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Microstructure and mechanical properties of alkali-activated slag mortar modified with latex

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HIGHLIGHTS

- SEM images reveal that alkali-activated slag (AAS) with or without latex had a solid matrix with microcracks.
- The addition of latex prolongs the setting time of AAS.
- The addition of (SBR or AE) latex resulted in great reduction in the drying shrinkage.
- Compressive strength and flexure strength improve by using SBR latex.

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ABSTRACT

Alkali-activated slag (AAS) binders are considered as eco-friendly materials due to its production process. The drawback of using AAS was its rapid setting and microcracks that can be formed due to its shrinkage process. In this study, different types and dosages of latex were suggested to improve setting characteristics and shrinkage of AAS. The used types of latex were Styrene-Butadiene Rubber (SBR) latex and Acrylic Ester (AE). The percentages of latex were 5%, 10% and 15%. Microstructure of AAS was studied to investigate the reaction and the effect of latex using thermogravimetric analysis, scanning electron microscopic and energy dispersive. The alkali-activated slag mortar properties were investigated by setting time, compressive strength, flexural strength, and drying shrinkage. The test results show that setting time increases by increasing the latex ratio from 0% to 15%, the highest compressive and flexure strength was observed in AAS mortar incorporating 5% SBR.

1. Introduction

Nowadays researches focused in producing a new environmentally friendly alternative building material to concrete called “Alkali-activated cements and concretes”. The alkali-activated cements and concrete do not contain any Portland cement in its production while it results from the combination of a by-product (aluminosilicate) materials such as ground granulated blast furnace slag, fly ash, silica fume, etc. with alkaline liquid [1,2].

The use of industrial waste materials like blast furnace slag (BFS) to produce alkali-activated slag cement was used widely as repair materials or for maintenance of concrete structure like bridge joint, and road way [3]. Previous researchers [4,5] studied many factors that can affect the AAS performance; such as ratio between SiO_2/AL_2O_3,type and concentration of activator. They reveal that by reducing the ratio of SiO_2/AL_2O_3, setting time reduces and high strength was attained. Many researchers [6,7] indicated that by adjusting the type and chemical composition of activator the setting characteristics and high strength of AAS was achieved.

Even though the alkali-activated material is considered as an excellent material, however, there are drawbacks when using this type of binder [8] such as highly shrinkage, the shrinkage of these materials increase by six times that cement as reported in literature [4,9]. Collins and Sanjayan [10] explain the reason of high drying shrinkage of AAS concrete, they indicated that the mechanism of drying shrinkage is not only due to amount of water loss from concrete but it significantly depends on the pore size distribution and characteristics of calcium silicate hydrate gel. Intensive researchers have suggested using polymeric materials to enhance compressive strength and arrested microcracks [11,12]. However, the mechanisms of reaction between polymeric materials and AAS have yet to be clearly defined due the shortage of available studies in this area. Most of available works were focused on

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physical and mechanical properties of polymer and geopolymer composite materials [8,13,14].

Thus, the present study assesses the microstructure, setting characteristics and mechanical properties of alkali-activated slag mortar modified with latex SBR or AE as an example of polymeric organic materials. The effect of latex type and dose and curing temperature were studied.

2. Experimental program

2.1. Materials

In this study, blast furnace slag "BFS" was used as a binder material. Also, Cem I 42.5 N cement was used only to compare between drying shrinkage of cement mortar specimens and that of AAS specimens. The chemical composition of slag and cement are shown in Table 1 sodium hydroxide (NaOH) solution, sodium silicate (Na_2SiO_3, NS) solution with 14.5% Na_2O and 29.5% SiO_2 by weight were used for the solution. Tap water was used to dissolve the solid NaOH (98%); NaOH solution and sodium silicate (Na_2SiO_3) solution was mixed together to prepare the alkali activator solution. and kept for 24 h before mixing. Siliceous Graded sand with 2.4 fineness modulus and specific gravity of 2.6 was used as a fine aggregate material. Modified styrene butadiene emulsion (Styrene-Butadiene Rubber – SBR) latex and Acrylic Ester (AE) latex were used as polymeric organic materials to improve the AAS behavior. The density of each type is 1.01 ± 0.02 Kg/L and 1.03 ± 0.01 Kg/L respectively.

2.2. Test parameters

Type and concentration of polymeric materials "Latex" have a main role to modify the AAS behavior. Therefore, this study studied the effect of these factors on microstructure and other physical and mechanical properties of AAS. Two types of latex were studied Styrene-Butadiene Rubber (SBR) and Acrylic Ester (AE), where the concentration of these materials were 5%, 10% and 15%–5% and 10% by weight of slag respectively. Two curing temperature degrees were considered 30 °C and 60 °C.

2.3. Mixture proportions

The mix proportions of the alkali-activated slag mortar are listed in Table 2. The alkali activator consists of 10 M of sodium hydroxide (NaOH) solution and (Na_2SiO_3) solution. The alkali solution (SiO2/Na_2O) ratio (by mass) was 2.0. The liquid to binder ratio (L/B) was kept constant of 0.46. The alkali activator was prepared by mixing NaOH to sodium silicate (Na_2SiO_3) solution by mass 1:1. Sodium silicate in pellet from 98% purity was dissolved in potable water to prepare 10 M concentration, its chemical composition of 29.50% SiO_2, 14.50% Na_2O and 56% H_2O. The activator was prepared one day prior to use the alkaline liquid [15]. Mortar with 0%, 10%, of SBR or AE were prepared with the liquid/binder ratio of 0.46. It should be noted that the liquid binder ratio was calculated using the solid quality of the used latex (41% solid content).

