

Alkali-Activated Blast furnace Slag as a Green Construction Material

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ABSTRACT: The Portland Cement industry contributes approximately 7% of global greenhouse gas production. The reduction of CO₂ emissions can be possible through the development of alternate binders like Alkali-activated slag (AAS). An attempt has been made to manufacture Alkali-Activated Slag composites which can be considered as a Green construction material. The paper presents the effect of curing conditions on engineering properties such as Water absorption, Apparent porosity and Compressive strength of AAS pastes. The alkali-activation was done using a combination of potassium hydroxide and sodium silicate. The test parameters include curing types (Water curing at room temperature (28^o C), Heat curing at 40^o, 50^o and 60^o C) and Alkali content (6.41%, 10.41% and 12.41%) of the mass of blast furnace slag). It has been found that Curing condition and Alkali content have significant effects on the physical and mechanical properties of AAS.

Keywords: Alkali activated blast furnace slag, Apparent porosity, Compressive strength, Curing conditions, Water absorption

I. INTRODUCTION

Construction industry contributes around 5-8 % of all global CO₂ emissions and this figure will increase in the coming decades as the developing world continues to use more and more concrete [1]. Ordinary Portland cement is one the most pollutant products in terms of CO₂ emissions. However, Cement and concrete industries have implemented several mechanisms to reduce the CO₂ emissions of concrete, but they have had only a very minimal effect [1]. The greatest carbon dioxide savings from the industry are likely to be achieved by the inclusion of supplementary cementitious materials [2], such as fly ash [3] or ground granulated blast-furnace slag [4]. The manufacture of Alkali-activated blast furnace slag may be considered as an alternate binder to ordinary Portland cement. Alkali-activated binders are receiving much attention because of their high strength, durability and low environmental impact [5]. The greenhouse gas savings achievable through the use of alkali-activated concrete has been estimated around 80 % compared to Portland cement concretes [1, 6].

Alkali-activation of ground granulated blast furnace slag (GGBS) has become the subject of intense research interest within the past decade. Strength development of slag cement is highly sensitive to curing conditions [7]. Alkaline activation of blast furnace slag is affected due to the high concentration of OH⁻ ions in the mix [8,9,10]. It has been reported that all caustic alkalis and alkali compounds whose anions or anion groups can react with Ca²⁺ to produce Ca compounds that are less soluble than Ca(OH)₂ can act as activators of slags [10-14]. Bakharev et al. [15] reported that heat treatment had a significant accelerating effect on strength development of slag pastes. They further concluded that sodium silicates provided the best activation, with compressive strength of pastes and mortars exceeding that of OPC pastes of the same w/b ratio. The alkali and silicate content also plays a significant role in the development of compressive strength [16-18]. The curing conditions had a significant effect on the mechanical behavior of the hardened state of alkali-activated slag paste [19,20]. This paper investigates the effect of curing conditions on engineering properties such as Water absorption, Apparent porosity and Compressive strength of AAS pastes.

II. EXPERIMENTAL INVESTIGATION

2.1. Materials

2.1.1. Blast furnace slag

Blast furnace slag used in this investigation was obtained from the Tata Metaliks Ltd. Kharagpur, India. The obtained blast furnace slag particle were coarser (4-5 mm), popcorn like friable structure. The slag was then ground to size 45 microns [21]. The chemical composition was determined by XRF as shown in Table 1. Its density was 2900 kg/m³. The moisture content was less than 1%.

