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Alkali Activated Concrete using Industrial and Agro Waste-Mix proportioning and Experimental Investigation

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Abstract

The demand for concrete is increasing day by day due to vast development in urbanisation. One of the important ingredients to manufacture concrete is cement whose production is leading to large amount of carbon dioxide (CO_2) releases attributing to global warming. To reduce the usage of cement in concrete, Supplementary Cementitious Materials (SCM) are given importance and plenty of research is done on them. SCM's can replace cement upto permissible limits and enhance the concrete properties. The concretes that can replace the cement content completely are Geo Polymer Concrete (GPC) and Alkali Activated Concrete (AAC). They are eco-friendly concretes in which the wastes coming from various types of industries, treatment plants and agro wastes can be used as binders. Alkaline activator solution is used to activate the binder materials which is a combination of silicates and hydroxides. GPC and AAC has wide range of applications like making of concrete benches in park, balusters, paver blocks and non-load bearing components etc. In this paper, a novel mix design for AAC for a constant alkaline solution to binder ratio of 0.4 is presented. The molarity of sodium hydroxide used in this study is 10M. Various mix combinations of binders using Fly ash, Ground Granulated Blast Furnace Slag (GGBS) and Rice husk ash (RHA) were considered. Workability, Physical and mechanical properties of AAC mixes were determined including Non-Destructive tests (NDT). Mixes with RHA resulted in poor compressive strength as the water demand was high and curing under ambient conditions proved to be of low impact especially for AAC with RHA.

Keywords: Alkali Activated Concrete, Activator, Rice Husk Ash, Sodium hydroxide, Sodium silicate, Compressive strength, NDT

1. Introduction

With the burgeoning growth of urban infrastructure, the stipulation of cement being the primary binder material in concrete is high [1]. The utilization of cement was nearly 2 billion tons per year in the last 10 decades and presently the production of cement is almost 3 billion tons per every year responsible for carbon dioxide (CO_2) in the same trend [2]. Since recent years, tremendous research is taking place around the globe regarding the alternate materials to cement [3]. The advent of Geo Polymer Concrete (GPC) and Alkali Activated Concrete (AAC) have gained prominence as sustainable concretes, replacing the cement content completely and contributing to lowering the carbon foot print. The cementitious matrix produced by blending solid precursors rich in silica and alumina with a catalytic liquid system and aggregates is known as GPC whereas the concrete manufactured using solid precursors containing alumino silicates and calcium oxide content (CaO) is termed as AAC [4]. The solid precursors which can be used as binders in AAC are coal based fly ash, Ground Granulated Blast Furnace Slag, Rice Husk Ash, Metakaolin, Silica Fume, Calcined clays, red mud (clays rich in iron) and natural pozzolans etc [5]. The most commonly adopted alkaline activators are Sodium hydroxide and Sodium silicate or Potassium hydroxide and Potassium silicate [6]. Other compounds like Sodium carbonate (Na_2CO_3) and Sodium sulfate (Na_2SO_4) also proved successful in activating precursors with good calcium content [7]. The alkali activated mixes made of calcium containing binders are cured at ambient temperature where in the binder materials with low calcium like fly ash alone require curing at elevated temperature [8]. AAC made with fly ash as one of the binders displayed very less expansion related to Alkali Silica Reaction (ASR) in comparison to other concretes [9].

The extensive studies made by various researchers around the world on Life Cycle Assessment (LCA) of AAC has concluded that the CO_2 emissions reduced by minimum of 40% and a maximum of 80% in comparison to Ordinary Portland Cement (OPC) [10-15]. The present study explains the mix proportioning and mechanical properties of AAC manufactured using combination of fly ash, GGBS and RHA with a constant alkaline solution to binder ratio of 0.4. The effect of slump and Non-Destructive Testing (NDT) on AAC have also been discussed.

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2. Materials

2.1. Fly ash

Fly Ash is the industrial waste coming out from thermal power plants and is used as a predominant admixture in concrete. The fly ash used in this study was procured from Sri Bhavani RMC Plant, Hyderabad. The values of various physical tests performed on Fly ash are shown in Table 1.

2.2 Ground granulated Blast furnace Slag (GGBFS)

Ground-granulated Blast-furnace Slag (GGBFS) is waste coming from steel and iron industries, used extensively as an admixture in conventional and special concretes. The GGBS used in this study was procured from IJM industry, Hyderabad. The values of various physical tests performed on GGBS are shown in Table 1.

2.3 Rice husk ash (RHA)

Rice husk ash (RHA) is obtained by combustion of rice husk which is the protective covering of a rice grain. RHA being a good filler, rich in silica content and possessing good pozzolanic reactivity its use as a potential supplementary cementitious material (SCM) is studied worldwide. The RHA used in this study is procured from Sri Rajalaxmi rice mill, Hyderabad. The values of various physical tests performed on RHA are shown in Table 1. The oxide composition of the binder materials is tabulated and shown in Table 2.

