Performance Assesment of GGBS and Rice Husk Ash Based Geopolymer Concrete

Maria Eldho, V. Srinivasan, and Sarah Anil

Abstract Geopolymer concrete technology is a promising technology for the construction industry. Replacing the conventional resource consuming Portland cement with supplementary cementitious material can reduce the carbondioxide emission as well as energy consumption. It serves as an effective way of disposing industrial wastes that found difficult to be handled in past. Rice husk ash, an agricultural biomass which is rich in silica can be used as an effective source material. In the present study M30 grade GGBS and rice husk ash based geopolymer concrete is developed. Rice husk ash of varying percentage of 5 and 15% is considered to study its effect on mechanical and durability properties. 6 M sodium hydroxide is used. Ratio of sodium hydroxide to sodium silicate used is 1:2. Ambient curing of 28 days is done. The result is compared with OPC concrete specimen to evaluate the performance of geopolymer concrete.

Keywords Geopolymer concrete · Supplementary cementitious materials · GGBS · Rice husk ash · Durability · Ambient curing

1 Introduction

Concrete is the major construction material used all over the world, and its use is second to water [1]. Construction industry has now become the largest consumer of the global natural resources. The production of cement consumes large amount of natural resources [2, 3]. And it can be said that production of cement means production of pollution due to production of carbondioxide. The cement industry contributes to about 5–7% of the global carbondioxide emission [4]. Moreover there is an ever-increasing need for cement in the world so that about three tons of concrete

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would be consumed annually per one human living on the earth [5]. Therefore, to produce environmentally friendly concrete, it is inevitable to use alternative materials to replace traditional Portland cement that consumes resources. The use of industrial byproducts as source material can reduce the CO_2 emmission and problem of disposing the waste to atmosphere.

In this respect geopolymer concrete is a promising technique. The term geopolymer concrete was first introduced by Joseph Davidovits in 1978. Geopolymers are chains of mineral molecules linked with covalent bonds. Geopolymers are produced by the alkaline activation of source materials such as fly ash, GGBS, rice husk ash, metakaolin.

Fly ash is popular due to amorphous alumina silica content inside and it is abundantly available. The total amount of fly ash produced in the world has now reached 480 million tons annually, while the total OPC production is reaching 3.3 billion. There is a gap between fly ash and OPC production. Therefore additional source material is imperative, which will reduce these gap to lower value.

Rice husk ash is generated from the combustion of rice husk. Rice husk is an issue for environment due to its abundance and capability to resist natural degradation. The annual world production of rice husk ash is about 130 million tons. The current available disposal method of rice husk ash by burning and dumping create environmental pollutions. Rice husk when subjected to control burning of 500–700 °C produces Micronized Biomass Silica (MBS) which contains very high amount of silica content and is amorphous in nature. The amorphous silica contained in RHA can react with cementitious binders to perform pozzolanic activity. Thus it can be effectively used as a source material [6].

2 Experimental Program

2.1 Materials

GGBS and rice husk ash has been used as the source material. Natural sand as fine aggregate and crushed stone aggregate with size 20 and 12 mm in the ratio 40:60 were used. The aggregates confirms to IS 383–1970 [7]. The alkaline activators used were NaOH and Na_2SiO_3 in the ratio 1:2. The molarity of NaOH used is 6 M. Ordinary potable water is used. The oxide composition of GGBS and rice husk ash by XRF analysis is listed in Table 1. The physical properties of the materials are given in Table 2.

Table 1 Oxide composition of GGBS and rice husk ash

Oxide	GGBS (%)	RHA (%)
SiO_2	43.40	88.18
Al_2O_3	12.50	1.61
Fe_2O_3	–	0.56
CaO	40.30	1.59
MgO	1.50	1.63
Na_2O	0.90	–
K_2O	0.60	1.67
TiO_2	–	–
Mn_2O_3	–	–
SO_3	–	–
Carbon	–	2.67
Others	–	2.09
Moisture	–	0.79

Table 2 Physical properties

Physical properties	GGBS	RHA	Sand	Aggregate
Specific gravity	2.87	2.19	2.63	2.7
Water absorption	–	–	0.4	0.5
Bulk density	–	–	1520	1630

2.2 Mix Proportion

As no standard mix design is available for geopolymer concrete, the mixes were designed by trials. The concrete was designed for a grade of M30. 5 and 15% replacement of GGBS with rice husk ash is made. Ordinary Portland cement concrete was used for control specimen with w/c of 0.45. The mix proportions are given in Table 3.