TABLE 1: Chemical composition of blast furnace slag by XRF

Chemical composition	SiO ₂	CaO	Al ₂ O ₃	MgO	Fe ₂ O ₃	SO ₃	Na ₂ O	K ₂ O	TiO ₂	MnO	LOI ^a
Mass (%)	32.50	33.50	18.50	8.00	0.40	0.5	0.7	0.4	1.01	0.55	0.7

^aLoss on ignition

2.1.2 Alkaline Solution

The alkaline activator liquid was the combination of sodium silicate and potassium hydroxide pellets. Laboratory grade potassium hydroxide was supplied by Merck India Ltd. (84% purity with K₂O =83. 93% and 16.07% water) and sodium silicate solution (Na₂O = 8%, SiO₂ = 26.5% and 65.50% water) with silicate modulus ~3. 3 and bulk density of 1410 kg/m³ was supplied by Loba Chemie Ltd. India, were used to adjust the desired composition of alkali activated GGBS paste. The activator solution was prepared at least one day prior to its use.

2.2 Mixing and castings of test specimens

The alkali activated GGBS paste was prepared according to the composition presented in Table 2. The compositional change in GGBS paste was obtained by adjusting the quantity of potassium hydroxide, sodium silicate solution with water. To make alkali activated GGBS paste, the desired proportion of blast furnace slag and activating solution were first mixed together for 5 min in a Hobart mixer to get a homogeneous paste. The mixing procedure is similar to that described by Qureshi and Ghosh [22]. The workability was assessed using mini flow table [22] and is presented in Table 2.

TABLE 2: Mix composition and Flow of Alkali-activated GGBS.

Mix	% K ₂ O	% Na ₂ O	W/S ratio	Flow (mm)
Series 1	4	2.41	0.32	150
Series 2	8	2.41	0.32	165
Series 3	10	2.41	0.32	175

2.3 Curing conditions of test specimens

The test specimens were cured in water curing, oven curing at 40⁰ C, 50⁰C and 60⁰C. For water curing, the specimens after casting were left at room temperature for 24 hours , then de-

molded and kept in water in fully immersed condition at room temperature until the day of testing. For heat curing, the specimens were given a rest period of 2 hrs after casting and then kept in the oven at 40°C, 50°C and 60°C for 24 hours. The test specimens then removed from the molds and left to air dry at room temperature until the day of the test at a specified age.

2.4 Test Procedure

The alkali activated GGBS paste specimens (50mm x 50mm x 50mm) were tested for compressive strength using 20 ton capacity digital compressive testing machine with a loading rate of 20 MPa/min. The compressive strength tests were conducted at the age of 3, 7 and 28 days. Three specimens of each series at each age were crushed in a digital compression testing machine in accordance with ASTM C-109-02 [23] and the average strength of three specimens is reported as the compressive strength. To determine the water absorption, three cube specimens from each series were oven dried at a temperature of 850 C for 24 hours and its weight was determined as initial weight. The specimens were then immersed in water for 24 hours and its saturated dry weight was recorded as a final weight. Water absorption is reported as the percentage increase in weight. The apparent porosity was determined for 28 days specimens according to Archimedes principle with water as immersion medium.

III. RESULTS AND DISCUSSION

3.1 Influence of Alkali content on Compressive strength

The relationship between Alkali content and Compressive strength is presented in Fig. 1. The increase in compressive strength was observed with increase in alkali content until 10.41 % alkali content. Further increase in alkali content reduces the compressive strength. This trend was observed for all types of curing method. This may be due to excess K^+ ions in the framework, the slag grains might not completely participated in the reaction process forming C-S-H gel and the degree of reaction of the system might remain moderate [19]. The optimum alkali content was observed to be 10.41 % for all types of curing methods. The optimum silicate modulus phenomenon to the formation of “primary C-S-H” and /or polymerization of silicate anions in the water glass, which promotes the hydration of slag and the formation of less porous structure [24].

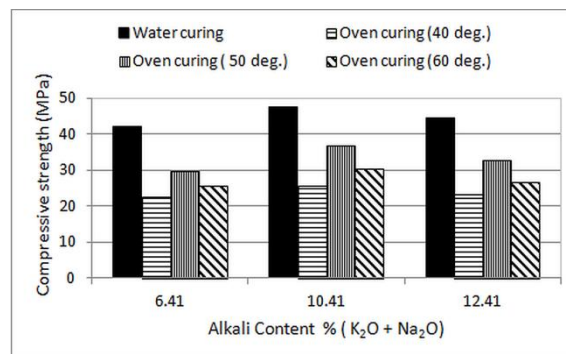


Fig. 1 Relation between Alkali content and Compressive strength for various Curing conditions.