Table 1
Chemical composition of slag.

Chemical composition (%)	Slag	Cem I 42.5 N
Silicon dioxide (SiO_2)	36.74	20.17
Aluminium oxide (Al_2O_3)	10.78	4.7
Iron oxide (Fe_2O_3)	0.42	3.38
Calcium oxide (CaO)	43.34	62.4
Magnesium oxide (MgO)	3.21	2.8
Sulphur trioxide (SO_3)	0.53	2.76
Potassium oxide (K_2O)	0.17	0.34
Sodium oxide (Na_2O)	0.18	0.51
Chloride (Cl)	0.04	0.05
Loss on ignition (LOI)	0.60	3.63

2.3.1. Hydrated specimens

For thermogravimetric analysis "TGA" and scanning electron microscopic "SEM" measurements, paste specimens with liquid binder ratio of 0.4 were prepared. Different pastes were produced; paste of slag & water, paste of slag & activator, and pastes of slag with activator and 5% SBR as an example of Latex to discover the effect of polymer admixture (Latex) on slag reactivity. Also it should be determined the cementing properties of slag in presence of activator and latex, thus, paste was prepared by mixing slag and activator and water. All pastes were casted in cubic molds of 50x50x50mm, they were demoulded after 24 h of casting and stored in 30 °C for 28 days. The powder was taken from paste specimens by using electrical sewing, and then TGA analysis was performed immediately between 20 and 1000 °C at a heat rate of 20 °C/min. The mineralogy and microstructure analysis was performed using scanning electron microscopic and energy dispersive "SEM/EDX" investigation of the slices of hydrated samples surfaces at 28 days.

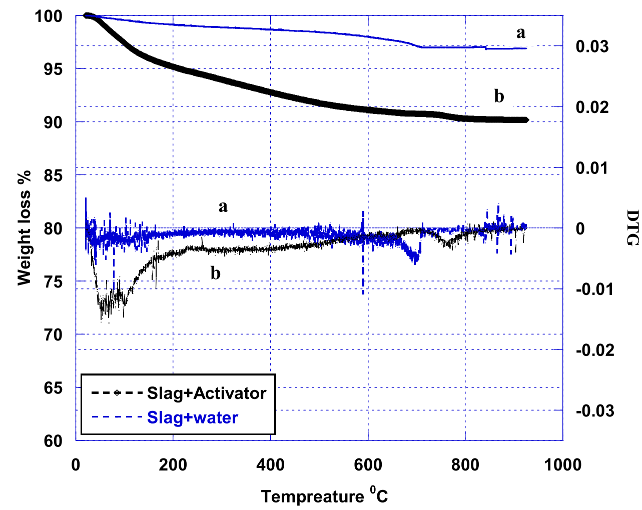

Fig. 1. TGA/(DTG) curves of the slags with (a) activator and (b) water at 28 days.

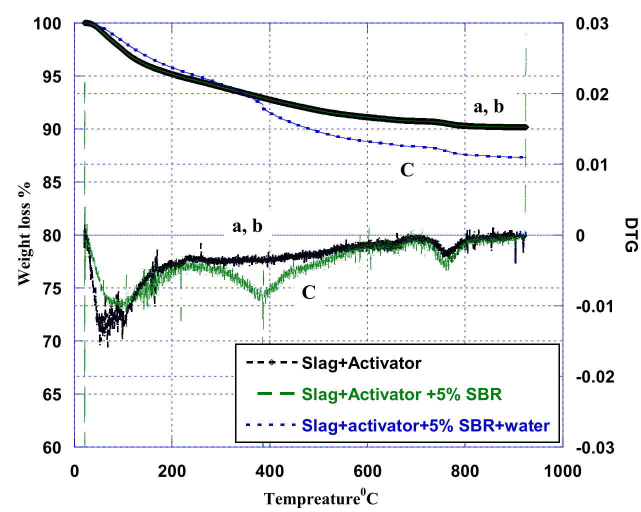

Fig. 2. TGA/(DTG) curves of the (a) slag with activator, (b) with 5%SBR and (c) 5% SBR and water at 28 days.

Table 2
Test parameters and mixture proportions of alkali-activated slag mortar (Kg/m^3).

Mix designation	Slag (Kg)	Fine aggregate (Kg)	NaOH (Kg)	Na_2SiO_3 (Kg)	Liquid/binder ratio	polymer Admixture dose %
S0	599	1647.3	119.8	119.8	0.46	–
SSB5	599	1647.3	119.8	119.8	0.43	5% SBR
SSB10	599	1647.3	119.8	119.8	0.46	10% SBR
SSB15	599	1647.3	119.8	119.8	0.49	15% SBR
SAE5	599	1647.3	119.8	119.8	0.43	5% AE
SAE10	599	1647.3	119.8	119.8	0.46	10%AE