Effect of alkali content and slag content on the fresh and hardened properties of air-cured alkali activated mortar containing fly ash

Thushara Raju[1*], Namitha S.[2], Muhammed Nabil K.[2], Mohammed Rafeeque N. V. [2],
Reshma Sundhar[2], Ramaswamy K. P[3], Saraswathy B.[4]

[1] Ph.D. Scholar, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala
[2] B.Tech students, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala
[3] Assistant Professor, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala
[4] Professor, Department of Civil Engineering, TKM Institute of Technology, Kollam, Kerala

*Corresponding author: thushararaju2014@gmail.com

doi: https://doi.org/10.21467/proceedings.112.48

ABSTRACT

Alkali Activated Material (AAM) is introduced as a pioneering construction material in the construction diligence to trim down the utilization of Ordinary Portland Cement (OPC) and to curtail the amount of carbon dioxide released during the production of OPC. Modestly refined industrial by products or natural materials rich in alumino silicates are the binding agents used in AAM. Generally, heat curing is needed for the alkali activated mortar to achieve the required hardened properties and this difficulty can be overcome by adding slag to the mix. In this experimental analysis, the alkali activated mortar mixes with different proportions of glassy granulated slag and Class F fly ash were prepared without the usage of superplasticizers, with alkali to binder (a/b) ratios of 0.7, 0.8 and 0.9. The rheological characteristics of mortar were studied using flow table apparatus and hardened properties were studied using compressive strength test and ultrasonic pulse velocity (UPV) test by testing cylindrical specimens of size 25 mm diameter and 50 mm height. The mortar specimens were air-cured, and the compressive strength and UPV test were conducted after 3 and 7 days. The test results showed that due to the presence of higher alkali content and the decrease in slag content, the workability of alkali activated mortar was improved, but the measure of strength decreased. The mix with 100% slag and a/b ratio of 0.8 had the best UPV value, indicating its quality among the various mortar mixes studied. This study portrays the significance of optimising the alkali and slag content in tailor making an alkali activated mortar system with good hardened properties.

Keywords: Alkali activated material, fly ash, slag, alkali to binder ratio, flow table test, compressive strength, ultrasonic pulse velocity, air curing and mortar.

1 INTRODUCTION

Ordinary Portland cement production is highly energy and resource consuming and act as a major source of greenhouse gas emission. Hence the development of a sustainable binder material against environmental hazard becomes an urgent need. In 1979, Davidovits introduced a new binder system, termed as ‘Geopolymer’ and produced by the exploitation of alkalis blended with a burnt mixture of kaolinite, dolomite and calcareous such as limestone. These are found to be uncrystallized to semicrystalline, three dimensional structures made of silicon-aluminate [Davidovits, 2005]. Silicon and aluminium-affluent source materials from industrial by-products such as flyash (FA), rice husk ash and ground granulated blast furnace slag (GGBFS) can be used with alkaline liquids [Davidovits, 1994]. The principal flyash-based geopolymer reaction product is an alkaline silico-aluminate gel [Jimenez et al. 2003]. Heat curing, FA-based geopolymer concrete production is low budget, when

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

compared to OPC based concrete (20%-30%) [Hardijito et al. 2005]. Slag based alkali activated concrete has strong resistance to penetration of chloride ions, resistance to corrosion, better resistance to environments of sulphuric acid and magnesium sulphate and greater resilience against acid attack [Bernal et al. 2011, Chaparro et al. 2012, Nitendra et al. 2016 and Chaitanya et al. 2018]. Many researches focus on the heat cured geopolymers and relatively less focus is on the development of air-cured alkali activated binder systems.

This study mainly focuses on the behaviour of alkali activated mortar in fresh and hardened stage, which consists of the mortar flow, strength and dynamic modulus of elasticity. The significant parameter that defines the properties of hardened mortar is the workability of fresh mortar. Literature study reveals that, the presence of higher polymer powder content reduces the workability of geopolymer mortar [Jumrat et al. 2011] and also the grading and particle size of aggregates influences the flowability and consistency [Bhowmick et al.2012]. The strength value mainly depends on the composition of source precursor material used for the study. Considering the different types of precursor materials, the use of Palm oil fuel ash (POFA) delayed the geopolymerization process and trim down the early age strength [Ranjbar et al. 2014] and the combination of 70% GGBFS with 30% POFA gave maximum strength of 66MPa [Islam et al. 2014]. Higher concentration of NaOH enhances the compressive strength of metakaolin based geopolymer mix and low calcium FA based mix, which is contrary to the case of high calcium FA mix [Vasconcelos et al. 2011 and Malkawi et al. 2016]. Another way to improve the compressive strength of FA based geopolymer system is the replacement of FA with GGBFS, up to 35% or with 20% metakaolin, beyond the limits, negative impact was observed [Mallikarjuna et al. 2015 and Kabir et al. 2015]. In this study, the rheological and strength behaviour of ambient cured FA and GGBFS based alkali activated systems were evaluated for the practical implementation of such environment friendly concrete instead of conventional concrete for the resilient and sustainable infrastructure development.

