 1999; John, 1995; Puertas and Fernandez-Jimenez, 2003) and Fly Ash (FA) from coal-fired power plants (Fernandez-Jimenez *et al*., 2005; Katz, 1998; Skvara *et al*., 2003; Sofi *et al*., 2007). The degree of dissolution of aluminosilicates in high pH alkaline solutions is largely depend on the particle size, morphology and composition of the source material (Bakharev, 2006; Chen-Tan *et al*., 2009; Fernandez-Jimenez *et al*., 2005; Gordon *et al*., 2005; Jaarsveld *et al*., 2003) in particular the amorphous aluminosilicates.

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Most of the reports acknowledged that alkaline activator is a mixture of sodium hydroxide (NaOH) in flakes of 98% purity and sodium silicate (Na_2SiO_3). Usually, a sodium silicate solution is characterized by its SiO_2/Na_2O weight ratio in the range of 2-3.75 where a value >2.85 signifies a neutral solution (Pacheco-Torgal *et al*., 2008). A few researchers used commercial potassium silicate solution with 15.8 wt.% K_2O, 24.2 wt.% SiO_2 and 60 wt.% H_2O (SiO_2/K_2O molar ratio is 2.4), potassium hydroxide flakes with 85% purity and tap water (Obonyo *et al*., 2011).

The object of this study is to examine the effect of sodium silicate content on fresh and hardened properties of multi blend geopolymer mortar cured at ambient temperature.

MATERIALS AND METHODS

Multi blend binder included glass powder (WGB), low calcium Fly Ash (FA), Granulated Blast Furnace Slag (GBFS) and ceramic powder (WC). Table 1 shows the chemical composition of materials by using the XRF test. Their XRD and FSEM are shown in Fig. 1 and 2, respectively.

Figure 1 illustrates the XRD patterns of WBG, FA, GBFS and WC. The XRD pattern of WBG and GBFS verifies their highly amorphous nature because of the absence of any sharp peak. One of the most important factors in WBG formation is the reactive silica andalumina content. This high content of reactive amorphous silica in WBG is a potential source of silica for GPs preparation. However, incorporation of FA is required to overcome the low Al_2O_3 content (2.48 wt.%).

The XRD pattern of FA and WC revealed pronounced diffraction peaks around 2θ = 16-30° which are attributed to the crystalline silica and alumina compounds. Nonetheless, the occurrence of other crystalline peaks is ascribed to the presence of crystalline quartz and mullite phases.

Table 1: X-Ray Fluorescence (XRF) test of materials

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI
WBG	70.57	2.48	0.28	5.59	3.05	1.35	14.49	0.19	0.95
FA	57.20	28.80	3.67	5.16	1.48	0.94	0.08	0.10	0.12
GBFS	30.80	10.9	0.64	51.80	4.57	0.36	0.45	0.06	0.22
WC	72.80	12.20	0.54	0.01	1.00	-	13.5	-	-

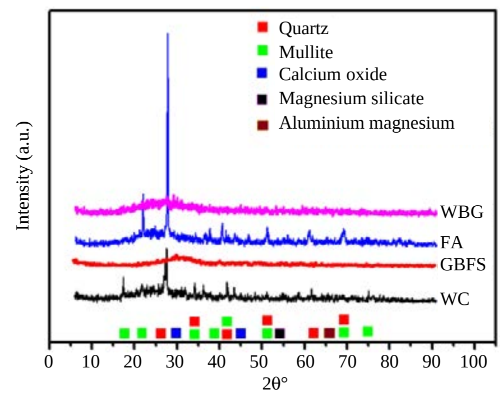

Fig. 1: X-Ray Diffraction (XRD) test of materials used as binder to prepare geopolymer mortar

