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Challenges in production and placement of alkali activated concrete for *in-situ* applications

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Despite the significant decarbonisation potential of alkali-activated concrete (AAC), its adoption for *in-situ* structural applications remains limited due to challenges related to workability retention, ambient curing, batching-plant compatibility, and safe handling of highly alkaline activators. This study has presented a comprehensive demonstration of the successful scale-up, production, placement, and structural application of a two-part AAC system in a conventional ready-mix concrete (RMC) plant. An optimised AAC mix incorporating locally available ground granulated blast furnace slag (GGBFS) and fly ash in a 70:30 ratio has been developed to achieve structural-grade performance under ambient curing conditions. The AAC has exhibited compressive strength, flexural strength, and drying shrinkage comparable to OPC-based M35 concrete, while achieving significantly higher early-age strength development. A critical operational barrier - heat generation during alkaline activator preparation (about 70 - 80 °C) has been addressed through targeted batching-plant modifications, including a water-circulation-based cooling system that has reduced activator temperatures to 35–40 °C, enabling safe handling and continuous production. Compatibility of a modified sulphonated naphthalene formaldehyde (SNF)-based admixture has ensured stable rheology and workability retention, with a slump of approximately 135 mm after 60 min, facilitating pumping and placement using a boom placer. Full-scale field casting has confirmed dense, homogeneous structural elements with sharp surfaces and no evidence of efflorescence or leaching. The results have demonstrated that, with minor plant modifications and robust safety protocols, two-part AAC can be reliably produced and placed in an RMC environment, providing a technically viable pathway for sustainable *in-situ* structural concrete construction.

Keywords: Alkali activated concrete, Ambient curing, Ready mix concrete, Slump retention, Workability

1 Introduction

Concrete still remains one of the most widely used construction materials in the world and as a commodity, its consumption is second only to water[1]. Cement is the binder used in concrete and among the different types of cement commercially available, Portland Cement accounts for bulk of the world's cement production[2]. With rapid urbanisation and infrastructure expansion, the global demand for cement is projected to increase to about 6 giga tonnes per annum by 2056[3]. However, Portland Cement production is associated with high CO_2 emissions due to clinker production, resulting in the release of about 0.5-0.6 tonne of CO_2 into the atmosphere per tonne of Portland cement produced and contributing to about 7-8% of the total anthropogenic CO_2 emissions[4-6]. It is also noteworthy that without any major change in the current structure of cement production, the contribution of Portland cement to the global anthropogenic CO_2 emissions has been projected to rise to an estimated share of about 26%[7]. The high energy demand and CO_2 emissions associated with Portland cement production have prompted the search for more sustainable binders. As interest grows in more sustainable binder systems, alkali-activated materials (AAMs) or alkali-activated binders (AABs) have emerged as a promising alternative[7]. This in turn has led to an increasing interest in AAC as a viable alternative to conventional Portland cement-based concrete. Studies suggest that CO_2 emissions in AAC is about 40-70% of that produced in case of conventional OPC based concrete[8]. One type of alkali activation is the polymerization reaction of aluminosilicate materials such as fly ash with alkaline activators resulting in the alkali activated reaction which can be used to produce AAC, a type of AAC, which significantly reduces CO_2 emissions as

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compared to concrete made with conventional portland cement[9-15].The alkali-activated reaction of fly ash with highly alkaline solutions produces an amorphous aluminosilicate gel which behaves like a binder with promising mechanical properties[10]. Another type of alkali activation results from the activation of CaO-rich precursors like ground granulated blast-furnace slag [GGBFS] having hydratable calcium oxides with alkaline solutions. This results in both alkali hydrations of the slag and alkali-activated reaction, which is a complex process involving several steps, the main product of which is believed to be calcium aluminosilicate Hydrate (CASH) gel by many researchers[10-17]. AAC made with alkali activation of both ground granulated blast furnace slag (GGBFS) and fly ash (FA) as precursors is therefore likely to involve both polymerisation and alkali hydration reactions resulting in the strength imparting phase. Among AAMs, those with higher calcium content (for example GGBFS or other CaO-rich precursors) can yield earlier strength gain, improve setting behaviour and more closely mimic OPC hydration mechanics[7]. Alkali activated mixes can be either two-part in which the alkaline activators are mixed with precursors in the liquid phase or one-part in which the alkaline activators are added in the solid phase. Two-part mixes (i.e., liquid alkali activator + precursor) remain more common for practical applications, despite handling challenges primarily due to greater control over their fresh and hardened properties[7].The *in-situ* applications of two-part AAC mixes still remain limited primarily due to issues such as - difficulties involved in the handling of the highly alkaline activator solutions, issues with workability retention over prolonged periods without compromising strength properties and achieving curing under ambient conditions[18]. Most studies on AAC mixes remain confined to laboratory settings, where controlled mixing and curing conditions do not reflect industrial-scale realities. This paper addresses the critical aspects of scaling up AAC technology to a ready-mix concrete (RMC) plant environment, focusing on the two-part mix system-where the precursor (solid) and activator (liquid) components are stored and combined separately-to ensure workability, consistency, and safe handling. Modifications made in the batching plant set-up along with the safety measures adopted for adapting the production process to a ready-mix plant are discussed along with the experimental investigations carried out to ascertain the best suited ingredients and their mix proportions to achieve the desirable fresh and hardened properties for *in-situ* application.

