EXPERIMENTAL INVESTIGATIONS ON ALKALI ACTIVATED CONCRETE WITH GGBS AND RHA ICSTaGE-2017

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Abstract*— Alkali activated concrete is becoming an attractive alternate to Portland cement concrete to address sustainability issues and its solids are made of industrial by products. This paper aims to investigate the strength properties of alkali activated concrete with Ground Granulated Blast furnace Slag (GGBS) as source material. Rice husk ash (RHA), industrial waste material obtained from modernised rice industries has to be partially replaced up to 20% by weight, of GGBS for the production of geo polymer concrete. Sodium hydroxide and sodium silicate was used as alkaline activating solution. Geopolymer concrete specimens were casted with sodium hydroxide of 10M concentration and alkaline/binder ratio of 0.55 and subjected to ambient curing. In order to improve the workability of fresh concrete, sulphonated naphthalene based super plasticizer was used as water reducing agents. Compressive strength, split tensile strength and flexural strength of geopolymer concrete were determined at various ages. The results indicated that addition of RHA reduced the workability of geopolymer concrete and resulted in comparable/reduced compressive strength as that of GGBS based geopolymer concrete.

***Keywords*— Geopolymer concrete, GGBS, RHA, Ambient curing, Compressive strength.**

I. INTRODUCTION

Concrete is one of the fastest growing industry in the worldwide, as there are many construction works has been carried out. Cement is the major source material for the production of concrete and it is the binder material. During the production of cement a huge amount of CO_2 is released into the atmosphere which leads to the pollution of atmosphere and in the global warming problem. Every year around 2.6 billion tons of cement has been produced worldwide and it is gradually growing at the rate of 5% per year. Production of cement leads to the release of CO_2 into the atmosphere as green house gas which plays a major role in the global warming reasons. Portland cement production has been releasing about 5% to 8% of CO_2 of the total gas produced through human production. Among the global warming reasons CO_2 gas part has been around 65% of the global warming [1].

Many efforts have been taken to reduce the CO_2 gas releasing by usage of the industrial/ agricultural waste materials such as Ground granulated blast furnace slag(GGBS) , Rice husk ash(RHA), fly ash(FA) etc. Geopolymers are a relatively new group of materials which were developed by Joseph Davidovits in 1970's. GGBS based geo polymer are one of the branch in the geo polymer family and these have attracted more attention nowadays. When activated by alkali (NaOH, Na_2CO_3, KOH, etc.) solutions, slag dissolves and forms C-S-H similar to that found in OPC -based concrete.

Blast Furnace Slag is a by-product of the ore refinement process. While as ore refining processes create slag of one sort or another (e.g., copper slag, gold slag) the term is generally used to refer to the by-product of pig iron production. As the iron ore is melted various agents are added to draw out

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impurities they create a non-metallic liquid composed mainly of silicates and alumina silicates of calcium and other alkalis. The rapid quenching in water of the liquid slag, which floats at top of the liquid iron, leads to an amorphous structure that can then be ground and used as a replacement for OPC due to its latent hydraulic properties (Environmental Protection Agency, 2010). After grinding, the resulting material is referred to as ground granulated blast furnace slag, or GGBS. Air-cooled slag can also be used as an aggregate in concretes, road bases, and other applications, but the crystalline structure of air-cooled slag essentially nullifies reactivity.

Rice husk ash is an agricultural residue abundantly available in rice producing countries. Rice husk, the outer covering part of the rice kernel, is an agricultural waste from the milling process of paddy. Rice husk is abundant in many parts of the world, especially in rice cultivating countries like India. From the paddy about 22% of their entire weight is produced as rice husk and from that 22% about 25% is obtained as rice husk ash. It is produced by burning rice husk at a temperature in the ranges of 600°C [2].

So far many research works have been carried out in the production of geopolymer concrete using ground granulated blast furnace slag, fly ash, metakaolin, silica fume, as the source materials. There are also some works that has been done with the use of rice husk ash as partial replacement to the source material because of their silica and alumina content.

Significant amount of research attempts have been made on strength and durability properties of fly ash based geopolymer concrete. Both low calcium fly ash and high calcium fly ash are suitable source materials due to their high SiO_2 and Al_2O_3 content. One of the problem faced with the use of fly ash in the production of geopolymer concrete is the low strength development at ambient curing conditions. It attains desired strength only when it is subjected to elevated temperature conditions [3]. Replacement of fly ash with GGBS results in increased strength with increase in GGBS content on replacing with fly ash. It was reported that GGBS based geopolymer concrete results in increased compressive strength when compared to fly ash based geopolymer concrete. It is may be due to the higher fineness and high CaO content in the GGBS, which in turn increases the strength in room temperature itself [4&5]. It was reported that replacement of GGBS with RHA replacement up to 20% resulted in increased compressive strength of geopolymer concrete and beyond which compressive decreases. Workability also reduces with the increase in RHA content beyond 20%. At 28 days, geopolymer concrete has attained a maximum compressive strength of about 63MPa [6]. Increasing the molarity of NaOH beyond 10M leads to decrease in the setting time of the concrete mix [4]. So far few attempts has been made to effectively utilize rice husk ash along with GGBS for the production of geopolymer concrete. In this paper, it has been aimed to study the effect of RHA as source material for the production of GGBS based geopolymer concrete.