2.3 Specimen Preparation

For casting, source materials and aggregates were dry mixed in the mixer for about 2–3 min. Then it is mixed with alkaline solution for another 3–4 min to form a uniform mix. The fresh concrete was cast into cubes of 100 mm, cylinders of 100 mm diameter and 200 mm height and prism of 100 mm × 100 mm × 500 mm. After casting the specimens were left for 24 h before removing mould. Then samples were cured under ambient condition for 28 days.

Table 3 Mix details in m^3

Materials	Quantity		
	5%	15%	OPC
Cement	–	–	430 kg
w/c	–	–	0.45
GGBS	409 kg	366 kg	–
Rice husk ash	21 kg	65 kg	–
Fine aggregate	683 kg	683 kg	683 kg
12 mm coarse aggregate	650 kg	650 kg	650 kg
20 mm coarse aggregate	434 kg	434 kg	434 kg
Molarity of NaOH	6 M	6 M	–
AAS	360 kg	360 kg	–

2.4 Experimental Set Up

2.4.1 Mechanical Property Testing

The hardened geopolymer concrete specimen were tested for destructive tests. Compressive strength, split tensile strength, flexural strength were conducted for 3 samples after 28 days of curing and the average of three was taken.

2.4.2 Water Absorption Test

ASTM C642 [8] determines the rate of water absorption by two saturation methods. In the present study, oven dry mass of the specimen is obtained by placing concrete discs of diameter 100 mm and thickness 50 mm in an oven at a temperature of 100 ± 5 °C for 24 h. The specimens are the cooled down to room temperature. Later, the saturated mass of samples is determined by immersing them in water for 24 h. The water absorption is calculated by Eq. 1.

$$\text{Water absorption} = \frac{W_2 - W_1}{W_1} \times 100 \tag{1}$$

W_1 Oven dry mass in kg
W_2 Saturated mass in kg.

2.4.3 Rapid Chloride Penetration Test

Rapid Chloride Penetration Test (RCPT) is commonly used to evaluate the resistance of concrete to chloride ion ingress through electrical conductivity measurements. The RCPT test was conducted as per the guidelines of ASTM C1202 [9]. The test consists