2 Materials and Methods

2.1 Characterisation of concrete making materials

An AAC mix corresponding to M35 grade as defined in IS 456: 2000[19] was developed with locally sourced FA and GGBFS as precursors. Firstly, characterisation of the concrete-making materials was done to check their conformance to relevant Indian Standards. GGBFS used was evaluated for its different chemical and physical characteristics as per test methods mentioned in IS 4032[20] and was found to conform to the requirements of IS 16714: 2018[21]. Results of chemical and physical characterization of GGBFS and Fly ash have been tabulated below in Table 1 and Table 2. Fly ash used was evaluated for

Table 1 — Chemical characteristics of GGBS and fly ash.

Chemical Parameter	Result GGBFS	Limits as per IS 16714: 2018	Result Fly ash	Limits as per IS 3812 (Part1): 2013
Loss on Ignition, (% by mass)	-0.97	≤ 3.00	4.67	≤ 5.00
Calcium Oxide, (% by mass)	37.66	-	5.80	-
Silica, (% by mass)	34.60	-	48.66	≥ 35.00
Reactive Silica, (% by mass)	33.96	-	23.52	≥ 20.00
Alumina, (% by mass)	18.38	-	26.72	-
Iron Oxide, (% by mass)	0.98	-	8.87	-
Magnesium Oxide, (% by mass)	5.15	≤ 17.00	1.43	≤ 5.00
Na_2O & K_2O, (% by mass)	0.28 & 0.48	-	-	-
Insoluble residue, (% by mass)	0.17	≤ 3.00	-	-
Total Sulphate as SO_3, (% by mass)	0.05	≤ 3.00	-	-
Sulphide sulphur, (% by mass)	0.39	≤ 2.00	0.75	≤ 3.00
Chloride, (% by mass)	0.024	≤ 0.10	0.026	≤ 0.05
Manganese Oxide, (% by mass)	1.32	≤ 5.50	-	-

Table 2 — Physical characteristics of GGBS and fly ash.

S. No.	Physical Parameters	Result GGBFS	Requirements as per IS 16714: 2018	Result Fly ash	Requirements as per IS 3812 (Part1): 2013
1	Blaine's Fineness (m^2/kg)	335.0	≥ 320.0	325.00	≥ 320.00
2	Specific Gravity	2.9	-	2.33	-
3	Slag Activity Index at 07 days, %	63.5	≥ 60.0	0.03	≤ 0.80
4	Slag Activity Index at 28 days, %	78.6	≥ 75.0	6.40	≥ 4.50
5	Compressive strength at 28 days as % of the strength of mortar cubes (%)			90.8	≥ 80

its chemical characteristics as per test methods mentioned in IS 1727[22] and was found to conform to the requirements of IS 3812 (Part1): 2013[23].

Commercial grade Sodium Hydroxide (NaOH, 97.16% purity) and Sodium Silicate (Na_2SiO_3, 48.10% total soluble silicates) were used as the alkaline activators for developing the mix. This choice of activators aligns with findings from previous studies, which have identified these compounds as best for synthesis of alkali activated mixes[24-26]. Both the alkaline activators were used as solutions in the liquid state to prepare the two-part AAC mix. To prepare the NaOH solution, NaOH pellets were dissolved in water (same as the mixing water used) at least 24 hours prior to the use of the activator solution, to allow ample time for the heat generated by the addition of NaOH to water to dissipate. For aggregates, two separate fractions of 20 mm and 10 mm maximum nominal sized coarse aggregates conforming to IS 383: 2016[27] used in combined form were used as coarse aggregate and crushed stone sand conforming to the requirements of IS 383: 2016 was used as fine aggregate for preparation of the mix. Water conforming to the requirements of construction water as per IS 456: 2000[19] was used as mixing water.

2.2 Mix design for strength with high workability retention

To prepare an AAC mix suitable for ready mix application, it is imperative for the mix to have adequate workability along with the desired retention so that it can be mixed in the mixers available in a ready mix batching plant set up, transported in transit mixer trucks over long distances and placed with appropriate pumping equipment. Further, to make it suitable for *in-situ* applications, the mix needs to exhibit strength development characteristics similar to conventional OPC based mixes while being cured at ambient curing temperatures. In order to address this challenge, several trials using various proportions of the precursor materials (fly ash and GGBS) were carried out and it was observed that a precursor mix with GGBS and fly ash proportioned in the ratio of 70:30 respectively yield optimum results in terms of strength gain while being cured at and ambient temperature of around 25-30°C. This is line with the findings of a previous study done by Ojha et al.[28] and also supports the findings by various researchers that AAC mixes with high calcium content develop early age strength gain similar to OPC based mixes[7,29-30]. Around 15 to 18 mix trials were conducted for development of the AAC mix by varying the total Na_2O (% by weight of total binder, i.e., GGBS + fly ash) from 5% to 8% and keeping activator modulus (ratio of SiO_2 and Na_2O) as 1 and varying water to binder ratio to achieve mixes of required strength and desired level of workability. The mix was designed to have a workability of at least 100-120 mm slump measured as per IS 1199: Part 2: 2018[31] after 60 minutes to ensure smooth pumpability. In order to achieve such an AAC mix, laboratory trials with different types of chemical admixtures were done and it was seen that modified sulfonated naphthalene formaldehyde (SNF) based superplasticiser gave the best results in terms of workability as well as strength gain. This finding is in line with the study done by Amer et al.[32]on the use of chemical admixtures in slag-based alkali activated concretes which concluded that SNF based admixtures improve compressive strength, workability, and slump retention better than Poly carboxylic ether (PCE) based admixtures in GGBS-based alkali activated concrete. The adsorption-dispersion effect of SNF based admixture on slag-based alkali activated concretes could be a possible reason for this. Further, SNF based admixtures are known to exhibit much better chemical stability in highly alkaline environments (pH>13)[33], which is critical in the highly alkaline AAC mixes. The addition of the superplasticiser enhances workability with a slight decrease in strength in GGBFS-based ambient-cured alkali activated concrete[34]. For the final mix, 7% Na_2O by weight of the total binder was adopted. The final mix proportions corresponding to saturated surface dry aggregates are presented in Table 3.

