Experimental Study on Red Mud, Fly Ash and GGBFS based Geopolymer Concrete

A Green Substitute to Conventional Concrete

Supriya Kulkarni
Assistant Professor, Department of Civil Engineering
KLS, Gogte Institute of Technology
Belagavi, Karnataka India

Abstract — **Rapid urbanization and industrialization has led to generation of abundant quantity of industrial wastes. Red mud (RM), Fly ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) are a few amongst the wastes that are generated is huge quantities and are indiscriminately disposed on to open lands which not only occupy space but also leads to soil and ground water pollution. Also increased construction activities have increased the use of conventional construction materials. Production of conventional construction materials such as cement poses a lot environmental threat during its production. Thus there is a need to find sustainable alternate materials for a better future.**

The objective of this study is to investigate a green alternate material for conventional concrete using geopolymerization of industrial wastes. In this study geopolymer concrete using RM, FA and GGBFS was tested for various physical and mechanical properties. The properties that were tested include water absorption, compressive strength, flexural strength, tensile splitting strength. The test results indicated that geopolymerization of industrial wastes can be a good and sustainable alternative to conventional concrete.

Keywords— Red mud, fly ash, ground granulated blast furnace slag, geoplomer concrete.

I. INTRODUCTION

Replacing conventional construction materials with wastes or by-products from industries will help cater problems related to waste management [1]. Red mud is one such potential replacement material which is found in abundance produced during extraction of alumina from bauxite ores by the Bayer's process. The quantity of red mud produced accounts to about 55% to 65% of processed bauxite depending upon the quality of bauxite ore. According to literature bauxite ore mined globally amounts to 202 million tons (MT) in 2007 and 205 million tons in 2008 [3]. Quantity of red mud produced globally per year approximates to 90 million tons [4]. In India red mud production is up to 4 million tons [1]. Bayer's process uses highly concentrated NaOH solution at high temperatures and pressures for ore digestion. Fresh red mud slurry thus produced is characterized by strong alkalinity (pH 10.5-13), high water content, concentrated heavy metals and other trace elements make the proper reuse or disposal of red mud difficult [5]. Widely used method of disposal of red mud is onto the land in waste ponds. But this method is not economical due to its high maintenance cost and also requires constant monitoring [3]. Disposal of red mud onto waste lands poses potential threat to public health and environment. Thus new and sustainable methods of reuse or disposal is the need of the hour. Though a lot of efforts have been made on reuse, recycle and treatment of red mud, a widely accepted technology or method is yet to be established [5].

Rapid urbanization has resulted in increased construction activities. Concrete is one most widely used construction material [7]. Concrete also uses conventional construction material which again leads to increase in carbon footprint. Geopolymer is one such alternative for conventional concrete. Geopolymer are materials formed by activation of alumina silicate materials using alkaline solutions. Chemical solutions which are used as alkaline activators mainly include sodium or potassium hydroxide and sodium or potassium silicate [6]. Thus the present study focused on using industrial by-products such as red mud, fly ash and ground granulated blast furnace slag (GGBFS) in geopolymer concrete. The objective of this experimental study is to provide a sustainable alternative construction material by geopolymerization of industrial by-products.

II. LITERATURE REVIEW

A. Kumar and S. Kumar (2013) [8] used Red Mud and Fly ash in Geopolymer for development of a paving block. Red mud addition enhanced the intensity of reaction and structural reorganization but in the improvement in setting time and compressive strength was observed only in the sample containing 5-20% red mud. The use of Red mud and fly ash is environmentally safe and these materials are free of cost in India. Experiments were carried out using 6M NaOH solution, 7g solid sample and 3.5 ml alkaline activator. The amount of red mud varied between 0 and 40%.The liquid to powder ratio was kept 0.35 in all batches. Compressive strength was tested after 3 and 28 days curing and results in comparison with cement based paving block were of same quality, the reduction in raw material cost was 10%.The main advantages of this research is reduction in Carbon dioxide and utilization of industrial wastes.