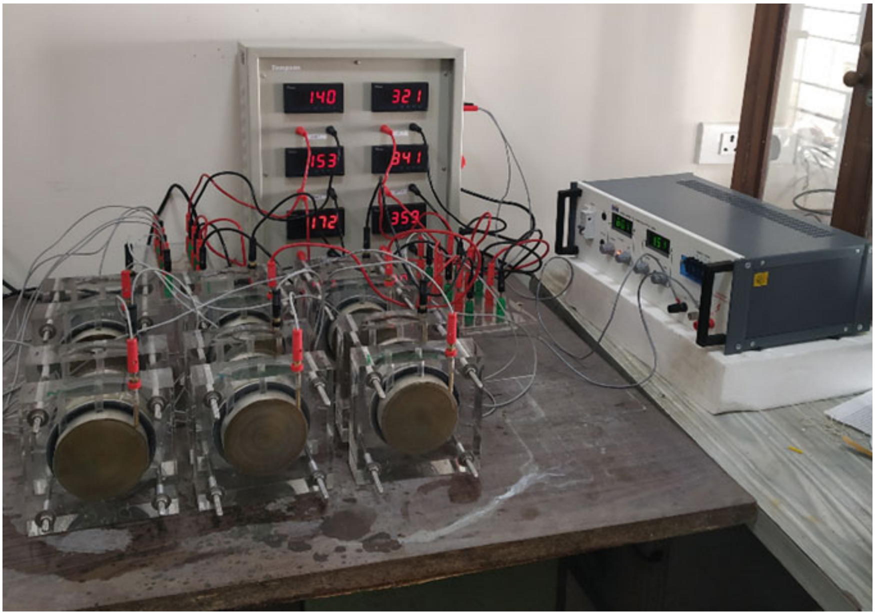

Fig. 1 RCPT set up

of cutting a 50 mm thick disc from cylinder of 100 mm diameter and 200 mm height. The slices were immersed in water for 24 h. It is then placed in the RCPT cell. The −ve side of test cell is filled with 3% NaCl solution and +ve side with 0.3 M NaOH solution. The system is then connected and a 60 V potential is applied for a period of 6 h. Readings are taken at every 30 min. At the end of the test the amount of current passed through the specimen in coulombs is calculated. Figure 1 shows the RCPT set up.

3 Results

3.1 Mechanical Properties

The 28 days compressive strength, split tensile strength and flexural strength properties are listed in Tables 4, 5 and 6 respectively.

The 28 days compressive strength of geopolymer concrete is well above the target mean strength. The increase in strength is due to high silica to alumina ratio (silica content >80%) and higher fineness of RHA compared to GGBS which increases the specific surface and thereby reactivity. The split tensile and flexural strength of

Table 4 Compressive strength results

Mix	Compressive strength (N/mm^2)
GPC-5	58.03
GPC-15	64.10
OPC	47.08

Table 5 Split tensile strength results

Specimen	Split tensile strength (N/mm^2)
GPC-5	3.4
GPC-15	3.64
OPC	4.55

Table 6 Flexural strength results

Specimen	Flexural strength (N/mm^2)
GPC-5	3.953
GPC-15	4.393
OPC	5.268

Table 7 Water absorption results

Specimen	Water absorption (%)
GPC-5	4.322
GPC-15	4.8
OPC	5.016

geopolymer concrete is slightly lower than that of OPC concrete. As per IS 456—2000, flexural strength is given by $0.7\sqrt{fck} = 3.8$ N/mm^2. The experimental results is well within the limit.

3.2 Water Absorption

The water absorption results is listed in Table 7.

The geopolymer concrete specimens performs better in water absorption when compared to that of OPC concrete specimen. This may be due to the improved microstructure of geopolymer concrete.

3.3 Rapid Chloride Penetration Test

The RCPT results is listed in Table 8.

Table 8 RCPT results

Specimen	Current (coulombs)
GPC-5	3680
GPC-15	3223
OPC	3980

Based on ASTM C1202, the chloride penetrability of all three specimen is classified as moderate. The chloride ion penetrability of geopolymer concrete is lower than that of control specimen. The decrease in chloride ion permeability is due to the fine particle size of RHA which produce micro filler effect. The micro filler effect results in dense and compact microstructure thereby reducing the penetration of chloride ions.

4 Conclusions

In the present study, ambient cured geopolymer concrete with GGBS as the source material and partial replacement of it by rice husk ash was developed. GGBS was partially replaced by RHA by 5 and 15%. The performance of geopolymer concrete in mechanical and durability properties was studied. On the basis of the experimental results obtained, it is evident that geopolymer concrete performs better than OPC concrete. Following are the conclusions made from the study:

- The compressive strength of geopolymer concrete is higher than OPC concrete.
- The indirect tensile strength of geopolymer concrete is marginally lower than OPC.
- The mechanical properties improves by increasing the percentage of replacement of RHA from 5 to 15%.
- The durability properties such as water absorption and rapid chloride penetration test results shows better performance of geopolymer concrete over OPC concrete.
- The chloride ion penetrability of the specimens falls under moderate class as per ASTM C1202.
- This improvement may be attributed to the improved dense and compact microstructure of geopolymer concrete due to the inclusion of RHA [2].
- Utilization of GGBS and RHA for concrete production proved as a solution for the disposal of these industrial and agricultural byproducts.
- The geopolymer concrete reduces the emission of carbondioxide that are released during the manufacture of cement.

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