2 MATERIALS USED

The binder precursors used for the preparation of geopolymer mixes were ultrafine GGBFS obtained from Astrra Chemicals, Chennai and low calcium (Class F) fly ash. As an alkaline activator, the mixture of sodium hydroxide (NaOH) solution and sodium silicate solution was used. The water glass solution (Sodium silicate (Na_2SiO_3)having density of 1.59 gm/cm^3) with SiO_2 to Na_2O ratio by mass of 2.4 and 40 percent solid content, and 97-98 percent purity NaOH pellets were combined with water to form a solution of 10M concentration. The ratio of water glass to NaOH solution was used as 2.50 by weight. The fine aggregates used in the analysis were crushed stone sand (M Sand) in the standard gradation conforming to IS 650.

3 METHODOLOGY

An experimental study on mortar mix, without superplasticizer was performed with alkali to binder (a/b) ratios of 0.7, 0.8 and 0.9. After demoulding, the mortar was air cured to achieve the compressive strength at specific ages. Initially the slag was dry mixed with sand for about one minute to obtain homogeneity of solid particles. Later, after getting a homogenous dry mix, alkaline solution was added and mixed for three minutes in a Hobart mortar mixer. Immediately after mixing, the workability of the mortar was checked using the flow table apparatus (Figure 1(a)). In order to simulate the mortar fraction in a medium strength concrete, mortar was developed with a binder to aggregate ratio of 1.5. The alkali activator systems selected for the mortar test were 100% slag, 75% slag + 25% fly ash, and 50% slag + 50% fly ash. The fresh mortar was mounted in 3 layers in the flow table mould with 70 mm top diameter, 100 mm bottom diameter and 50 mm height to determine the workability of mortar and each layer was tamped 20 times using 16 mm diameter tamping rod. Just enough to ensure the uniform filling of the mortar in the mould, the tamping pressure was preserved. The mould was then lifted up vertically and the spread diameter was measured in 15 seconds with 25 blows provided to the unit. The final spread is compared with the initial bottom diameter and the workability is expressed as percentage flow.

(a) (b) (c)

Figure 1. Experimental setup a) Flow table apparatus b) Compression testing machine c) Ultrasonic pulse velocity test

In order to determine the compressive strength of the mortar specimens, cylinders of 25mm in diameter and 50mm in height were cast by filling the mould with mortar in three layers and tamping each layer. After the removal of cylinders from the mould, they are subjected to ambient air curing (at temperature of 30 ± 2℃), and it was then followed by testing of 3 cylinders at 3rd and 7th day for finding the compressive strength of the specimen (Figure 1(b)). The test was conducted using a digital compression testing apparatus and the loading rate was maintained at 0.5kN/sec. The Ultrasonic pulse velocity test was conducted on the ambient cured cylindrical specimen of diameter 25 mm and height 50 mm on 3rd, 7th day and 28th days (Figure 1(c)). The P-wave transducer of bandwidth 150 kHz was used to measure UPV conforming to IS 13311-1 (1992). The ultrasonic pulse is produced by the transducer that is kept in contact with the sample specimen's two end surfaces. White grease was applied between the transducer surface and the specimen, in order to ensure that the ultrasonic pulses produced by the transducer pass into the mortar specimen. The time of travel and velocity of electronically generated mechanical pulses passing through the specimen was measured.

4 RESULTS AND DISCUSSIONS

4.1 Flow Behaviour of Mortar

The percentage flow of alkali activated mortar was determined by comparing the initial bottom diameter of the mould and final spread of the mix in the flow table apparatus, and the variation in flow with varying a/b ratios are summarized in Table 1.

Table 1. Flow table test results

Mix	a/b ratio	% flow
100% slag	0.7	120
100% slag	0.8	Overflow (>150%)
100% slag	0.9	Overflow (>150%)
75% slag and 25% FA	0.7	130
75% slag and 25% FA	0.8	Overflow (>150%)
75% slag and 25% FA	0.9	Overflow (>150%)
50% slag and 50% FA	0.7	115
50% slag and 50% FA	0.8	Overflow (>150%)
50% slag and 50% FA	0.9	Overflow (>150%)

The flow of various mixes obtained after conducting the flow table test with 25 blows is shown in Figure 2 and in Figure3.

