An Experimental Study on Strength and Durability Properties for Utilization of Rice Husk Ash (RHA) in Geopolymer Concrete

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Abstract Among many environmental issues, carbon dioxide released into the atmosphere takes a serious effect at the time of manufacturing the cement. Cement-less binder is an elective material to prevent the earth from global warming. Utilizing pozzolanic-filled industrial waste as source material can decrease the pollution from depravity of environment. Presence of chlorides in the building is the root for causing corrosion in reinforcement and degradation of the reinforced concrete structures. In this paper, tertiary materials such as fly ash, ground-granulated blast-furnace slag, and rice husk ash are employed and activated with 10 Mof NaOH. The results showed that replacement of fly ash by 30% of RHA improves the mechanical properties. Water absorption, sorptivity, and carbonation test are examined to study the durable nature of rice husk ash-based geopolymer concrete. The durability test results exhibit that RHA-based geopolymer concrete enhances the durable properties of concrete by making denser structure by providing strong bonding among the aggregate and paste which resulted in diminishing the water permeability.

Keywords Geopolymer · Rice husk ash · Durability · Interfacial zone · Permeability

1 Introduction

In the world, mankind is benefitted largely by utilizing concrete more and estimated that second priority is given to concrete next to water. The environment faces warming issues at the time of production of cement. Approximately, 1 ton of cement releases 0.95 tons of CO_2 and reaches 6–8% of global warming in the year 2020 as per

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sustainable development scenario. The letting out of carbon monoxide and carbon dioxide into the atmosphere can be controlled effectively by green concrete called geopolymer concrete. The mechanism of geopolymer in the field of chemistry was identified by the scientist Davidovits in [1], and the zero cement concrete was used majorly in the construction by the Professor B.V. Rangan. The geopolymer will be differentiated as 3D inorganic polymer by adopting a rule: Mn [−(Si−O) z−Al−O] n.w(H_2O), where 'n' is degree of polymerization [2]. This technology removes and replaces the cement by incorporating the different pozzolanic materials such as FA, GGBS, RHA, and metakaolin which are high in silica and alumina content [3]. These resources are mixed with fine aggregate and coarse aggregate and activated by alkaline solutions to achieve the desired strength then allowed for better curing to enhance the speed of polymerization [4]. The strength and durability parameters not only depends on the grading properties but also depends on the source materials used, type of alkaline activator [5] solution which used and curing methods [6, 7] adopted to produce geopolymer concrete. As per the data, the total production of fly ash in the global market is around 780 MT per year, but utilizing the fly ash in concrete is limited to 17–20 percentage only [8].

Partial amount of fly ash [9] was used for the manufacture of Portland pozzolana cement, and the remaining percentage of ash is disposed off either in land or water bodies as a waste material which causes groundwater and soil pollution [10]. Similar to cement, fly ash also becomes shortage nowadays due to extreme usage by the entire construction industry sector being the conventional material. Since 1900s, ground-granulated blast-furnace slag is used as a cementitious matter in concrete due to rich calcium oxide content and developing strength properties of concrete. Rice milling industries produces enormous amount of rice hull and ash was left over during the production of biomass energy. Rice husk ash [11] is also an organic waste and non-bio degradable residue which contains 80–90% of silicon dioxide [12, 13]. Incorporation of RHA in geopolymer concrete increases its corrosion resistance [14]. The literature study revealed that rice husk ash can be used as a cementitious material in geopolymer concrete, enhancing its early age mechanical properties as well as long-term strength properties [15, 16]. The effort has been taken to produce a geopolymer concrete with fly ash, GGBS, rice husk ash and activated with alkaline activator solution. The objective of this experiment is aims to study and compare the mechanical strength and durability properties of rice husk ash-based geopolymer concrete (RHAGPC) with conventional geopolymer concrete (FAGPC).

2 Literature Review

A chemistry Professor [1] found the name geopolymer and identified that geopolymer substances belong to inorganic family. Ganesan et al. [17] assessed the durability characteristics of plain and fiber-reinforced geopolymer concrete (GPC) and its correlation to Portland cement-based conventional concrete (CC). The investigation's results included microstructure-related properties such as water absorption,

Table 1 Chemical oxides of different source materials

Chemical oxides	Present study		
	Fly ash (%)	GGBS (%)	RHA (%)
SiO_2	55.90	41.24	88.64
Al_2O_3	15.23	20.64	1.23
Fe_2O_3	21.78	7.28	1.19
CaO	0.17	25.45	1.09
LoI	0.62	Nil	<6%

apparent porosity, and sorptivity of GPC being lower than in CC and expansion of less steel fiber which improved GPC. VijayaRangan [18] investigated a detailed study on the effect of Geopolymer concrete in environmental protection and concluded that, geopolymer concrete had excellent compressive strength and was suitable for structural applications. Arshad et al. [19] studied on the preparation of geopolymer concrete using Metakaolin (MK) and rice husk ash (RHA) as alternative material for Portland cement. From the observation, it was seen that the major crystal was formed with minor crystals (mullite) which was started to develop at a temperature of 1000 °C [20]. The occurrence of crystalline phase correlated to the mechanical properties of geopolymer concrete.

