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Review on Mix Parameters on the Fresh and Hardened Properties of Alkali Activated Concrete

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Abstract

Alkali-activated concrete (AAC) has attracted considerable attention since its first use as an alternative material to the well-known traditional Portland cement concrete (PCC) due to their superior properties and environmental impact. Most studies have demonstrated the superior mechanical properties of Alkali Activated Slag and Fly Ash Concrete and their applicability in the construction engineering field. However, more studies and investigations related to mix design including mix proportions, mixing procedures and curing regime, with which the Alkali Activated Slag Concrete could demonstrate the best engineering properties, are required. This paper provides a review on the materials composition and the fresh properties of Alkali activated binders. Alkaline activator solutions based on sodium and potassium are also stated. We summarise previous research on the effects of Alkaline activator Binder (AAB) characteristics on workability (namely consistency, flow, and slump), setting time. The results demonstrate that, depending on mix design and processing parameters, the fresh properties of AAB may be customised for certain applications.

Keywords: *Alkali-activated concrete (AAC), Portland cement concrete (PCC), Alkali Activated Binder (AAB), Setting time, curing regime, mechanical properties.*

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I. INTRODUCTION

Infrastructure development is under high demand due to global urbanisation. The construction sector has rising demand for cement as a result of expanding infrastructural development. Carbon dioxide, methane, and nitrous oxide are among the greenhouse gases that cement manufacture releases into the environment. An estimated 0.7-0.8 t of carbon dioxide (CO_2) are released into the environment during the manufacturing of 1 t of cement. Therefore, finding alternative binders is essential for lowering carbon dioxide emissions. Utilising industrial byproducts as cement substitutes is one of the possible solutions. Alkali-activated binders are thought to be a suitable cement alternative. It is estimated that alkali-activated concrete emits about 26–45% less CO_2 than cement. Fly ash (FA) and granulated granulated blast furnace slag (GGBFS OR GGBS) are examples of aluminosilicate materials that may be used to create alkali-activated concrete. An aluminosilicate material is activated with a strong alkaline activator at high temperatures or ambient conditions to produce alkali-activated concrete. Alkaline activators, the chemical composition of the aluminosilicate material, curing conditions, and more all have an impact on the chemical reaction and strength development of alkali activated concrete [15].

The addition of more GGBS to the FA-containing binder enhanced the compressive strength of alkali-activated concrete. Alkali-activated concrete with GGBS added had a setting time and compressive strength comparable to that found in conventional portland cement [15]. As the basis of alkali activated materials (AAMs) and factors into their strength performance, the high SiO_2 and Al_2O_3 content is significant. Since the parameters are selected separately and adapted to the required applications, mix design parameters for the creation of AAMs are regarded of as flexible [5].

1.1 ALKALI ACTIVATION

Alkali activation for the formation of AAMs which includes the geopolymerization process is carried out by mixing aluminosilicate materials and alkali solution. Raw materials with high silica and alumina (usually > 50% on total summation of both SiO_2 and Al_2O_3) contents are commonly used as precursors to ensure that the AAMs formed have building units of Si and Al networks (Si-O-Al/ Si-O-Si). Hydroxide solutions, such as sodium hydroxide or potassium hydroxide, are the most common alkali solution or alkali activator. The alkali solution consists of the combination of sodium hydroxide or potassium hydroxide, with sodium metasilicate (Na_2SiO_3) or potassium hydroxide with potassium metasilicate (K_2SiO_3). The overall process of alkali activation has not been fully elucidated due to its complexity based on the raw materials used [5].

Step I is known as dissolution of aluminosilicate materials in alkali medium (also called as alkali activator). Due to the high alkalinity of alkali activator used, the covalent bonds of Si-O-Si and Al-O-Al from aluminosilicate precursors were broken down to form silicate and aluminate monomers during this step. Nucleation growth and polymerization (Step II) occur almost immediately, with monomers forming polymeric structures that gel and harden, releasing the water and heat consumed during dissolution. The formed geopolymer networks begin condensing immediately, causing the polymeric structures to reorganize and polycondensate (Step III), resulting in a 3-D aluminosilicate network of geopolymers that strengthens the geopolymers. These steps are considered exothermic due to the heat produced as by-products. Therefore, heat evolution has been regarded as a significant initiative for monitoring the alkali activation process [5].