Figure 2. Flow of mix with 100% slag and a/b ratio of 0.7, 0.8 and 0.9 respectively

Figure 3. Flow of mix with 50% slag and 50% fly ash and a/b ratio of 0.7, 0.8 and 0.9 respectively

From the experimental test results and ocular measurement, the flow of the mix was found to be increased with gain in a/b ratio. This is primarily due to the addition in liquid content in the mix, which enhances the workability [Arun et al. 2018]. The minimum % spread of 115 % was obtained for the mix with a/b ratio of 0.7 and having 50% fly ash and 50% slag and it fulfilled the mortar workability of range,110 ± 5% as per IS standards. It shows that a/b ratios selected is appropriate to carry out the mortar works without using any chemical admixture. It is also noted that mortar with a/b ratios of 0.8 and 0.9 were highly flowable (the spread exceeded the diameter of the flow table, i.e. 25 cm).

4.2 Compressive Strength

The 3rd and 7th day compressive strength of alkali activated air cured mortar were found out and the influence of a/b ratio on compressive strength are shown in Figures 4 and 5. Variation of compressive strength with respect to percentage of slag content is depicted in Figure 6 and 7. The results clearly express that the compressive strength of alkali activated mortar decreases with an increase in a/b ratio and increases with increase in percentage of slag. The slag dominated alkali activated mix accelerates the setting time with epochal betterment of strength and ablated workability. The increased strength may be due to the act of C-A-S-H gel and N-A-S-H gel at lower a/b ratios and the shaping of C-A-S-H gel accelerated by the presence of slag [Fang et al. 2018].