Table 3 — Mix details of the finalised AAC mix.

Binder (kg/m^3)		Effective Water Content (kg/m^3)	Chemical Activators (kg/ m^3)		Admixture (%)	Sand (kg/m^3)	Aggregate (kg/m^3)	
FA	GGBFS		NaOH	Na_2SiO_3			10 mm	20 mm
245	105	161	17.3	74.3	2.0	662	494	606

Fig. 1 — Test set-up for compressive strength.

Fig. 2 — Test set-up for flexural strength.

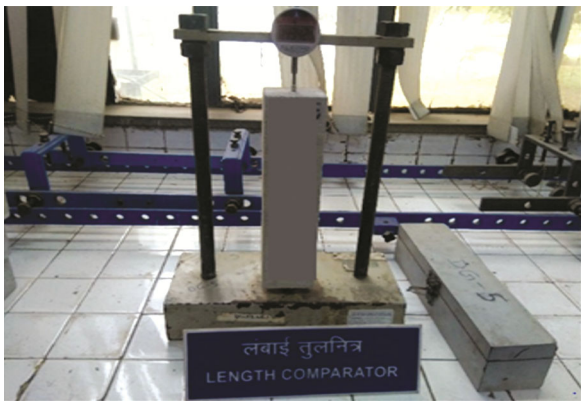

Fig. 3 — Test set-up for drying shrinkage.

2.3 Evaluation of fresh concrete properties

All of the mix trials were evaluated for workability in terms of slump as per IS 1199: Part 2: 2018[31]. The finalized mix was observed to have a slump of 135 mm at 60 minutes. The finalized AAC mix was also evaluated for the following fresh properties and compared with those of an Ordinary Portland Cement Concrete (OPCC) mix of equivalent strength grade: (a) Workability: Test for workability in terms of slump was carried out as per IS 1199: Part 2: 2018[31]. The slump loss of the mix with respect to time was measured up to a time period of 60 minutes. (b) Air Content: This test was conducted on fresh concrete using the pressure method as per IS 1199 (Part 4): 2018[35]. (c) Plastic Shrinkage: This test was conducted on concrete slab (of size 560 mm × 355 mm × 100mm) as per ASTM C1579[36].

2.4 Evaluation of hardened concrete properties

The finalized AAC mix was evaluated for few hardened mechanical properties and compared with those of an Ordinary Portland Cement Concrete (OPCC) mix of equivalent strength grade. The following mechanical properties are discussed in this paper: (a) Compressive strength: This test was conducted on concrete cubes (of size 150mm × 150mm × 150mm) as per IS 516 (Part1/Sec1): 2021[37] at the age of 7 and 28 days. Test set up for compressive strength is shown in Fig. 1(b) Flexural strength: This test was conducted on concrete beam (of size 500 mm × 100 mm × 100 mm) as per IS 516 (Part1/Sec1): 2021[37]at the age of 28 days. Test set up for evaluation of flexural strength has been shown in Fig. 2. (c) Drying Shrinkage: This test was conducted on concrete beam (of size 75 ×75 ×300 mm) as per IS 516 (Part 6): 2020[38]. The test sample being evaluated for drying shrinkage is shown in Fig. 3.

2.5 Batching plant set up and modifications done

In addition to the evaluation of the AAC mix for mechanical and durability properties of hardened concrete, in order to ensure suitability of the AAC mix for *in-situ* applications, it was felt necessary to scale up the production of the designed AAC mix in a ready mix concrete batching plant set up. The batching proposed for use in its existing form had the following key components and features:

Fig.4 — Arrangement of hoppers and silos in the batching plant.