II. ALKALI ACTIVATED SYSTEM COMPONENTS

The most commonly cementitious materials that utilized for alkali activated concrete-related research are GGBFS, FA and Silica fume. The higher alkali concentration could improve the geopolymerization of fly ash [6].

2.1 ALKALINE ACTIVATORS

Concrete voids and water absorption have decreased as a result of using more binder and having a higher solution/binder ratio [2]. Upon reaching a particular alkali content (dependent on the mineral type, activator type, and curing conditions), no more appreciable increase in strength can be seen. The best activator is produced by combining potassium hydroxide with a sodium silicate solution [1]. Due to the mixture's higher viscosity, larger activator dosages resulted in a greater bond between the aggregate and binder [19]. higher solution alkalinity was necessary to dissolve fly ash and form the corresponding sodium aluminate silicate products [20]. High alkalinity may lead to a systematic reduction in silicate chain length, hinder the occurrence of alkali-activated material polymerization, and affect the durability and stability of the adhesive [22].

Highest activator concentration has the greatest strength due to higher reaction rate and the formation of a less porous matrix. In comparison to accelerated carbonation, AAC exposed to ambient CO_2 concentrations will maintain more alkalinity [25]. Most of the slag in mortar samples with a binder made up of 50% slag and 50% fly ash would have completely reacted by the age of 28 days at a low NaOH concentration of 10 mol/L, while the slow-reacting fly ash would have had enough time to create polymerization products at a later age. Raising the NaOH molarity substantially increases the reaction rate in the 7-28 phase but marginally slows it down in the 28-90 phase. When NaOH molarity was raised from 2M to 8M, fly ash-based mortar showed a rise in temperature/heat of evolution, suggesting enhanced dissolution and polymerization of the precursor [20].

2.1.1 Sodium hydroxide (SH)

Higher the SH concentration, which improves the efficiency of activation reaction and increases the early-age compressive strength. More sodium ions are available due to the increase in SH molarity, which may allow the alkali-activated mixture to form aluminosilicate networks by balancing the charges. However, a low molarity of SH could restrict the activation reaction since less silica and alumina from the source material would be leached [17]. When treated to mixed water at greater NaOH concentrations, slag tends to create C-S-H at an early age, along with reprecipitation of the hydration products, which may delay further hydration and the development of geopolymerization products [20]. NaOH-activated AAM exhibited more brittleness and had three times higher drying shrinkage than PC mortar [22].

2.1.2 Sodium silicate

The silicate modulus of an activator and alkali content have a significant impact on the setting times, workability, mechanical characteristics, and microstructure of AAS-based binders. The activator type and its content can be changed to modify the features of AAS mortars [18]. Water absorption in slag-based mortars decreases when the sodium silicate/sodium hydroxide ratio of the alkaline activator increases. This is because when the alkaline activator's sodium silicate concentration rises, free silicates react with calcium that is evaporating from Ground granulated blast furnace slag to form calcium hydrates [20].

2.2 CEMENTITIOUS COMPONENTS

Ground granulated blast furnace slag, and fly ash were used as source materials to prepare the alkali-activated slag–fly ash concrete.

2.2.1 GGBS

Ground granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. Ground granulated blast furnace slag is a latent hydraulic binder forming calcium silicate hydrates (C-S-H) after contact with water. It is a strength-enhancing compound improving the durability of concrete.

2.2.2 Fly Ash

Compared to GGBS, FA has a substantially lower specific surface area. Therefore, substitution with FA decreased the need for water during surface wetting of precursors after mixing to enhance the quantity of free water. spherical FA particles result in better compatibility with irregular-shaped particles , which promotes a denser packing in the concrete [21]. As a precursor in the alkali-activated materials, fly ash superior to GGBS [26].