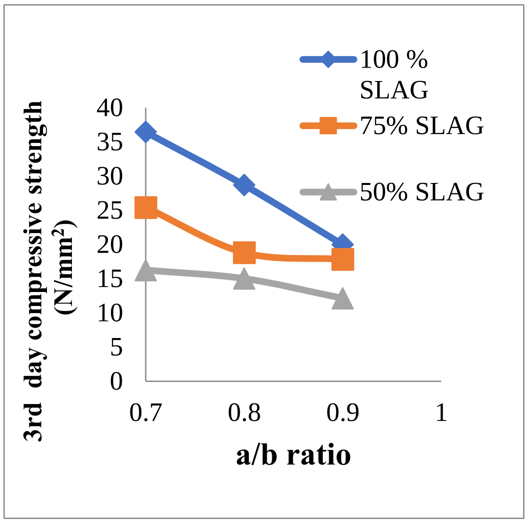

Figure 4. Variation of 3rd day compressive strength with a/b ratio

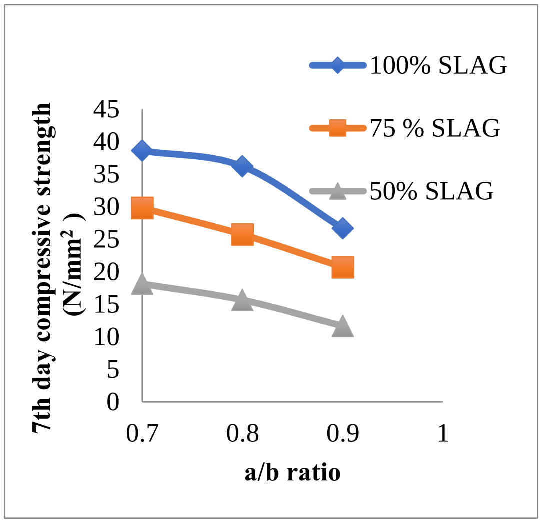

Figure 5. Variation of 7th day compressive strength with a/b ratio

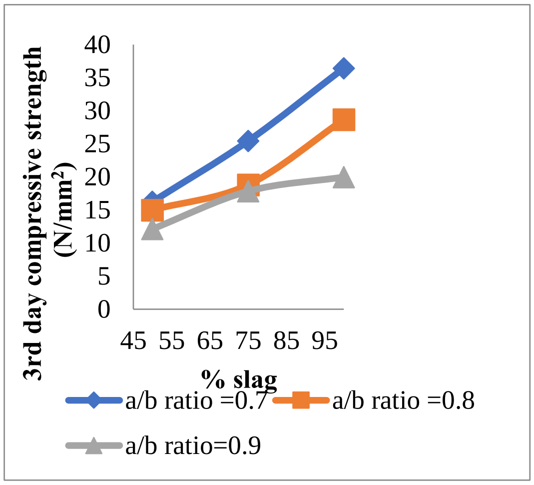

Figure 6. Variation of 3rd day compressive strength with slag content

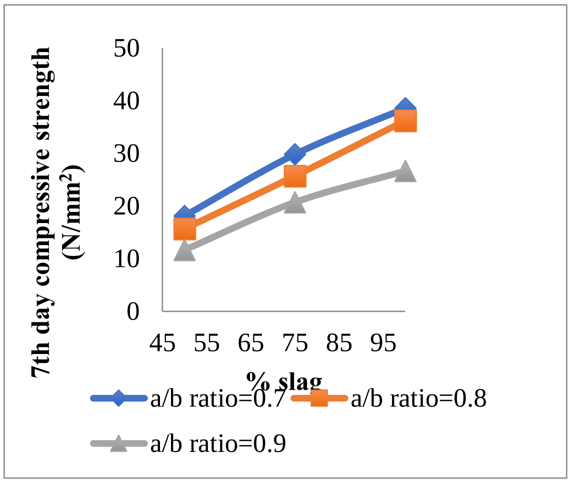

Figure 7. Variation of 7th day compressive strength with slag content

4.3 Ultrasonic Pulse Velocity (UPV) Test

The ultrasonic pulse velocity was done to assess the quality of the mortar and the values of UPV are related to the density and modulus of elasticity of the mortar specimen. The UPV measurements of the samples under ambient curing are given in Table 2 and it was found that the UPV is increasing with increase in the slag content and there was only marginal variation of UPV with a/b ratio. From the test results, the dynamic Young's modulus of elasticity was computed using the Eq. (1)

$$E=\frac{\varrho(1+\mu)(1-2\mu)V^2}{1-\mu} \qquad (1)$$

From Table 2, it can be seen that the UPV and E value decreases with increase in a/b ratio for all the mixes studied. These observations are in alignment with the strength test results. As slag was replaced with fly ash, both UPV and E values were found to decrease for the same a/b ratio. The mix with 100% slag and a/b ratio of 0.8 obtained highest UPV value and the dynamic modulus of elasticity, which indicate that it is the best quality mortar among the mixes studied. It is also seen that the 7th day UPV and E values were marginally lesser than the 3rd day, and this needs further investigation.

Table 2. UPV and dynamic modulus of elasticity of mortar mixes

Mix	a/b ratio	UPV (m/s)		Dynamic Modulus of Elasticity (GPa)	
		3rd day	7th day	3rd day	7th day
100% Slag	a/b = 0.7	3652	3467	26.5	23.3
100% Slag	a/b = 0.8	3888	3610	30.3	24.9
100% Slag	a/b = 0.9	3578	2938	24.9	16.6
75% Slag + 25 % Fly ash	a/b = 0.7	3435	3191	23.4	19.1
75% Slag + 25 % Fly ash	a/b = 0.8	3194	3044	20.2	17.6
75% Slag + 25 % Fly ash	a/b = 0.9	3198	2554	19.5	12.3
50% Slag + 50 % Fly ash	a/b = 0.7	3192	2638	19.5	12.2
50% Slag + 50 % Fly ash	a/b = 0.8	2878	2746	19.7	14.1
50% Slag + 50 % Fly ash	a/b = 0.9	3133	2308	17.9	9.7

5 CONCLUSIONS

The experimental investigation reveals the effect of replacement of fly ash with slag and alkali to binder ratio, in the behaviour of fresh and hardened phase alkali activated mortar. Based on the research outcome, the following conclusions were drawn.

- Based on the flow table test results, all the mortar mixes had good workability even without the use of superplasticizer.

- The mortar compressive strength was found to be decreasing with increase in alkali to binder ratio, and increases with increase in the slag content.
- The dynamic modulus of elasticity obtained from ultrasonic pulse velocity test was found to be decreasing with the addition of alkaline solution for all the mixes studied, and for the mixes with same a/b ratio, the value of dynamic modulus elasticity shows a tremendous increment with rise in slag content.
- The mix with 100% slag and alkali to binder ratio of 0.8 had the maximum UPV and dynamic modulus of elasticity.