Fig. 5 — (a) Auto-cut feature display after measurement of batched quantities, (b) control panel of the fully automated batching system and (c) software interface showing batching parameters and mix data.

i. There were 3 silos in the batching plant. There was one separate silo each for GGBS and fly ash which were loaded into the batching plant mixer by pumping. The 3rd silo was for OPC which was not used for production of the AAC mix (Fig. 4).
ii. Aggregates were being stored in hoppers. There was one hopper each for coarse aggregate of 20 mm and 10 mm maximum nominal size respectively. Two hoppers were being used for storing fine aggregate (crushed sand) because of concerns regarding storage problem in one single hopper resulting from moisture due to the ambient weather conditions.
iii. A graduated jar of 15 l capacity was being used for measuring the quantity of chemical admixture added to the AAC mix.
iv. The mixer being used for mixing of concrete mixes in the batching plant was a 60 HP twin shaft mixer with a maximum capacity of 60 cum/hr. The mixing time after feeding a single batch into the batching plant mixer was about 30 seconds.
v. The batching system was fully automated, with auto-cut feature after measurement of the batched quantities as per the input given (Fig. 5).

In the existing batching plant setup, the ingredients of the AAC mix would have to be added to the batching plant mixer either from the silos, or hoppers or the graduated jars. However, there were some major challenges in using the batching plant set up in its existing form for preparing the AAC mix. Firstly, the excessive heat generated while adding the NaOH pellets to water for preparing the alkaline activator solution, made it necessary to allow sufficient time for the temperature of the activator solution to cool down to a manageable level before adding it to the solid precursors in the batching plant mixer. This made it impractical to prepare the AAC mix in a ready mix plant set up where large quantities of concrete are required to be produced by producing successive batches of concrete in quick succession to meet day to day demands. Second, the high alkalinity of the alkaline activator solution would make it extremely corrosive at high temperatures for the conventional batching plant components which are made of mild steel. This would again make it very difficult to produce successive batches of the AAC mix in quick succession and produce large quantities of AAC mixes to meet daily demands without compromising the integrity of the batching plant components and affecting the safety of the personnel handling the equipment and the highly alkaline activator solutions. In order to overcome these challenges and make it practical to produce the AAC mix in the ready mix plant setup, the modifications were made such as (a) Two separate stainless steel drums were arranged for preparing the alkaline activator mix. First NaOH was added to the water present in these drums. A lot of heat was liberated after addition of NaOH, (b) Na_2SiO_3 was stored in separate containers kept around these activator mixing drums. Na_2SiO_3 was added to the alkaline activator mix from these containers around 15-30 minutes after the addition of NaOH, (c) In order to shorten the time for bringing down the temperature of the alkaline activator mix, a simple arrangement for cooling of the activator mix was designed. This consisted of using pipes wrapped around the drums through which water drawn by pumping from a reservoir/tank next to these drums was circulated. The high specific heat of liquid water would result in the water absorbing a significant amount of heat generated in the alkaline activator mix, (d) After mixing Na_2SiO_3, the cooling was done for about 1 hour using the pipes through which water drawn from the reservoir was being circulated. The alkaline activator mix was then introduced into the batching plant mixer through a motorized pumping arrangement (Fig. 6).

The following line diagram (Fig. 7) depicts the modified batching plant set up and the sequence of production of the AAC mix and its subsequent transportation and placement:

2.6 Safety aspects during production

The production of AAC, including GC, in batching plants involves handling of highly alkaline chemical activators, fine aluminosilicate powders, and energy-intensive mixing and curing operations. These processes introduce safety risks that differ significantly from those associated with conventional Portland Cement concrete and therefore require specific safety provisions, as emphasised in IS 17452: 2020[39].IS 17452: 2020 identifies alkaline activators such as sodium hydroxide (NaOH) and sodium silicate solutions (Na_2SiO_3) as critical safety-sensitive materials. NaOH solution preparation, being an exothermic process, was carried out in a controlled environment using corrosion –resistant containers. In the present case cylindrical stainless steel drums placed in a designated area were used for preparing the NaOH solution. Personnel involved in handling the activators used appropriate personal protective equipment, including chemical-resistant gloves, eye and face protection, and safety helmets, in accordance with IS 15928: 2012[40], IS 5983: 1980[41] and IS 8519: 2024[42], respectively. The designated areas for preparation of the activator solutions had adequate ventilation. Provision of emergency eyewash and shower facilities were also provided in the batching plant premises as these are essential to mitigate chemical exposure risks. Handling and storage of aluminosilicate source materials such as FA and GGBFS, as permitted under IS 17452: 2020[39], require effective dust control measures. Enclosed silos, dust extraction systems and controlled material transfer mechanisms by means of pumping lines (Fig.4) were provided to minimise inhalation hazards. Respiratory protective equipment conforming to IS 9473: 2002 (Reaffirmed 2014)[43]were used in dust-prone zones. All Batching and mixing equipment used for AAC were calibrated to ensure their compliance with IS 4925: 2023[44], with particular attention to higher torque demand and altered rheological behaviour of alkali-activated mixes. Safety interlocks, emergency stop systems, and restricted access to moving components are mandatory aspects of safety measures and as such were also made an integral part of the batching plant. IS 17452: 2020[39] further emphasizes the importance of chemical spill management, worker training and procedural control.