II. EXPERIMENTAL PROGRAM

A. *Materials and mix proportions*:

Ground Granulated Blast Furnace Slag, obtained from ASTRAA Chemicals Ltd, Chennai, was used as the source material. The physical and chemical properties of GGBS are summarized in Table I. Rice husk ash, waste obtained from modernized rice mills, located at Pondicherry was used. A laboratory type ball mill of 15 l capacity, running at a speed of 38 rpm was used to grind the ash samples. In order to ensure high efficiency of grinding, the volume of abrasive charge should be 30–50% of the volume of the mill and in a given volume of mill different sizes of abrasive charge with the maximum possible weight are essential. In this work 30, 25, 12.5 and 6.25 mm diameter steel balls were used as abrasive charges. The duration of grinding was varied from 30 to 90 minutes. The variation of fineness of RHA for various duration of grinding was shown in Fig.1. As expected, the fineness of RHA was found to be increased with increase in duration of grinding. In this work, for every batch of grinding one kilogram of ash was ground

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with 50% of volume of mill filled with abrasive charge for 90 minutes. The properties of RHA were determined as per IS: 1727, 1967 and tabulated in Table II. GGBS was partially replaced by RHA from 0 to 20% by volume.

Locally available river sand and crushed granite stone aggregate of 20-mm (maximum) size was used as fine and coarse aggregate respectively. The physical properties of aggregates were determined in accordance with IS: 2386-1963 and was presented in Table III. The combination of sodium silicate solution and sodium hydroxide was used as alkaline activators. The sodium silicate solution was A53 grade with SiO_2 and Na_2O ratio by mass approximately 2.2, i.e. (Na_2O=15.5 percent. SiO_2 =31.0 percent and water 53.5 percent by mass). The sodium hydroxide with 97-98 percent purity, in flake or pellet form was used. The solids were dissolved in water to make a solution of required concentration. The ratio of sodium hydroxide to sodium silicate was maintained as 2.5. The sodium silicate solution and sodium hydroxide solution were mixed together at least one day prior to use.

Table I: Properties of GGBS:

Physical Properties:			
Si.No	**Property**	**Result**	
1	SPECIFIC GRAVITY	2.90	
2	FINENESS % PASSING 75 MICRON SIEVE	41	
Chemical Properties: *			
Si.No	**Component**	**Requirements as per BIS:6999**	**GGBS**
1	($CaO+MgO+SiO_2$) (%)	66.6(MIN)	76.03
2	CALCIUM OXIDE (%)	<1.40	1.07
3	MAGNESIUM OXIDE (%)	14.0(MAX)	7.73
4	SULPHIDE SULPHUR (%)	2.00(MAX)	0.50
5	LOSS ON IGNITION (%)	8.00(MAX)	0.26

***- ASTRAA CHEMICALS, Ltd, Chennai**

In order to improve the workability of fresh concrete, sulphonated naphthalene based super plasticizer was used as HRWRA. The super plasticizer was a dark brown solution containing 42% solids. Gradation curve for the fine aggregate is shown in Fig.2.

Table II Physical Properties of Rice Husk Ash

SI.No	Property	Result
1	SPECIFIC GRAVITY	2.02
2	COLOUR	OFF- WHITE
3	FINENESS PASSING 75 MICRON	86%

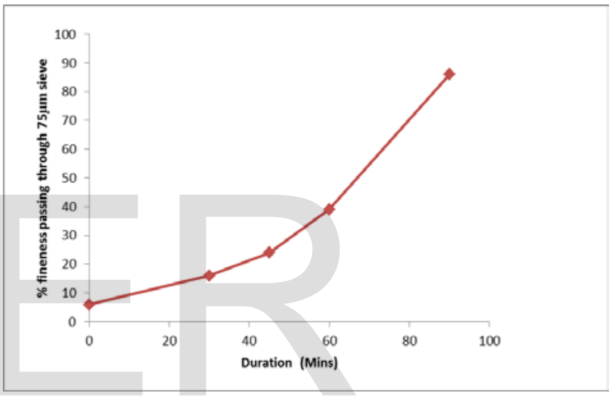

Fig.1 Fineness of RHA for various duration of grinding.