2.4 Fine aggregate

Locally available river sand confirming to Zone III was used as fine aggregate in this study. To overcome the problem of bulking, sand was oven dried beforehand.

2.5 Coarse aggregate

Natural crushed granite stone of sizes 10mm and 20mm were used depending upon the workability. Tests on physical properties of aggregates such as Fineness modulus, Bulk density, Specific gravity and Water absorption were conducted on coarse aggregate and the results are tabulated and shown in Table 3.

2.6 Activator Solution

The alkali activator solution is a mixture of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution. Sodium silicate is also known as Water Glass (WG) and is available in the market gel form whereas NaOH is available as pellets or flakes. NaOH solution of required molarity is obtained by dissolving NaOH pellets in distilled water. In the present study, 10 molar NaOH solution was used and is prepared by dissolving 400 grams of sodium (Na) pellets in 1 litre of regular tap water. This NaOH solution must be prepared 24 hours before casting the specimens and should be used within 36 hours of mixing pellets with water.

2.7 Super Plasticizer (SP)

The chemical admixture used in this study is Master Glenium Sky 8233 based on polycarboxylic ether which is free of chloride and is less alkaline in nature, with a specific gravity of 1.07.

Fig. 1. NaOH Solution

Table-1 Physical property test results of Fly ash, GGBS and RHA

Material	Physical Property	
	Fineness	Specific gravity
Fly ash	86%	2.18
GGBS	97%	2.80
RHA	91%	2.15

Table-2 Oxide composition of alkali activated binders

Oxide Composition	Fly ash	GGBS	RHA
CaO	1.8	41	2.3
SiO_2	60.1	35.6	72.5
Al_2O_3	28.4	19.58	4.8
Fe_2O_3	5.1	0.52	1.2
SO_3	0.1	1.9	1.1
K_2O	2.2	0.39	1.3

Table-3 Physical property test results of Coarse aggregate

Physical property	Test result
Fineness modulus	6.14
Specific gravity	2.51
Bulk density	1559.49 kg/m^3
Water absorption	2%

3. Mix design guidelines

The following mix design process has been followed and step by step procedure is explained below.

3.1 Water to activated binder solids ratio (W: ABS)

Water in this step constitutes the total summation of water (by mass) from Na_2SiO_3, NaOH and any added extra water and activated binder solids ratio means the sum of all solid content (by mass) from fly ash, GGBS, RHA, Na_2SiO_3 and NaOH. The water to activated binder solids (W: ABS) ratio was fixed as 0.24.

3.2 Alkaline liquid to Binder ratio (Al: B)

Alkaline activator liquid solution to binder ratio was maintained a constant value of 0.4 for all the mixes.

3.3 Sodium Silicate to Sodium hydroxide solution ratio (Na_2SiO_3: NaOH)

The ratio of Sodium Silicate to Sodium hydroxide solution ratio (Na_2SiO_3: NaOH) is maintained as 2.5 for good strength achievement.

3.4 Molar Concentration of NaOH

The molarity of NaOH is taken as 10M in this study.

3.5 Ratio of Silica dioxide to Sodium oxide (SiO_2: Na_2O) in Na_2SiO_3 solution

Sodium silicate (Na_2SiO_3) was procured from locally available market where in the ratio of Silica dioxide to Sodium oxide (SiO_2: Na_2O) was 2.

3.6 Designation of mixes

The following mix proportions were designed and designated for determining the Mechanical properties of Alkali Activated Concrete (AAC) and the designations are shown in Table 4.

Table- 4 Mix proportions of Alkali Activated Concrete (AAC)

Designations	Fly ash (%)	GGBS (%)	RHA (%)
Mix I	-	100	-
Mix II	50	50	-
Mix III	90	-	10
Mix IV	-	90	10
Mix V	45	45	10

The various mixes of AAC were proportioned for a volume of 1m^3 and summarised in Table 5.

Table- 5 Various mix quantities of AAC

Quantities in kg/m^3

Mix	Fly ash	GGBS	RHA	CA 20 mm	CA 10 mm	FA	NaOH solution	Na_2SiO_3	SP
I	-	394	-	665	444	739	45	113	3.152
II	197	197	-	665	444	739	45	113	3.152
III	354.6	-	39.4	665	444	739	45	113	3.152
IV	-	354.6	39.4	665	444	739	45	113	3.152
V	177.3	177.3	39.4	665	444	739	45	113	3.152

4. Tests on fresh and hardened concrete

4.1 Workability

Workability is the property of fresh concrete or mortar which ascertains the ability with which it can be mixed, compacted and placed. In the present study, workability was found by slump test as shown in Figure 1. The apparatus consists of slump cone, scale for measurement and tamping rod made of steel. The slump values for various mixes is determined and tabulated as follows shown in Table 6.

