EFFECT OF ALKALI CONTENT ON COMPRESSIVE STRENGTH AND EFFLORESCENCE OF NaOH ACTIVATED COPPER SLAG MORTAR

Jagmeet SINGH, Surinder Pal SINGH

Department of Civil Engineering, Dr B R Ambedkar National Institute of Technology, Jalandhar-144011, India

jagmeet.dhanoa.99@gmail.com, spsingh@nitj.ac.in

Introduction

Alkali-activated materials (AAMs) are hardened products of a chemical reaction of aluminosilicate materials and alkali-activators.[1] These materials have gained most attention recently as energy incentive materials and have a successful future as alternative binder in construction industry due to its comparable mechanical and durability properties to Portland cement.[2] Alkali-activated materials have been synthesised using a large variety of aluminosilicate and activators or combination of activators.[3] However, to develop the low-cost AAMs in any specific region, locally available sources of aluminosilicate have to be identified and also specified the correct activator for the activation of these aluminosilicate.

Copper slag (CS) is a by-product of the smelting process of copper and in India around 15 million tonnes CS is generated annually.[4] Some environmental issues have arisen with the dumping of CS and these problems can be minimised with the utilisation of CS in the construction industry. Intense research has been carried out on the utilisation of CS as replacement of Portland cement in concrete.[5] However, very few studies are available regarding the use of CS for the development of AAMs.[6,7]

The presents study was conducted to synthesise AAMs using copper slag as aluminosilicate and NaOH as alkali-activator. The effect of different alkali contents *i.e.* 4%, 6%, 8% and 10% by weight of CS on compressive strength and efflorescence of Alkali Activated Copper Slag Mortar (AACSM) was investigated.

Materials and Methods

Granulated CS obtained from a smelting plant in India was used in this study. The copper slag was first ground in a laboratory ball mill using steel balls to attain its fineness similar to Portland cement. The major constitutes of CS determined with XRF were Si_2O (37.6%), Al_2O_3 (11.5%), Fe_2O_3 (42.4%), CaO (3.80%) and Na_2O (0.74%). The specific gravity and surface area of CS was 3.92 and 405 m^2/g respectively. Stranded

sand was used to prepare AACSM. Locally supplied sodium hydroxide solution of 12 M was used as alkali-activator.

Four AACSM mixes were prepared using alkali contents of 4%, 6%, 8% and 10%. The mix proportion of different mixes for 1000 g of CS is given in Table 1. Standard sand to CS ratio of 3 and water to solid ratio of 0.3 was fixed for all mixes. To prepare AACSM, all materials were mixed in mortar mixtures for 5 minutes and then poured into cube specimens of size 50x50x50 mm. Two different curing regimes were selected; ambient curing (25 ± 3°C) and heat curing (80°C for 24 h). The specimens were de-moulded after 24 h and placed in laboratory conditions at a temperature of 25 ± 3°C and relative humidity of 50 ± 5% until testing. The compressive strength of AACSM was determined after 7 and 28 days. For efflorescence formation, 28 days ambient cured specimens of AACSM were immersed in distilled water for further 28 days. Efflorescence formation of AACSM was visually compared and the pH value of specimens leaching liquid was also determined.

Table 1: Mix proportions for 1000 g of CS (By weight)

Mix	Alkali content (%)	12 M Sodium Hydroxide solution (g)	Extra Water (g)
1.	4	148	204
2.	6	222	156
3.	8	296	108
4.	10	370	60

W/S ratio= Water/Solid ratio, where water is water in activator and extra water; Solid is solid part of activators and CS

Results and Discussion

Compressive strength

The effect of alkali content and curing regime on the 7 days and 28 days compressive strength of AACSM is shown in Figure 1a and Figure 1b respectively. It was observed that 7 days and 28 days compressive strength of AACSM was increased with increase in alkali content and this behaviour was the same for both ambient and heat cured specimens. In ambient cured specimens, the 28 days compressive strength for 4% and 10% alkali content was 1.91 MPa and 16.93 MPa respectively. For heat cured specimens 28 days compressive strength was increased by 2.5 times, when the alkali content was increased from 4% to 10%. The significant improvement in compressive strength was attributed to the formation of aluminosilicate gel. The increase in alkali content raised the pH of the alkali-activator solution, which increased the leaching of

Si and Al from CS and formation of aluminosilicate gel takes place.[8,9] Heat cured specimens show better compressive strength than ambient cured specimens and a remarkable gain in compressive strength for heat cured specimens was observed at 7 days of curing. However, the development in compressive strength for ambient cured specimens was less at the curing age of 7 days. Similar behaviour was also observed in literature that heat curing accelerates the alkali-activation process of CS.[6]

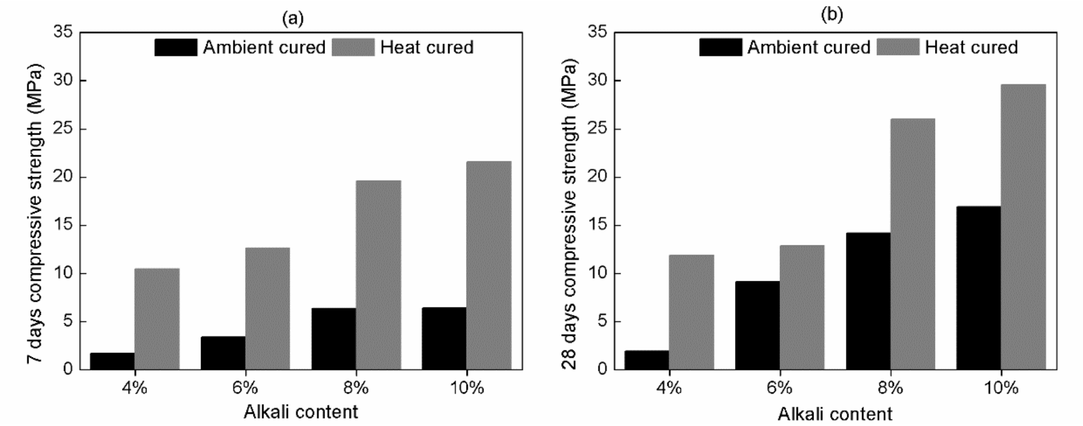

Figure 1: Effect of alkali content and curing regime on (a) 7 days compressive strength and (b) 28 days compressive strength