3.2 Influence of Curing conditions on Compressive strength, Water absorption and Apparent porosity

The variations of compressive strength of the specimens cured in water at room temperature (28^oC), oven curing with 40^oC, 50^oC and 60^oC are shown in Fig. 1. It was observed that the compressive strength increases with increase in alkali content from 6.41 % to 10.41 % for all types of curing methods and reaches maximum 47.50 MPa for alkali content of 10.41 % for water cured specimens followed by oven cured specimens at 50^oC. The results revealed that the 28 days strength of water cured specimens were 86.27 %, 30.55 %, 57.28 % higher than that of oven cured specimens at 40^oC, 50^oC and 60^oC respectively for the optimum 10.41 % alkali content.

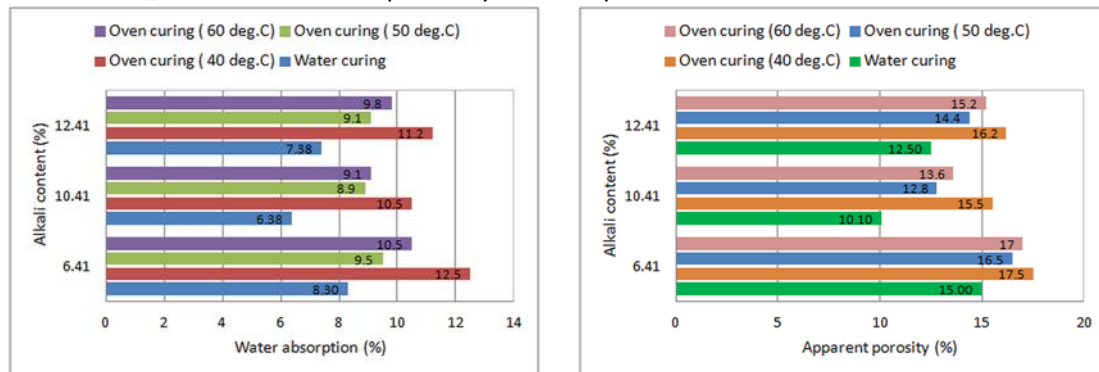


Fig. 2 Relation between Alkali content with Water absorption and Apparent porosity for various curing conditions.

The relationship between alkali content with water absorption and apparent porosity is presented in Fig. 2. A decrease in water absorption and apparent porosity was observed for water cured specimens compared to oven cured specimens for alkali content ranging from 6.41 % to 10.41 % and thereafter, there was an increase in water absorption and apparent porosity for 12.41 % alkali content. A similar trend was observed for all types of curing conditions. The minimum water absorption and apparent porosity of 6.38 % and 10.10% was observed for water cured specimens having alkali content of 10.41% indicating more homogenous and compact structure of the matrix.

IV. CONCLUSIONS

The effect of curing conditions on engineering properties such as Water absorption, Apparent porosity and Compressive strength of alkali activated GGBS paste has been investigated. Based on experimental study, the following conclusion is drawn.

- Water curing was found to be the best curing method compared to oven curing for alkali activated GGBS paste.
- The maximum compressive strength of 47.50 MPa was achieved for water cured specimens for alkali content 10.41%, having lowest water absorption and apparent porosity of 6.38 % and 10.10 % respectively.
- The oven curing was found to be more sensitive for alkali activated slag. The higher water absorption and apparent porosity were observed in oven cured specimens. The optimum oven curing temperature was found to 50^oC, which provided compressive strength of 36.50 MPa.
- The compressive strength of the alkali activated blast furnace slag composites can be controlled by judiciously choosing the curing conditions.

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