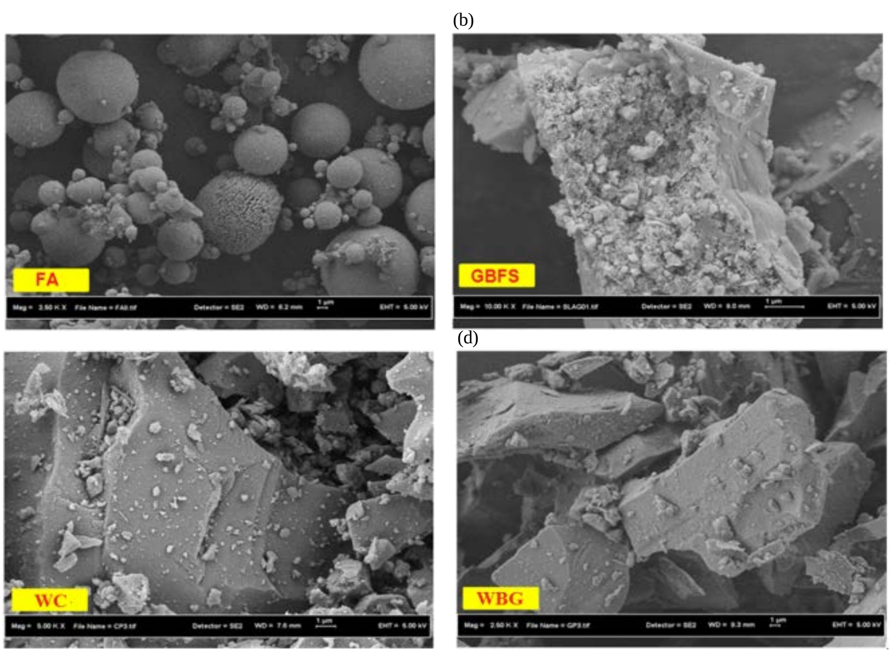

Fig. 2a-d): Scanning Electron Microscopy (SEM)

Table 2: GPMs Mixtures design with different NS content

Binder				Factors			
GBFS	FA	CP	GP	M	S/B	NS (%)	B/A
55	15	15	15	6	0.35	50-85	1.5

Figures 2 shows the SEM images of FA, GBFS, WC and WBG, respectively which are blended in the GPMs to achieve enhanced comprehensive strength and improved microstructural properties. It is evident that FA consists of spherical particles with smooth surface while the GBFS comprises irregular and angular particles.

Locally available river sand having a specific gravity of 2.74 and passing 100% of 2.36 mm sieve was used as fine aggregate for geopolymer mortar mixes. Sodium Hydroxide (NH) prepared with 6 molarity mixed with different ratios of sodium silicate (NS) and used as an alkali activator solution.

Preparation of GPM mixtures: Seven GPM mixtures were prepared with different sodium silicate content (50, 60, 65, 70, 75, 80 and 85). Binder to Aggregate (B:A), Sodium Hydroxide (NH) and the Solution to the Binder (S: B) were fixed with 1.5, 8 M and 0.25 for all mixtures in this study as depicted in Table 2.

Specimen preparation: Mixing was performed in accordance with Standard ASTM (2012). The 50 mm cube specimens were cast in steel moulds. Binder was added to fine aggregate and mixed for 3 min to become homogenous followed by solution addition and mixed for other 3 min. Mortar was placed in moulds with 2 layers. Each layer was vibrated by using vibration table for 15 sec. Moulds were left in laboratory atmosphere 27°C and 75% humidity for 24 h before de-moulding. Samples after de-moulding were kept for curing at same condition mentioned above. They were left at ambient temperature till testing date after 1, 3, 7 and 28 days.

RESULTS AND DISCUSSION

Workability: The workability of fresh GPM mixtures is determined using flow test (Anonymous, 2010). Flow test is conducted immediately after mixing. Effects of NS content on the workability of GPMs are inspected. The workability of the mortar is found to be higher at lower NS content. The flow of GPMs is reduced from 24-15 cm as the NS content is increased from 50-85%, respectively. Figure 3 depicted the effect of NS content on the workability of GPMs. An increase in the NS content is observed to diminish the workability that measured in terms of flow test.