III. FRESH PROPERTIES OF ALKALI ACTIVATED BINDER

The initial fresh properties of AAM concrete mixtures were significantly improved with an increasing FA replacement ratio. [21]

3.1 NORMAL CONSISTENCY AND FLOW

The reduction of AL/B ratio would decrease the consistency of Alkali activated fly ash slag (AAFS) concrete, which would result in the accelerated reaction of raw materials [3]. Unless the w/s ratio was increased at the same time, increasing the GGBS content generally resulted in mixes with lower consistency. The slump was significantly reduced when the GGBS concentration was high (70%) but did not follow a clear trend for intermediate GGBS contents (20% and 40%) due to the scatter in the results. In general, it was found that for the mixtures to be cast, larger GGBS contents needed higher w/s ratios [10].

An increase in lime and/or plaster of Paris content in the mixture results in an increase in consistency values [14]. Increasing the water to binder (w/b) ratio, resulted in an increase in the flowability and initial setting time of the samples [23]. As the ratios of alkaline solution and flyash increases, the liquid content and flowability also increase, which causes a decrease over time [24]. The alkali-activated mortar's flowability was decreased in comparison to the OPC mortar specimen due to the increased viscosity of the alkaline solutions (sodium hydroxide and sodium silicates) [30]. The consistency of the mixture is significantly impacted by a molar concentration increase. It gets difficult to obtain a uniform mix as the mixture grows sticky and the viciousness of the mixture increases [12].

3.2 WORKABILITY

Workability of AAFS concrete is mostly influenced by the alkaline activator level in the mixtures [3]. Increasing mixing periods can help prevent fast setting times and enhance workability when preparing AAS concrete [7]. Increased alkaline solution concentration speeds up and intensifies the chemical reactions with the slag, which results in decreased water content and less slump of the final concrete [9]. In general, increasing the w/s ratio resulted in an increase in the slump values [10]. High alkali affects workability resulting in the mixture's porous nature [11]. In ambient-cured alkali-activated slag-fly ash concrete, the reduction in workability increased as the volume percentage of various kinds of steel fibres increased [15].

The workability was significantly reduced by the addition of steel fibres. Fly ash's larger spherical shape, which reduces interparticle friction, increased workability when it was used in place of slag. The molarity of sodium hydroxide (SH) solution was inversely proportional to workability [17]. The initial fresh properties and workability retention properties of AAM concrete mixtures were enhanced when blast furnace slag (BFS) was replaced with FA [21]. As FA are less reactive in the alkaline environment than BFS, substituting BFS also slows down the activation process to improve the workability retention qualities of AAM concretes [21]. Slag concentration had a greater impact at higher Sodium Hydroxide molarity (12 M) and higher AL/B ratios (0.4). Workability of AAFS decreased with the increase of SH molarity. the increase of SH molarity increased the viscosity of the solution [3].

3.3 SETTING TIME

The activator type and concentration have the greatest impact on setting times [14]. With an increase in the level of slag replacement, the initial and final setting times of AAFS pastes decreased. In mixes, adding more SH increases the concentration of hydroxide ions, which speeds up the dissolution of raw materials and reduces the setting time [3]. A higher slag to fly ash replacement ratio resulted in a quicker setting time because the mixture's hydration reaction was sped up by an increase in the major chemical component of slag, CaO. According to the interaction between the NaOH solution and the water glass, it can be said that the setting qualities will be affected [7]. Longer initial setting times were due to greater w/s ratios. The reaction may have been delayed by the increased water volume due to a dilution effect. Extremely low w/s ratios led to inappropriate initial setting times, such as less than 15 min for 60/40 mixtures with w/s ratios lower than 0.37 [10].