How to Cite this Article:

Raju, T., Namitha, S., Muhammed, NK., Mohammed, R NV., Sundhar, R., Reshma, S., Ramaswamy, KP., & Saraswathy, B. (2021). Effect of alkali content and slag content on the fresh and hardened properties of air-cured alkali activated mortar containing fly ash. *AIJR Proceedings*, 399-405.

REFERENCES

Arun, B. R. Nagaraja, P.S and Srishaila Jagalur Mahalinga Sharma. (2018) *Combined effect of fly ash and GGBS on workability and mechanical properties of self compacting geopolymer concrete*, International Jurnal of Pure and Applied Mathematics, 119(15), 1369-1380.

Bernal, S.A. De Gutierrez, R.M. Pedraza, A.L. Provis, J.L. Rodriguez, E.D and Delvasto, S. (2011) *Effect of binder content on the performance of alkali-activated slag concretes*, Cem. Concr. Res. 41 (1), 1-8.

Bhowmick, A. and Ghosh, S. (2012) *Effect of synthesizing parameters on workability and compressive strength of fly ash based geopolymer mortar*, International Journal of Civil and Structural Engineering, 3 (1), 168-177.

Chaitanya, S.T. and Gunneswara Rao, T.D. (2018) *Mix design procedure for alkali-activated slag concrete using particle packing theory*, J. Mater. Civ. Eng. 30 (6), 1-11.

Chaparro, W.A. Ruiz, J.H.B and Gomez, R.D.J.T. (2012) Corrosion *of reinforcing bars embedded in alkali-activated slag concrete subjected to chloride attack*, Mater. Res. 15 (1), 57-62.

Davidovits, J. (1994) *Properties of geo-polymer cements*, in: First International Conference on Alkaline Cements and Concretes, SRIBM Kiev State Technical University, Kiev Ukraine, 131-149.

Davidovits, J. (2005) *Geopolymer*, Green Chemistry and Sustainable Development Solutions, Institute Geopolymer, Saint-Quentin, France, 9-15.

Fernandez-Jimenez, A. and Palomo, A. (2003) *Characterization of fly ashes. Potential reactivity as alkaline cements,* Fuel 82, 2259-2265.

Guohao Fang, Wing Kei Ho, Wenlin Tu and Mingzhong Zhang, (2018) *Workability and mechanical properties of alkali activated fly ash – slag concrete cured ambient temperature,* Construction and Building Materials, 172, 476-487.

Hardijito, D and Rangan, B.V. (2005) *Development and properties of low calcium flyash-based geo-polymer concrete*, Research Report GCI, Faculty of Engineering Curtin University of Technology, Perth, Australia.

Islam, A. Alengaram, U.J. Jumaat, M.Z. and Bashar, I.I. (2014) *The development of compressive strength of ground granulated blast furnace slag-palm oil fuel ash-fly ash based geopolymer mortar*, Materials and Design 56, 833-841.

Jumrat, S. Chatveera, B. and Rattanadecho, P. (2011) *Dielectric properties and temperature profile of fly ash-based geopolymer mortar,* International Communications in Heat & Mass Transfer, 38 (2), 242-248.

Kabir, S.M.A. Alengaram, U.J. Jumaat, M.Z. Sharmin, A. and Islam, A.(2015) *Influence of molarity and chemical composition on the development of compressive strength in POFA based geopolymer mortar,* Advances in Materials science and Engineering, 1-15.

Malkawi, A.B. Nuruddin, M.F. Fauzi, A. Almattarneh, H. and Mohammed, B.S. (2016) *Effect of alkaline solution on properties of the HCFA geopolymer mortars*, Procedia Engineering, 148, 710-717.

Mallikarjuna Rao, G. and Gunneswara Rao, T.D. (2015) *Final setting time and compressive strength of fly ash and GGBS-based geopolymer paste and mortar*, Arabian Journal of Science Engineering, 40, 3067-3074.

Nitendra, P. Ravi Shankar, A.U. and Mithun B.M. (2016) *Durability studies on eco-friendly concrete mixes incorporating steel slag as coarse aggregates*, J. Clean. Prod. 129, 437-448.

Ranjbar, N. Mehrali, M. Behnia, A. Alengaram, U.J. and Jumaat, M.Z. (2014) *Compressive strength and microstructural analysis of fly ash/palm oil fuel ash based geopolymer mortar,* Materials and Design, 59, 532-539.

Vasconcelos, E. Fernandes, S. Barroso de Aguiar, J.L. and Pacheco-Torgal, F. (2011) *Concrete retrofitting using metakaolin geopolymer mortars and CFRP*, Construction and Building Materials, 25, 3213-3221.