Spill containments and neutralisation systems were provided and ready accessibility of material safety data sheets was ensured. Prior to use of the batching

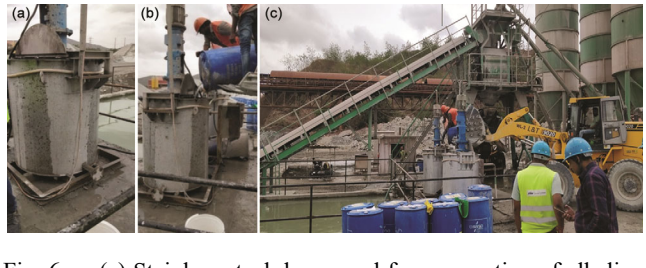

Fig. 6 — (a) Stainless steel drum used for preparation of alkaline activator solution, (b) addition of sodium hydroxide to water during activator preparation and (c) batching plant setup showing conveyor system and site-scale AAC production operations.

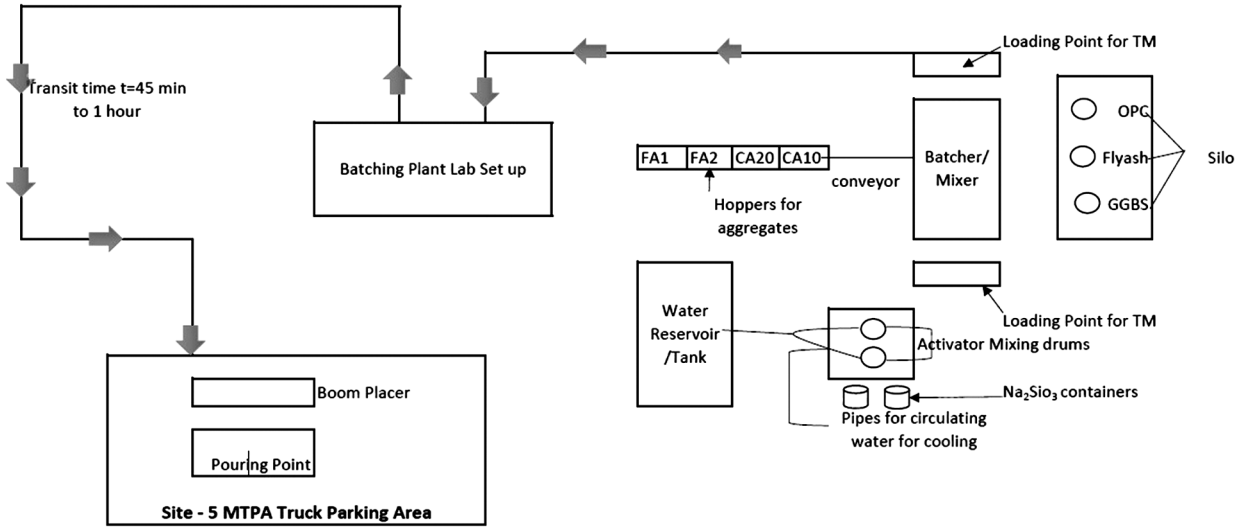

Fig.7 — Line diagram depicting the modified batching plant set up and the sequence of production of the AAC mix.

Fig. 8 — Pouring of concreting using a truck mounted boom placer pump.

plant for the full-scale *in-situ* casting, the batching plant staff were properly trained regarding the operational, health and safety aspects. They were rigorously trained so as to become properly acquainted with the batching and mixing equipment along with the specific safety mechanisms incorporated in the batching plant and the safety gear to be adopted and used. Prior to making the batching plant setup fully operational, a through safety audit was conducted in accordance with the requirement of IS 14489: 2018[45] to ensure fool proof readiness. Such periodic training and safety audits, as recommended in IS 14489: 2018[45], are essential to ensure safe and consistent AAC production in batching plants. Lab staff also wore lab aprons, long sleeves, and goggles for proper safety during testing, as irritating red spots on the skin can be caused by fragments of de-moulded AAC mixes[46]. Personal protective equipment, such as helmets, safety boots, rubber gloves, safety goggles, and other protective gear were used at the RMC plant as well as the site where pouring and placement of AAC mix was done.

2.7 Casting and curing

The prepared AAC mix was used in the casting of a single storey framed steel reinforced structure of approximate plinth area of 90 sq.m and the approximate quantity of concreting being about 30 m^3. The pouring of concreting was done using a truck mounted boom placer pump (Fig. 8) and compaction was done using immersion type needle vibrators of 40 mm diameter conforming to IS 2505: 2023[47].The ambient temperature during the casting varied from 25^0C to 38^0C. In AAC mixes, the main role of the mixing water is to provide adequate workability. Only part of the mixing water is used in the alkali activation and alkali hydration reactions. Therefore, in order to prevent sudden moisture loss, curing compound was applied on the surfaces of the structural elements which were cast at an ambient temperature exceeding 35^0C as soon as practically possible.

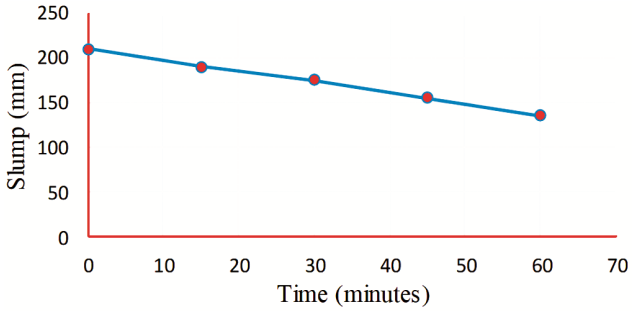

Fig. 9 — Slump of the mix w.r.t time.