3 Materials and Properties of GPC

3.1 Source Materials

Class F Fly ash was used in this work which has specific gravity and blain fineness of 2.46 and 2351 cm^2/g, respectively, and it was purchased from Mettur thermal power plant. Ground-granulated blast-furnace slag was received from Quality polytech, Mangalore and it has specific gravity and blain fineness of 3.11 and 4580 cm^2/g, respectively. Rice husk ash was incinerated and bought from locally available rice mill industry, then pulverized in a ball mill for every 60 min. The specific gravity and blain fineness of RHA are 2.13 and 5675 cm^2/g, respectively. Table 1 represents chemical oxides of different source materials and compared with some researchers also.

3.2 Aggregates and Geopolymer Liquids

Locally available Zone-II river sand and locally available 12-mm size of granite stone was taken as fine aggregates and coarse aggregates. The properties of fine and coarse aggregates such as specific gravity, fineness modulus, bulk density are 2.60, 2.60, 1675 kg/m^3, and 2.91, 5.40, 1520 kg/m^{3}was determined as per IS: 2386 (Part III)-1963 [21]. NaOH was available in the form of pellets with 97–98% purity, and Na_2SiO_3 was available in the form of liquid [2]. The Conplast SP 430 superplasticizer was added to the mix. The additional water of 15% of binder materials was added to attain the desired workability. Distilled water was utilized to make the NaOH solution with a concentration of 10 M.

3.3 Mix Proportion

Table 2 specifies the optimized mix proportion for 1 m^{3}of rice husk ash-based geopolymer concrete.

4 Experimental Set up and Results

4.1 Compressive Strength of FAGPC and RHAGPC

The fresh concrete samples were poured in 10 cm × 10 cm × 10 cm cube mold and compaction for each layer was done by compacting steel rod. The concrete was demolded next day and placed in room temperature at 27 ± 2 °C for ambient curing. Table 3 shows the compressive strength result of fly ash and rice husk ash-based geopolymer concrete.

4.2 Tensile and Flexural Strength of FAGPC and RHAGPC

The cylindrical specimen with a size of 15 cm × 30 cm was used to find the maximum failure load at the age of 7 days, 28 days, and 56 days. The testing procedure was followed as per the accordance of IS 516–1959, and all the test specimens were named for further identification. The tensile strength results for 90% replacement of fly ash and 10%, 20%, and 30% replacement of rice husk ash was listed in Table 3. The tensile properties of fly ash and rice husk ash-based geopolymer concrete was found by 10 cm × 10 cm × 50 cm prism in a universal testing machine with a loading capacity of 1000 kN. As per the guidelines in IS 516–1959, modulus of rupture was given to the prism under two-point loading condition. The flexural strength of fly ash and rice husk ash for different mixes at different age of curing was exposed in Table 3.

Table 2 Mix proportion for 1 m^3 of rice husk ash-based geopolymer concrete in kg

Mix Id	% of replacement			Fly Ash	GGBS	RHA	FA	CA	NaOH	Na_2SiO_3	Water	SP
	FA	GGBS	RHA									
GPC-1	90	10	0	354.60	39.40	0	554.40	1294.00	45.10	112.60	59.14	11.83
R10	80	10	10	315.20	39.40	39.40	554.40	1294.00	45.10	112.60	59.14	11.83
R20	70	10	20	275.80	39.40	78.80	554.40	1294.00	45.10	112.60	59.14	11.83
R30	60	10	30	236.40	39.40	118.20	554.40	1294.00	45.10	112.60	59.14	11.83

Table 3 Strength properties of RHA-based GPC

S. No.	Mix Id	Compressive strength in MPa			Split tensile strength in MPa			Flexural strength in MPa		
		7 d	28 d	56 d	7 d	28 d	56 d	7 d	28 d	56 d
1	GPC-1	21.20	31.30	32.32	1.62	2.25	2.64	2.12	3.26	3.42
2	R10	20.19	29.96	30.65	1.53	1.94	2.21	2.28	3.50	3.67
3	R20	17.33	24.46	25.95	2.08	2.39	2.54	2.06	3.17	3.39
4	R30	18.43	28.06	30.33	2.06	2.32	2.49	2.20	3.39	3.62