The water content must be raised to keep the mixture workable for extended periods of time since the shorter the setting time, the greater the GGBS content [10]. While the calcium-sulfate-hydrate gel is being hydrated, more of it is being generated as the setting progresses [14]. higher Na_2O contents results in longer setting times [18]. The initial setting time reduces as sodium hydroxide (NA) concentrations increase, whereas the slump flow varies [22]. In addition to the Si/Al ratio and the Na content, which served as a catalyst for the reaction, the high pozzolanic activity feature of slag had a significant impact on the paste's initial and final setting times [30]. If only SH is used as an alkaline activator, the setting time is reduced as the mixtures SH molarity increases [3].

IV. MECHANICAL PROPERTIES OF AAC

Mechanical properties of Alkali activated slag (AAS) mortars generally increased with the higher alkali contents. AAS mortars' early age mechanical properties were significantly lower than PC mortars'. But over time was done on, AAS mortars' compressive and flexural strengths exceeded those of PC mortars [18]. It is feasible to lower the water/GBFS ratio of AACs to a value of 0.40 and the dosage of the activator by up to 6% without affecting their mechanical or frost resistance [27].

4.1 COMPRESSIVE STRENGTH

One of the most static mechanical characteristics of AAC is compressive strength. The nature and fineness of the raw cementitious materials, the type and dose of the alkali activator, the solution to binder ratio, and the curing regime all have an impact on it. More compressive strength was produced by longer curing times, however the improvement reduced after the curing time approached 48 hours [5]. Alkali-activated fly ash/slag concrete's compressive strength may decrease if the mixture contains significant concentrations of water glass and NaOH solid. While the observed compressive strengths after 7 and 14 days were close to the expectations and the measured compressive strengths after 28 days were significantly bigger than the predictions, the measured compressive strength after three days was slightly lower than the predicted values [7].

Each mix's early compressive strength on the third and seventh days is approximately 72 and 83% of the mix's compressive strength on the 28th day [12]. Alkali-activated slag-fly ash concrete with steel fibres had a slightly greater average compressive strength than alkali-activated slag-fly ash concrete without steel fibres. The addition of steel fibres had no noticeable impact on the compressive strength of ambient-cured, alkali-activated slag-fly ash concrete mixtures [15]. 28 days of SS-activated AAM achieved the highest mechanical strength, much higher than NaOH and KOH [22] The compressive strength declined significantly as w/b ratio was increased [23]. Compressive strengths increase with water/GBFS ratio reduction [27] More water evaporation due to an increase in dry curing temperature reduces the amount of C-S-H production and thus decreases compressive strength [28]. Alkali activated slag concrete has a high early strength because it reaches about 90% of its cube compressive strength and split tensile strength at age 7 days [28]. AAC's compressive and tensile strengths both exhibit clear strain rate sensitivity, although the tensile strength impact is more evident. The damage process, energy absorption capacity, and strain rate sensitivity of AAC are all impacted by the strength grades obtained by various precursor compositions during dynamic loading [29].

4.1.1 Effect of Alkaline Solutions on Compressive Strength

Higher strengths are obtained by using higher sodium hydroxide concentration and higher alkaline solution/binder ratio. An increase in the content of sodium hydroxide, which improves polymerization and gives concrete enough alkalinity and also favours the dissolution of alumina and silica in the GGBFS, increasing the compressive strength of AASC. In terms of solution/binder ratio, the AASC exhibit relatively small variation in compressive strengths at increased sodium hydroxide concentrations. However, the compressive strengths are only relatively good at lower sodium hydroxide concentrations because some calcium-bearing compounds are present, which improves strength [2]. The early-age (14 d) compressive strength of AAFS concrete would be greatly affected by the amount of alkali (AL), whereas the 28d compressive strength would not be much affected [3]. Because the higher pH increased the reaction of the internal Si and Al to form gel phases, which provide structural strength, and caused an increasing breakage of the glassy chain at the surface of the fly ash, higher molar concentrations of sodium hydroxide solution produced higher compressive strengths. Regardless of the alkaline concentration, the mass ratio of sodium silicate solution to sodium hydroxide solution increased from 0.4 to 2.5, increasing the compressive strength of alkali activated fly ash concrete [6].