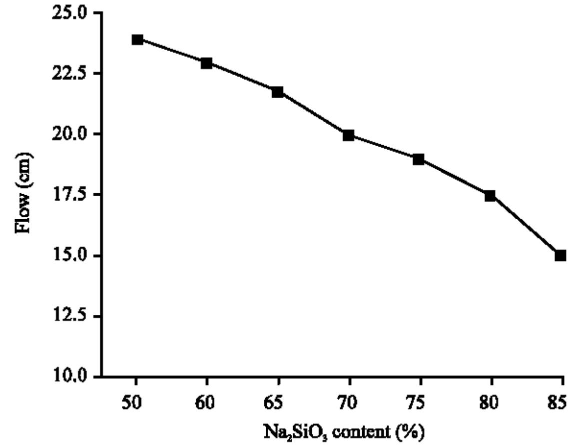

Fig. 3: Effect of NS content on GPMs workability

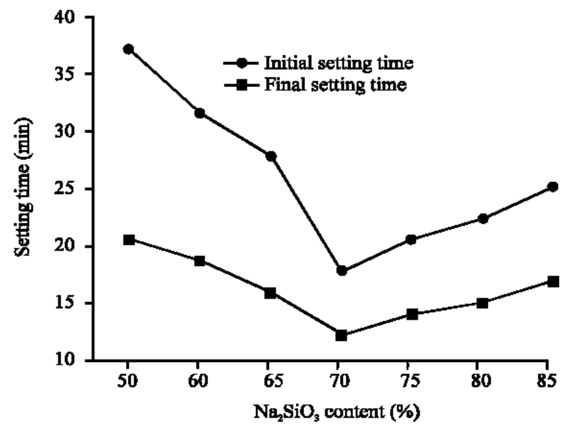

Fig. 4: GPMs setting time with different NS content

Setting time: Setting time of GPMs is tested at room temperature (27°C) following ASTM C191 standard. The mortar is prepared manually by mixing the binders and the alkaline solutions in a bowl and tested for setting time using Vicat apparatus. The GPMs activated at low NS content took significantly longer time to set due to slow rate of chemical reaction at low ambient temperature. The influence of NS content on the setting time of GPMs is presented in Fig. 4. It can be concluded from Fig. 4, that the GPM mixtures that are prepared with 70% content of NS revealed very fast setting time. The GPMs setting time is improved considerably with the reduction of NH content and increase NS content from 70-85%. It can also be concluded from Fig. 4 that both initial and final setting time is enhanced when NS content was more than 70%. Furthermore, the rate of setting is increased appreciably as indicated by the substantial difference in the initial setting time. The difference between initial and final setting time is also increased with the reduction of NS content <70% in the mortar.

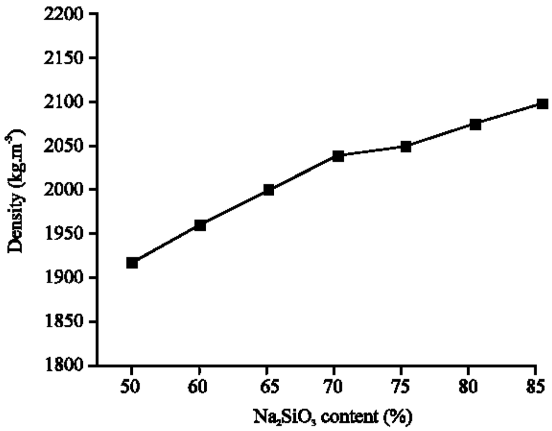

Fig. 5: GPMs density with different NS content

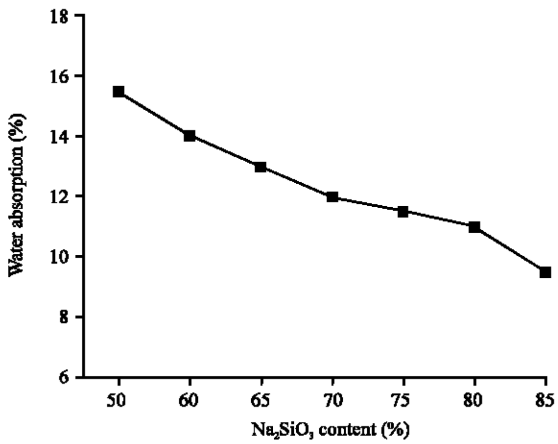

Fig. 6: Effect of NS content on GPMs water absorption

Density: Figure 5 demonstrates the variation of GPMs density as a function of NS content. An increase in the mortars density with increasing NS content is attributed to the compactness of the network structures. At lower NS content the microstructures are less dense and the flow is easier. However, with the increase of NS content the structural network of the GPMs becomes denser that caused a reduction in the flow as well as overall setting time.

Water absorption: The results of water absorption are presented in Fig. 6. Results revealed that water absorption decreasedwith increase in sodium silicate content. On the other hand, an increase in the NS content affected the geopolymerization system and increase the dissolution of Si and Al and led to enhance the GPM microstructure and reduce the porous. The same conclusion was reported by Al Bakri Abdullah *et al.* (2012).