3 Results and Discussion

3.1 Fresh concrete properties

3.1.1 Workability

The workability of the finalised AAC mix was studied by measuring the slump loss w.r.t time. The mix was initially observed to be in collapsed state with a measurable slump of 210 mm. The slump of the mix at the end of 60 minutes from the time of adding the full quantity of mixing water was measured to be 135 mm. The slump of the mix was measured at 15 minute intervals. The slump of the mix w.r.t time as measured in the laboratory is indicated in Fig. 9. The behaviour of the mix in terms of workability and loss in slump was found to be similar to that of an OPC mix which is possibly because of the precursor being rich in CaO because of the higher GGBFS content.

3.1.2 Air content

The air content of the AAC mix evaluated by the pressure method in accordance with IS 1199 (Part 4): 2018[35] was found to be 2.1% as compared to 1.7% for the conventional OPCC mix of equivalent strength grade. The higher amount of entrapped air is possibly because of the intrinsic microstructure of the C-A-S-H and N-A-S-H gels which are typically more porous than C-S-H gels found in OPC based mixes.

3.1.3 Plastic shrinkage

The plastic shrinkage test done on the concrete slab specimen as per ASTM C1579 did not indicate any observable plastic shrinkage cracks on the surface of

Fig. 10 — Plastic shrinkage test on AAC mix.

Table 4 — Hardened Properties of the AAC mix

Cube Compressive Strength(MPa)		Flexural Strength(MPa)	Drying Shrinkage(%)
7 Days	28 Days	28 Days	28 Days
43.29	48.93	3.84	0.018

the specimen.Evaluation of concrete specimen for plastic shrinkage is shown in Fig. 10.

3.2 Mechanical properties of hardened concrete

Results of hardened properties, i.e., compressive strength, flexural strength and drying shrinkage of the AAC mix have been tabulated below in Table 4.

The AAC system attained an average 28-day compressive strength of 48.93 MPa, meeting structural-grade requirements, while exhibiting a markedly higher early-age strength development than OPC concrete designed for the same 28-day strength class. This accelerated strength evolution is attributable to the rapid dissolution of reactive aluminosilicate species from GGBFS and fly ash in the highly alkaline activating environment, followed by fast precipitation and polycondensation of reaction products. The high calcium content of GGBFS promotes early formation of C–A–S–H type gels, while fly ash contributes to the development of N–A–S–H gel networks, resulting in a hybrid gel assemblage that rapidly densifies the matrix and enables early load-bearing capacity, in contrast to the slower clinker hydration–controlled strength development in OPC systems. The 28-day flexural strength of the AAC was 3.84 MPa, marginally lower than that of OPC concrete with comparable compressive strength, which can be ascribed to differences in microstructural homogeneity, gel connectivity, and fracture behaviour; although the hybrid C–A–S–H/N–A–S–H matrix provides high compressive resistance, tensile and flexural responses are governed by interfacial transition zone characteristics and the inherently more brittle nature of alkali-activated binders. The measured 28-day drying shrinkage of 0.018% is comparable to that of OPC concrete of similar strength and reflects the slag-rich binder composition, which produces a refined pore structure with reduced capillary porosity, limits moisture mobility, and mitigates shrinkage-induced volumetric changes, demonstrating that the developed AAC system does not exhibit the elevated shrinkage typically associated with low-calcium alkali-activated binders under ambient curing conditions.

3.3 Fresh and hardened properties of the AAC mix produced in the batching plant

The optimised AAC mix was employed for full-scale *in-situ* casting of a single-storey reinforced concrete framed structure with an approximate plinth area of 90 m², following targeted modifications to a conventional ready-mix concrete batching plant. Production, transport, and placement were monitored with emphasis onthermal control of activators, rheological stability, and admixture–binder interactions under field conditions. Immediately after dissolution of NaOH in water and prior to sodium silicate addition, the alkaline activator solution reached temperatures of approximately 70–80 °C due to the strongly exothermic reaction. Subsequent incorporation of sodium silicate, followed by application of a water-circulation-based cooling system for approximately 1 h reduced the activator temperature to 35–40 °C prior to dosing into the mixer, thereby limiting premature reaction kinetics and stabilising early-age rheology. During batching, ambient temperatures ranged from 24 °C to 38 °C; nevertheless, the AAC mix exhibited a cohesive response with no bleeding or segregation (Fig. 11), indicating effective control of yield stress and plastic viscosity. The temperature of the freshly mixed AAC at discharge was approximately 30 °C, and the mix showed a near-collapsed slump, reflecting low initial yield stress and high flowability facilitated by the chemically stable modified SNF-based admixture in the highly alkaline environment. After transportation for approximately 45 min, the AAC retained its cohesiveness at the placement site, with no segregation despite concrete temperatures
of 26–36 °C and ambient temperatures up to 38 °C (Fig. 12).

Slump measured approximately 60 min after batching was about 150 mm, confirming sustained workability and controlled structural build-up, indicative of favourable thixotropic behaviour

Fig. 11 — Cohesive with no bleeding and segregation.