Utilising alkaline solutions over the recommended level expands capillary pores and lowers compressive strength [9]. Reduced alkali content causes the solution's water content to decrease, which makes it easier to produce superior geopolymeric products and increases their strength [12]. The compressive strength increased as the molarity of NaOH, curing time, and temperature increased [16]. For NaOH molarities of 10 mol/L and above (16 mol/L), the 0–7 phase is when mortar compressive strength increases at the maximum speed [20]. extra silicate content in the activator has similar effects as FA to improve the workability of AAMs. [21]. The increase in the ratio of alkaline solution to fly ash results in a decrease in compressive strength [24]. strength behavior is due to the increase in the formation of hydration products as a result in the increase in alkalinity. The ratio of (NaOH: Na_2SiO_3) increases, the compressive strength of AASC concrete increases [28]. The compressive strength of the mortar made with 8 M NaOH was the maximum at both 7 and 28 days, while compressive strength decreased with an increase in NaOH concentration above 8 M [4]. Higher NaOH concentrations accelerate the dissolving and activation of fly ash, which improves the development of compressive strength when fly ash makes about 50% of the binder [20]. potassium hydroxide (KH) has more excellent precursor solubility and highest compressive strength values than NH [22].

4.1.2 Effect of GGBS on Compressive Strength

Higher strengths of AASC may also be due to higher reactivity and self-cementing property of GGBFS [2]. The compressive strength is not always increased when the amount of slag is increased [7]. In an open curing system, samples were exposed to the air, which caused water from the alkaline activator solution to evaporate. This had an impact on the growth of strength. Alkali-activated mortar with significant slag concentration was shown to lose strength after a particular amount of curing time [20].

4.1.3 Effect of Fly Ash on Compressive Strength

After 7 days, calcium aluminosilicate hydrate (CASH) gel was discovered to be the reaction product that was most important for strength. Due to the longer activation reaction of fly ash particles in ambient conditions, sodium aluminosilicate (NaSH) gel was only reported in small quantities [17]. FA content facilitated the long-term strength development [21].

4.2 FLEXURAL STRENGTH

In comparison to its compressive strength, the flexural strength of blast furnace slag/fly ash-based alkali-activated paste fluctuates more. Additionally, the flexural strength of blast furnace slag/fly ash-based alkali-activated paste is typically 1/9 of the compressive strength [11]. The NaOH-activated slag mortars' flexural and compressive strength values were found to be significantly lower than those of waterglass-activated and Portland cement mortars [13]. Higher the molarity resulted in increases in flexural strength [17]. Steel fibres were added to alkali-activated slag-fly ash concrete to significantly increase its flexural strength. [15] It is well known that, flexural strength is more sensitive to cracks than compressive strength [18]. The flexural strength values increased as the slag content increased [19].

V. CONCLUSION

From this study the following conclusions are obtained:

- The nature of the activator solution is the most statistically significant variable in the alkali activation of blast furnace slag.
- The ratio of alkaline solution to slag has a direct impact on the characteristics of alkali activated slag concrete, according to the study's findings.
- As the proportions of slag and water glass and the molarity of the NaOH solution increased, the alkali-activated fly ash/slag paste's setting times shortened.
- So although alkali-activated fly ash concrete often requires heat curing to achieve a reasonable early age strength, alkali-activated slag concrete possesses strong early age compressive strength and quick strength growth. AAC is able to reach a respectable early age compressive strength without heat curing due to the use of slag and fly ash in combination.
- When slag content, SH molarity, AL/B ratio, and slag content were increased and decreased, respectively, the compressive strength of AAFS increased significantly.
- Workability of AAFS decreased as slag concentration and SH molarity increased, along with a decrease in the AL/B ratio. Slag content found to have a greater impact at higher SH molarities and higher AL/B ratios. In comparison to specimens with lower slag concentration, specimens with higher SH molarity at higher slag replacement levels showed a more noticeable loss of workability.

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