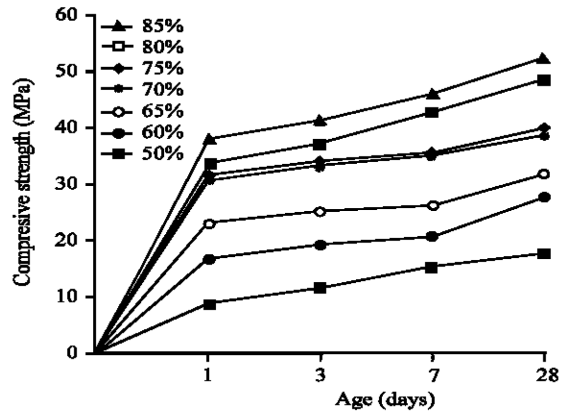

Fig. 7: The NS content effect of GPMs compressive strength

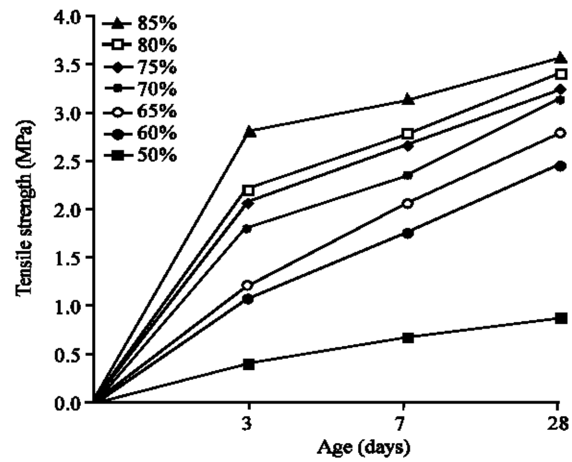

Fig. 8: Effect of NS content of GPMs tensile strength

Compressive strength: Figure 7 shows the effect of NS content on the compressive strength of GPMs ages for different durations. GPMs with 50% NS content revealed the lowest value of compressive strength (below 21 MPa). The mixture with 60% NS content displayed a compressive strength of 19.8, 21.3, 23.6 and 29.1 MPa at age of 1, 3, 7 and 28 days, respectively which is higher than GPM prepared with 50% NS content. The increase in compressive strength and density of GPMs with increasing NS content is in fact correlated (Fig. 6). On the other hand, the increase sodium silicate content accelerates the geopolymerization operation and increase the dissolution of Si and Al and enhance the microstructure of GPMs.

Tensile strength: The effect of NS content on tensile strength of GPMs was evaluated after 3, 7 and 28 days. Figure 8 shows the tensile strength of samples activated

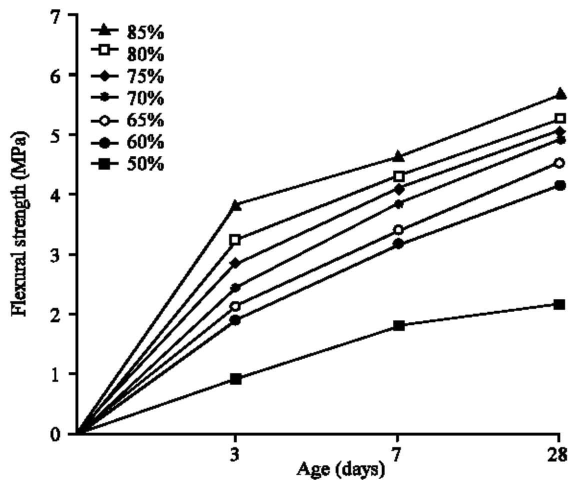

Fig. 9: Effect of NS content of GPMs flexural strength

by different NS content. The effects of increasing NS content were investigated. It is observed that the activation of GBFS by alkali could dissolve Ca whereas Si and Al participated to create CSH and CASH gel, thereby enhanced the mechanical strength. Samples activated with high NS content (85%) revealed better results (3.4 MPa) than those prepared with 50% NS content (0.67 MPa).

Flexural strength: In this study, prisms prepared with different NS content and tested with three points load. Figure 9 presents the effects of NS content on the flexural strength of GPM after 3, 7 and 28 days. The samples were prepared with high NS content showed better results in comparison to the samples prepared with low NS content. This is because of the reaction among CaO and SiO_2 that subsequently formed CSH. Samples prepared with 85% NS content showed higher flexural strength (5.6 MPa) compared to the samples prepared with 50% content which display 0.96 MPa. All the samples show increase in flexural strength with increase NS content.

CONCLUSION

Effect of sodium silicate solution content on setting characteristics and mechanical properties of geopolymer mortar was thoroughly investigated. Multi blend Granulated Blast Furnace Slag (GBFS), Fly Ash (FA) Waste Ceramic (WC) and Waste Glass Bottle (WGB) based geopolymer mortar were studied. Waste materials were activated by using an alkali solution prepared by mixed Sodium Silicate (NS) with sodium hydroxide (NH). Seven mixtures of Geo Polymer Mortar (GPM) were prepared with different sodium silicate content (NS) 50, 60, 65, 70, 75, 80 and 85. Sodium hydroxide concentration, binder to aggregate ratio and solution to binder content were fixed for all mixtures with 6 M, 1.5 and 0.35, respectively. The following conclusion can be withdrawn:

- Increase sodium silicate reduced the initial and final setting time
- Increase silicate content contributed to reduce workability of GPMs
- Increase NS content increases compressive, tensile and flexural strength
- The workability, measured in terms of the flow of mortars, decreased with increase NS content
- Increase sodium silicate content enhances microstructure and increase the density and strength of GPMs
- Water absorption decreases with increased sodium silicate content

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