Fig. 12 — Temperature measurement of AAC mix.

(Fig. 13). The observed rheological stability can be attributed to the adsorption–dispersion mechanism of the SNF-based admixture on slag-rich alkali-activated binders, which remains effective at high pH and mitigates rapid flocculation and premature stiffening. These results demonstrate that, through appropriate thermal management of alkaline activators and selection of alkali-compatible admixture chemistry, AAC can maintain stable fresh-state rheology during production, transport, and placement in a ready-mix environment, even under elevated ambient temperatures.

Two sets of concrete cubes of 150 mm size were cast for testing for compressive strength at 7 and 28-day age as per IS 516 (Part 1/Sec 1): 2021. The results are as under in Table 5:

Fig. 13 — Cohesive AAC mix at pouring location.

Fig. 14 — Constructed structure with AAC mix.

Table 5 — Compressive strength results of concrete cubes of the AAC mix cast at site during slab casting.

7 days' compressive strength	28 days' compressive strength
38.77	48.95

The finished structure was checked after 28 days using light hammering and a metallic sound was noticed on hammering of the slabs and columns. Both the mixes showed sharp surfaces with zero breakage, having no efflorescence or leaching. These observations highlight the favourable properties of the AAC mix, emphasizing the suitability of the mix and the production process for *in-situ* construction applications. The final construction is shown in Fig. 14. Subsequent to completion of casting of the structure, a full scale static load test was carried out on as per IS 456: 2000 to check the adequacy of the structure to carry static loads and the results of maximum defection and recovery in deflection were found to be well within permissible limits. The results have been discussed in detail elsewhere in literature[18].

4 Conclusion

This study establishes the technical feasibility of producing and placing two-part alkali-activated concrete (AAC) for *in-situ* structural applications using a conventional ready-mix concrete batching plant with modifications. The key conclusions are as follows:

a. The optimised AAC mix based on GGBFS and fly ash (70:30) achieved compressive strength, flexural strength, and drying shrinkage comparable to OPC concrete under ambient curing conditions, while exhibiting significantly higher early-age strength development. This confirms its suitability for structural applications without the need for elevated curing temperatures.

b. The exothermic preparation of alkaline activator solutions resulted in temperatures of approximately 70–80 °C, making direct handling and immediate batching impractical. A simple water-circulation cooling arrangement around activator storage drums effectively reduced the temperature to 35–40 °C, enabling safe handling, faster turnaround, and seamless integration of activator dosing into batching plant operations, thereby improving production efficiency at plant scale

c. A modified Sulphonated Naphthalene Formaldehyde (SNF)-based admixture showed superior compatibility with the developed AAC system, providing stable workability and slump retention. The mixes retained a slump of about 135 mm after one hour, exceeding the minimum requirement for pumping and placement using a boom placer, thus validating their field applicability.

d. The AAC mixes achieved 28-day compressive strengths meeting M35 grade requirements. Field-cast slabs and columns exhibited dense and homogeneous characteristics, sharp edges, absence of surface defects, and no evidence of efflorescence or leaching, indicating adequate reaction kinetics and matrix densification.

e. Safe production and placement of AAC require stringent health and safety measures due to the handling of highly alkaline activators and fine powders. Implementation of appropriate personal protective equipment, controlled activator preparation and transfer, dust mitigation systems, emergency response facilities, personnel training, and compliance-based safety audits was found to be essential for reliable and repeatable AAC production in ready-mix plants.

Overall, the study demonstrates that, with locally available materials, targeted batching plant modifications, and robust safety protocols, two-part AAC can be successfully scaled up to a commercial ready-mix environment, supporting its adoption as a structurally viable and sustainable alternative to OPC-based concrete.