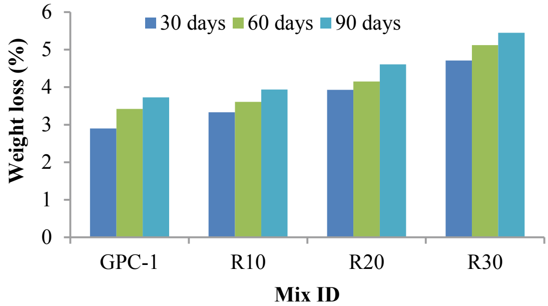

Fig. 1 Weight loss of RHA-based GPC

4.3 *Water Absorption of FAGPC and RHAGPC*

The porous structure of the geopolymer concrete can be noticed by immersing the specimen of cube with dimension 10 cm × 10 cm × 10 cm in water tank [22]. The weight of the hardened concrete cube was noticed initially then immersed in water tank for 30, 60, and 90 days. The less amount of water absorbed by the geopolymer concrete represents densely packed concrete. After the required time, the loss of strength for each ratio can be analyzed by determining the compressive strength in compressive testing machine. The weight loss of RHA-based GPC at different ages are shown in Fig. 1. The fineness of RHA is very high when compared to other two pozzalonic material. In other hand, RHA contains some unreacted particles in it which was evident from chemical composition of RHA. These two parameters resulted in the increased water absorption capacity of RHA-based geopolymer concrete.

4.4 *Sorptivity of FAGPC and RHAGPC*

The capillary suction of liquids can be determined by the unidirectional absorption test (or) sorptivity test. As per guidelines of ASTM C 1585-04, the concrete core sample of 100 mm × 50 mm size is placed in a tray with a depth of 3–5 mm. The sorptivity value can be obtained from the following the expression $Q = \mathrm{Ak}\sqrt{t}$ [23].

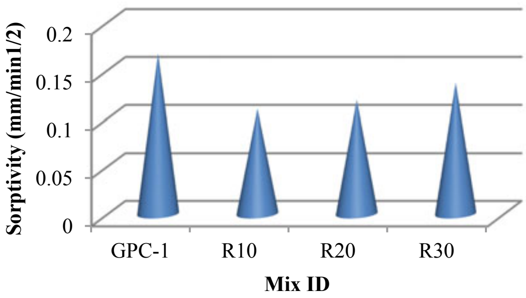

Fig. 2 Sorptivity of RHA based GPC

Figure 2 represents the sorptivity value for GPC 1, R10, R20, and R30 replacement of fly ash and rice husk ash-based geopolymer concrete. The reduction in sorptivity may be due to presence of excessive RHA affecting the structural compatibility by delaying the progress to the denser stage. The capillary suction was enhanced due to it.

4.5 Carbonation of FAGPC and RHAGPC

The concrete structures are mostly deteriorated by the action of corrosion attack in the reinforcement rod attached with the bonding materials. The cubical size of 10-cm test specimen was taken to find the carbonated sample. The specimen was placed in a carbonation chamber by passing carbon dioxide for 1 day. It is one of the simple and easy methods to establish the extent of carbonation on the cube samples. The pH of the sample was found at an age of 0, 3,7,28, and 56 days by water analyzer method. The pH of all mixes before and after carbonation is exposed in Table 4. In OPC concrete, Ca $(OH)_2$ and C–S–H gel assist buffering to ensure pH value greater than 13. Nevertheless, in RHA-based geopolymer concrete, such buffering is not buoyed by the gel. In geopolymer concrete, the carbonation is hypothesised as the reaction of the sodium hydroxide with CO_2 forming sodium carbonate hydrates [24]. This output leads to lesser minimization of pH value, which ranges from 10.58.

Table 4 pH from carbonation test

S. No.	Mix Id	pH (in days)				
		0	3	7	28	56
1	GPC-1	11.43	11.20	11.17	11.10	11.04
2	R10	11.20	10.91	10.86	10.75	10.72
3	R20	11.08	10.82	10.76	10.69	10.61
4	R30	11.03	10.77	10.69	10.61	10.58

5 Conclusions

The test result proves that rice husk ash can be utilized as pozzolanic material to make durable geopolymer concrete with relatively high loss on ignition. The increase in the fineness of RHA resulted in the enriched reactivity and high degree of polymerization. Experimental results on mechanical properties confirm that effective utilization of rice husk ash in the construction field up to 30% of addition with other pozzolanic materials improves the strength characteristics and also enhances the impermeability properties of geopolymer concrete. The test results of durability study also reveal that the production of geopolymer concrete with tri-blended pozzolanic materials resulted in reduced sorptivity and carbonation effect due to more densified structure formation. The durability of concrete structures would be more when incorporating the non-corrosive materials as an additive likes RHA, FA, and GGBS as an alternative to cement. By replacing 30% of RHA with fly ash and GGBS, we can achieve target strength of M_{20} grade concrete. Since, RHA is a waste material, with a maximum percentage, it can be more beneficial in the production of load bearing blocks, bricks, and tiles with low construction cost. By holding the RHA in construction, it shows promising results in diminishing the pollution which softens the environment and also dropping the principal cost of the infrastructure in the country.

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