Table III. Properties of aggregates

Si.No	Property	Fine Aggregate (River Sand)	Coarse Aggregate
1.	SPECIFIC GRAVITY	2.60	2.72
2.	WATER ABSORPTION (%)	1.2	1.67
3.	BULK DENSITY (KG/M^3)	1723	1469
4.	FINENESS MODULUS	2.74	7.95

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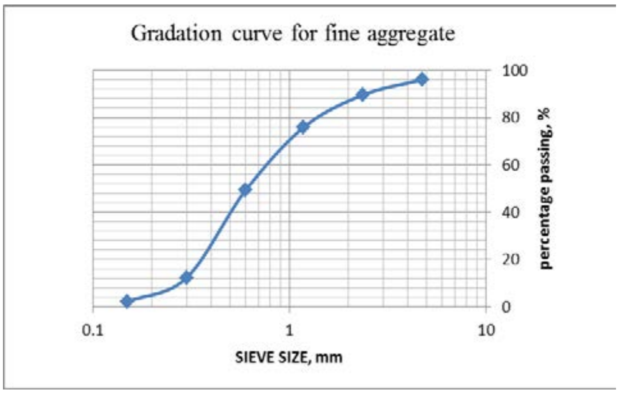

Fig.2 Gradation curve for fine aggregate

The mix proportions for alkali activated concrete were done as per "Modified guidelines for geo polymer concrete mix design using Indian Standard"[7]. GGBS content of 450kg/m^3; alkaline solution to GGBS ratio of 0.55 and sodium hydroxide solution concentration of 10M was maintained for all mixtures based on various trial mixes. The mix proportions of geopolymer concrete are given in Table IV.

Table IV: Mix proportions of geo-polymer concrete:

Mix	RHA (%)	GGBS (kg/m^3)	RHA (kg/m^3)	Sand (kg/m^3)	Coarse aggregate (kg/m^3)	SP (l/m^3)
P1	0	450	0	606	1170	6.75
P2	10	405	45	606	1170	6.75
P3	20	360	90	606	1170	6.75

C.Casting and Curing:

Geo polymer concrete was manufactured by adopting the same procedure followed for cement concrete. In the laboratory, aggregates in saturated surface dry condition, GGBS were first mixed together in the pan mixer thoroughly. Alkaline solution was mixed with HRWA and then added to the dry materials and the mixing continued till homogenous mixture was obtained. The fresh concrete was then transferred immediately into moulds and compacted with the help of table vibrator. After casting, geo polymer concrete specimens were subjected to ambient curing immediately. In ambient curing, specimens were kept under ambient laboratory conditions till the age of testing.

B.Tests conducted:

Compressive strength of geo polymer concrete cube specimens of size 10x10x10cm was determined at 7, 14, and 28 days. At appropriate ages, three specimens exposed to various curing conditions were tested in accordance with IS: 516-1959 using 3000 kN compression testing machine. Three numbers of 100mm×200mm cylinders and 500×100×100mm beam specimens were casted to determine splitting tensile strength and flexural strength of geo polymer concrete specimens at 28 days. The flexural strength corresponding to failure of the specimen is calculated based on mode of failure.

III. RESULTS AND DISCUSSIONS:

A.Workability test-

The workability of the fresh concrete was measured by conducting slump test as per IS: 1199(1989). It has been decided to maintain constant quantity of super plasticiser (1.5% by weight of GGBS) to study the effect of RHA in workability of geopolymer concrete mixtures. It was found that workability of geopolymer concrete decreases with increase in RHA content. Addition of RHA increases the water requirement and thus reduces the workability of geopolymer concrete from high degree to medium degree due to porous nature of RHA as shown in Fig.3. This is in good agreement with findings of Prabu, et.[8]

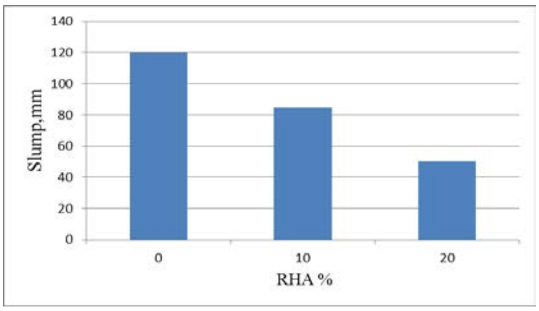

Fig.3 Variation of slump for various percentages of RHA in goepolymer concrete.