References

1 Environment U N, Scrivener K L, John V M & Gartner E M, *Cement Concr Res*, 114 (2018) 2.

2 Beyond ZeroEmissions, Zero Carbon Industry Plan: Rethinking Cement, 1st Edn, ISBN: 978-0-9923580-2-0, 2016, p. 48.

3 Amran M, Makul N, Fediuk R, Lee Y H, Vatin N I, Lee Y Y & Mohammed K, *Case Stud Constr Mater*, 17 (2022), 1439.

4 Provis J L & Bernal S A, *Annu Rev Mater Res*, 44 (2014) 299.

5 Garcia-Lodeiro I, Donatello S, Fernandez-Jimenez A & Palomo A, *Materials*, 9 (7) (2016) 605.

6 Arbi K, Nedeljkovic M, Zuo Y & Ye G, *Ind Eng Chem Res*, 55 (19) (2016) 5439.

7 Segura I P, Ranjbar N, Jensen L S, Canut M & Jensen P, *Heliyon*, 9 (5) (2023) 15718.

8 Alsalman A, Assi LN, Kareem R S, Carter K, Ziehl P, *Cleaner Environmental Systems*, 3(2021) 100047.

9 Davidovits J, Geopolymer Chemistry and Applications (InstitutGéopolymère), 5th Edn ISBN: 9782954453118, 2008, p. 14.

10 Palomo A, Grutzeck M W & Blanco M T, *Cement Concr Res*, 29 (8) (1999) 1323.

11 Purdon A O, *J Chem Ind*, 59 (1940) 191.

12 Glukhovsky V D, Rostovskaja G S &Rumyna G V, *Proc. 7th Int Congr Chem Cem*, 3 (1980) 164.

13 Teoreanu I &Puri A, *Silicattechnik*, 6 (1975) 209.

14 Kutti T, Malinowski R & Srebrenik M, *SilicesIndustriels*, 6 (1982) 149.

15 Malolepszy J, *Ceramika*, 53 (1989) 7.

16 Puertas F, *Mater Constr*, 45 (1995) 53.

17 Fernandez A, Puertas F & Arteaga A, *J Therm Anal*, 52 (1998) 945.

18 Trivedi A, Goel R, Kumar R, Singh B, Ghatak A, Kumar R, *Indian Conc J*, 99 (8) (2025) 17.

19 Bureau of Indian Standards, Plain and Reinforced Concrete – Code of Practice, IS 456:2000, New Delhi (2021).

20 Bureau of Indian Standards, Method of Chemical Analysis of Hydraulic Cement, IS 4032:1985, New Delhi (2019).

21 Bureau of Indian Standards, Ground granulated blast furnace slag for use in cement, cement mortar and concrete – specifications, IS 16714:2018, New Delhi (2018).

22 Bureau of Indian Standards, Methods of Test for Pozzolanic Materials, IS 1727:1967, New Delhi (2018).

23 Bureau of Indian Standards, Pulverized Fuel Ash - Specification - Part 1: For Use as Pozzolana in Cement, Cement Mortar and Concrete, IS 3812 (Part1):2013, New Delhi (2022).

24 Adeleke B O, Kinuthia J M, Oti J & Ebailila M, *Materials*, 16 (6) (2023) 2400.

25 Trivedi A, Ojha P N, Singh A, Singh B, Bansal S & Sengupta L. *J Asian Concr Fed*. 8(1) (2022) 16.

26 Rahman S K & Al-Ameri R, *Constr Build Mater*, 267 (2021), 121822.

27 Bureau of Indian Standards, Coarse and Fine Aggregates for Concrete – Specification, IS 383:2016, New Delhi.

28 Ojha P N, Singh B, Trivedi A, Singh P, Singh A & Pede C. *Res Eng Struct Mater.* 9(1) (2023) 31.

29 Wang S, Kong J, Li Z, Chen H, Cao Y, Wang Y, Wang X, Feng X & Chen M, *Constr Build Mater*, 464 (2025), 140179.

30 Huseien G F, Baghban M H, Faridmehr I & Dong K, *CivilEng*, 6(3) (2025) 43.

31 Bureau of Indian Standards, Fresh Concrete – Methods of Sampling, Testing and Analysis (Part 2), IS 1199 (Part 2): 2018, New Delhi.

32 Amer I, Abdelkhalik A, Mayhoub O A &Kohail M, *Int J ConcrStruct Mater*, 18(1) (2024) 27.

33 Raju T, Ramaswamy K P & Saraswathy B, *Mater Today Proc*, 65 (2022) 846.

34 Jithendra C & Elavenil S, *Mater Today Proc*, 18 (2019) 148.

35 Bureau of Indian Standards, Fresh Concrete - Methods of Sampling, Testing and Analysis, IS 1199: Part 4: 2018, New Delhi (2018).

36 ASTM International, Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert), ASTM C 1579-21, West Conshohocken, Pennsylvania (2021).

37 Bureau of Indian Standards, Hardened Concrete Methods of Test Part 1 - Testing of strength of hardened concrete - Section 1 - Compressive, Flexural and Split Tensile Strength (First Revision), IS 516 (Part1/Sec1):2021, New Delhi (2021).

38 Bureau of Indian Standards, Hardened Concrete Methods of Test Part 6 - Determination of Drying Shrinkage and Moisture Movement of Concrete Samples (First Revision), IS 516 (Part 6):2021, New Delhi (2021).

39 Bureau of Indian Standards, Use of Alkali Activated Concrete for Precast Products - Guidelines, IS 17452:2020, New Delhi (2020).

40 Bureau of Indian Standards, Sodium Hydroxide, Food Grade - Specification, IS 15928:2012, New Delhi (2022).

41 Bureau of Indian Standards, Specification for Eye Protectors, IS 5983:1980, New Delhi (2018).

42 Bureau of Indian Standards, Guide for Selection of Occupational Protective Clothing -Body Protection (Selection, Care and Maintenance), IS 8519:2024, New Delhi (2024).

43 Bureau of Indian Standards, Respiratory Protective Devices - Filtering Half Masks to Protect Against Particles – Specification, IS 9473:2002, New Delhi (2014).

44 Bureau of Indian Standards, Concrete Batching and Mixing Plant – Specification, IS 4925:2023, New Delhi (2023).

45 Bureau of Indian Standards, Occupational Health and Safety Audit - Code of Practice (First Revision), IS 14489:2018, New Delhi (2023).

46 De Vries P, *Proceedings of the 2017 fib Symposium*, (2018) 2327.

47 Bureau of Indian Standards, Immersion Type Concrete Vibrators - General Requirements, IS 2505:2023, New Delhi (2023).