Efflorescence

Efflorescence is white crystals formed on the surface of AAMs due to the reaction of alkali and CO_2, which provides hinder to the performance of AAMs.[10] Efflorescence formation on the top surface of different AACSM mixes is shown in Figure 2. It was seen that mixes with 4% and 6% alkali content demonstrates the negligible efflorescence as shown in Figure 2a and Figure 2b, however for 8% alkali content few white crystals were seen on the top surface in Figure 2c. A significant amount of efflorescence formation was observed in Figure 2d for the mix containing 10% alkali content.

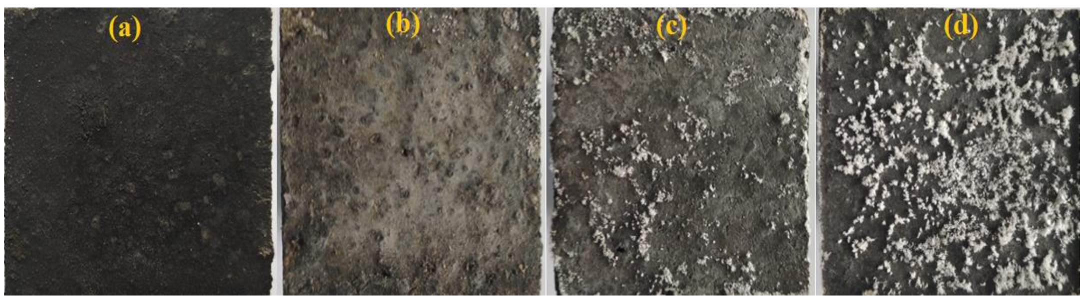

Figure 2: Effect of different alkali contents (a) 4%, (b) 6%, (c) 8% and (d) 10% on efflorescence formation on top surface of the AACSM mixes

It was observed that efflorescence formation in AACSM mixes was increased with increase in alkali content. The pH value of the leaching liquid of the AACSM mixes with alkali content of 4%, 6%, 8% and 10% was 10.35, 10.61, 11.53 and 12.65 respectively. It reflects that with the increase in alkali content, soluble alkalis were leached out from the AACSM mixes and react with atmospheric CO_2 to form bicarbonates which causes the efflorescence.[11,12]

Conclusions

The effect of different alkali contents on the compressive strength and efflorescence of AACSM was investigated. The compressive strength of AACSM was increased with increase in alkali content and a maximum of 29.6 MPa compressive strength was achieved with 10% alkali content. Heat cured specimens showed better compressive strength than ambient cured. The maximum efflorescence and alkali leaching was observed for the mix with 10% alkali content. Therefore, based on compressive strength and efflorescence, a maximum alkali content of 8% is recommended for alkali-activation of CS.

References

1. A. Purdon, "The action of alkalis on blast furnace slag", *J Soc Chem Ind*, **59** 191-202 (1940).
2. C. Shi, A. Fernández-Jiménez, A. Palomo, "New cements for the 21st century: the pursuit of an alternative to Portland cement", *Cem Concr Res,* **41** 750-763 (2011).
3. C. Shi, P.V. Krivenko, D.M. Roy, "*Alkali-activated Cements and Concretes*", Taylor & Francis, Abingdon, UK, 2006.
4. Government of India, *Monthly Summary on Non-ferrous Metals & Minerals*, Ministry of Mines, Government of India, 2018.
5. C. Shi, C. Meyer, A. Behnood, "Utilization of copper slag in cement and concrete", *Resour Conserv Recycl*, **52** 1115-20 (2008).
6. A. Nazer, J. Pay, J. Monzo, "Use of ancient copper slags in Portland cement and alkali activated cement matrices", *J Environ Manage*, **167** 115-123 (2016).
7. R. I. Iacobescu, V. Cappuyns, T. Geens, L. Kriskova, S. Onisei, P. T. Jones, Y. Pontikes, "The influence of curing conditions on the mechanical properties and leaching of inorganic polymers made of fayalitic slag", *Front Chem Sci Eng,* **11** (3) 17–327 (2017).
8. G. Gorhan, G. Kurklu, "The influence of the NaOH solution on the properties of the fly ash-based geopolymer mortar cured at different temperatures", *Composites: Part B,* **58** 371-377 (2014).
9. U. Rattanasak, P. Chindaprasirt, "Influence of NaOH solution on the synthesis of fly ash geopolymer", *Miner Eng,* **22** 1073-1078 (2009).
10. E. Najafi Kani, A. Allahverdi, J.L. Provis, "Efflorescence control in geopolymer binders based on natural pozzolan", *Cem Concr Compos,* **34** (1) 25-33 (2012).
11. A. Allahverdi, E.N. Kani, B. Shaverdi, "Carbonation Versus Efflorescence in Alkali Activated Blast Furnace Slag in Relation with Chemical Composition of Activator", *Int J Civ Eng*, **15** 1-9 (2017).
12. X. Yao, T. Yang, Z. Zhang, "Compressive strength development and shrinkage of alkali-activated fly ash-slag blends associated with efflorescence", *Mater Struct,* **49** (7) 2907-2918 (2016).