Fig. 2. Slump test

Table- 6 Values of slump test for various mixes

Mix	Al/ binder ratio	Slump value (in mm)
I	0.4	25
II	0.4	25
III	0.4	20
IV	0.4	25
V	0.4	25

4.2 Compressive strength

Cube mould of dimensions 150 mm X 150mm X 150mm is well tightened and lubricated with oil properly. Concrete is filled into the mould in layers, with each layer approximately 50mm deep. This layer of concrete is compacted properly by not less than minimum 25 strokes by a tamping rod to remove air voids. After a day, the specimens are removed and allowed for air curing at tested at desired ages. The compressive strength values of AAC at 3 days, 7 days and 28 days for various mixes is shown in Table 7.

4.3 Non-destructive Testing (NDT) of concrete

The most commonly used NDT tests on concrete are Rebound hammer (RH) test and Ultrasonic Pulse Velocity (UPV) test. Both of these tests were performed on all the alkali activated concrete specimens to assess the quality of concrete and the results are shown in Table 8 and 9.

Table- 7 Compressive strength of AAC mixes at various ages in MPa

Mix	Combinations	3 days	7 days	28 days
I	GGBS	65.32	70.44	80.6
II	Fly ash + GGBS	58.2	60.18	73.24
III	Fly ash + RHA	8.83	10.09	20.4
IV	GGBS + RHA	30.42	53.17	61.47
V	Fly ash + GGBS+ RHA	25.02	23.51	52.47

Table- 8 Ultrasonic Pulse Velocity (UPV) test results for AAC mixes at various ages in m/s

Mix	Combinations	3 days	7 days	28 days
I	GGBS	4385	4504	4108
II	Fly ash + GGBS	4425	4401	4252
III	Fly ash + RHA	1723	2569	3267
IV	GGBS + RHA	4361	4435	4086
V	Fly ash + GGBS+ RHA	3875	3814	4106

Table- 9 Rebound hammer test results for AAC mixes at various ages

Mix	Combinations	3 days	7 days	28 days
I	GGBS	28.43	28.23	23.26
II	Fly ash + GGBS	24.01	28.86	21
III	Fly ash + RHA	13.62	16.1	17
IV	GGBS + RHA	28.09	28.33	23
V	Fly ash + GGBS+ RHA	23.97	24.92	21

5. Results and Discussion

From the outcome of experimental investigation, the following conclusions were drawn:

- A slump of 20mm was observed for the AAC mix with a combination of fly ash and RHA and a slump of 25mm was observed was for all other AAC mixes implying the concrete to be less workable.
- The compressive strength of AAC using 100% GGBS showed higher results when compared to other mixes for Alkaline solution to binder ratio of 0.4. There was a very marginal increase in the compressive strength of about 7% from 3 days to 7 days. Later a good increment by 13% in the compressive strength was noted at the age of 28 days.
- The compressive strength of AAC using Fly ash and GGBS increased around 3% from 3 days to 7 days age of concrete and later increased by 26% from 3 days to 28 days age of concrete.
- The compressive strength of AAC using Fly ash and RHA increased steadily with the age of concrete. A strength gain of 13% was observed from 3 days to 7 days age and a strength gain of 51% was observed from 7 days to 28 days age of AAC.
- The compressive strength of AAC using GGBS and RHA increased by 43% from 3 days to 7 days age of concrete and later increased by 14% from 7 days to 28 days age of concrete.
- The compressive strength of AAC using Fly ash, GGBS and RHA slightly decreased by 6% from 3 days to 7 days but later the strength development improved by 55% from 7 days to 28 days of age.
- Even though the combination of Fly ash, GGBS and RHA showed good compressive strength, it was less in comparison with the compressive strength of AAC with GGBS at 28 days.
- The early strength of concrete (3 days and 7 days) was achieved for AAC made with combination of GGBS and Fly ash.

6. Conclusions

Preliminary investigation was carried in the present study to assess the role of industrial and agro wastes in making alkali activated concrete for a chosen molarity of 10M. It was observed that the workability of AAC mix was almost same for all the mixes which is at par with the target slump. Compressive strength of AAC mix with fly ash and rice husk ash was low due to the fact that the mixes took more than 48 hours to set in ambient curing. Despite the strength values being less that would definitely be a sustainable mix especially considering the durability of the mix. All the mixes with RHA resulted poor strength compared to mixes with GGBS. Triple blended AAC mix with GGBS, fly ash and RHA can be adopted for non-structural elements and for defence applications considering its higher strength gain. The quality of AAC mix with FA and RHA is poor compared to other mixes where as AAC mix with GGBS and GGBS and fly ash are in very good condition. Ambient curing temperature regime is sufficient for polymerisation to take place in between the alkaline solution and GGBS particles alone as binder and hence high strength values were achieved for this mix. When the results of AAC mix with combination of GGBS and fly ash was observed satisfactory results were achieved which were lesser than that of GGBS mix. Similar trend was observed with the combinations of fly ash and RHA and combination mix of fly ash, RHA and GGBS. Hence to enhance the strength of AAC mix with fly ash and RHA binder materials, elevated temperature curing is suggested.

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Disclosures

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