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B.Compressive strength:

Fig.4 gives the average results of compressive strength of three concrete samples tested in accordance with IS: 516 (1959) at 7 days, 14 days, and 28 days. Compressive strength of geopolymer concrete was found to be increased with age. Rate of increase in compressive strength development decreased with age. It was noticed that compressive strength attained at 7 days and 14 days was about 91% and 94% when compared to 28 days for GGBS based geopolymer concrete. Incorporation of RHA reduced the compressive strength of geopolymer concrete. Compressive strength was decreased with increase in RHA content. When compared to GGBS based geopolymer concrete, reduction in compressive strength was about 17% and 19% at 7 days and at 28 days, and it was about 12% and 19% for 10% and 20% RHA content respectively. GGBS based geopolymer concrete, attained maximum compressive strength of about 96 MPa at 28 days. When GGBS was partially replaced by RHA, maximum compressive strength achieved was about 84 MPa, at 28 days.

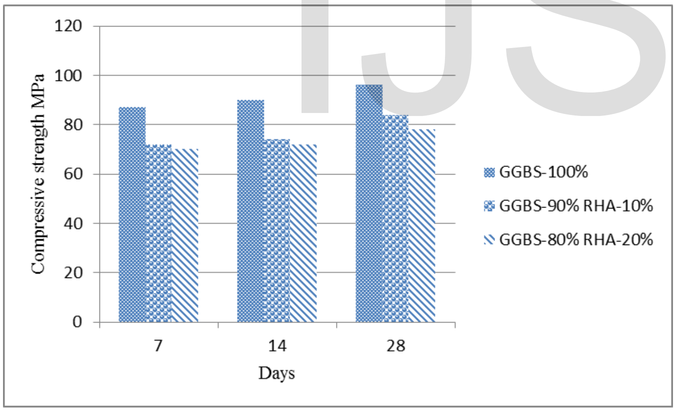

Fig.4 Compressive Strength of Geopolymer Concrete at 28 days for various percentage of RHA.

C.Splitting tensile strength:

The result of average splitting tensile strength of geopolymer concrete cylinder specimens shown in Fig.5 shows the variation from 3.52MPa to 4.61MPa. In general, the splitting tensile strength was affected by replacement of RHA, similar to that compressive strength. Maximum splitting tensile strength of about 4.61MPa was obtained for GGBS based geopolymer concrete specimens.

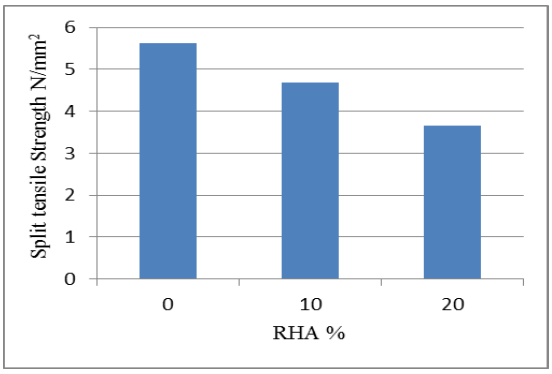

Fig.5 Split Tensile Strength of Geopolymer Concrete at 28 days for various percentage of RHA

D.Flexural strength:

The result of average flexural strength of geopolymer concrete varies from 3.65MPa to 5.63MPa as shown in Fig.6. The minimum 28 days flexural strength requirement for cement concrete was 3.83MPa for M30 grade as per IS: 456, 2000 specifications. Test results obtained was higher than IS strength requirement due to strong inter facial zone between geopolymer paste and aggregate zone. This is in good agreement with Ryu et al., 2013[9].

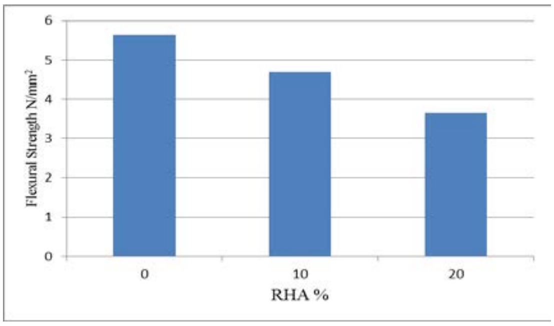

Fig.6 Flexural strength of geopolymer concrete at 28 days for various percentage of RHA.

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IV. CONCLUSIONS

Based on the test results, the following conclusions are drawn:

- Compressive strength of about 96 MPa was achieved when GGBS was activated at ambient curing with the alkaline solution to binder ratio of 0.55.
- At 7 days, GGBS based geopolymer concrete attained about 90% of its 28 days compressive strength.
- GGBS based geopolymer concrete can be practiced for various structural applications.
- Incorporation of RHA as source material for geopolymer concrete reduced the workability and compressive strength at all ages.
- Replacement of GGBS with RHA less than 10% can be practiced for the production of geo polymer concrete since there is only 12% reduction in compressive strength at 28 days when compared with reference mixture at 10% RHA content.

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