N. Ye et.al (2014) [9] used one-part geopolymer and was synthesized by using Bayer red mud as main raw material. Long-term strength of binder was significantly improved with addition of 20–30 wt. % SF. Lower water/solid ratio contributed to increasing the strength. The compressive strength of geopolymer cured for 28 days reached 31.5 MPa. Geopolymerization of dissolved aluminosilicate and silica formed dense matrices.

Y. Yao et.al (2014) [10] conducted studies and experiments on incorporation of RM and coal industry waste as raw material for production of cementitious materials. Partial replacement of OPC by RM, Coal Fly Ash and flue gas desulphurised gypsum. This composition was activated at 600˚C for 30 minutes before using in RCC. Experiments were conducted on Mechanical properties, Durability, Freezing and Thawing, Alkali-Silica Reaction and leaching test. The results show that the concrete made up of Reused Material had compressive strength and flexural strength (3-days curing) of 12.2 MPa and 3.5 MPa lower than that of RCC cubes made up of OPC. Good Solidification and durability results were found. The strength of the cubes were gained as it was aged of about 47.5 MPa in 180 days and 48.7 MPa in 360 days of this designed material.

Lemougna et.al (2017) [11] experimented tests to find the inorganic polymers made from red mud (RM) and slag. In this system RM and Slag were used in production of mortars. Percentage substitution of RM varied from 25% - 75% with sodium silicate solution (modulus varying from 1.6 - 2.2) as an activator. The samples were cured at higher temperatures like 25 ˚C, 40 ˚C and 65 ˚C only if large amount of RM is used. The addition of RM up to 25% did not affect the dry shrinkage and compressive strength of 54 MPa was obtained at 25˚C curing with geopolymer containing 50% RM and 50% Fly ash. But if Sand content in mortars increases it hinders the compressive strength in geopolymers made up of slag and RM. The overall results contribute to lesser CO_2 footprints on the environment and conversion of industrial by-products into valuable products.

Jian He et.al (2014) [12] used the raw materials for geopolymer synthesis such as red mud (RM) slurry, Rice husk ash (RAH), sodium hydroxide and deionized water. The study used weight ratio of RM/RHA of 0.4. It was found in the study that geopolymers have compressive strengths of up to 20.5 MPa, which is comparable to most Portland cements, suggesting that the RM–RHA geopolymers can be a potential cementitious construction material.

III. MATERIALS USED

A. *Following Materials were used in the study*

- Ordinary Portland Cement – 43 Grade (Confirming to IS: 8112-2013 [13])
- River Sand (Confirming to IS: 383-2016 [14])
- Coarse aggregates (20 mm downsize) (Confirming to IS: 383-2016)
- Red Mud (RM), Fly ash (FA), Ground Granulated Blast Furnace Slag (GGBFS)
- Alkali Activator Solution. Sodium Hydroxide to Sodium Silicate ratio ($NaOH$/ Na_2SiO_3) of 2.0 was adopted. Where 2 parts of NaOH is added to 1 part of Na_2SiO_3 to form a solution.

IV. METHODOLOGY

- The mix proportion used was as per conventional concrete mix design for M20 grade conforming to IS 10262: 2009 [15] and with the binder (RM: FA: GGBFS) mix of ratio 60:30:10
- Liquid to Binder ratio was 0.65
- Alkali activator solution containing Sodium hydroxide of molarity 6 M and Sodium silicate solution was mixed in a ratio of 2:1.
- Curing Method: Specimens were cured at ambient temperature.

V. TESTS CONDUCTED ON MATERIALS

A. *Tests on Cement*

Ordinary Portland cement confirming to IS: 8112 – 2013[13] was used for the experimental work and the following tests were conducted as per the standard procedure:

- Normal consistency test- IS: 4031 (Part-4) – 1999 [16]
- Initial and Final Setting Time- IS: 4031 (Part-5) – 1999[17]
- Specific Gravity of Cement- IS: 4031 (Part-11) – 2005[18]

B. *Tests on Fine Aggregates*

Natural Sand confirming to IS: 383-2016 [14] was used for the experimental work and the following tests were conducted as per the standard procedure

- Sieve Analysis of fine aggregate - IS: 2386 (Part-1) - 2016 [19]
- Silt content - IS: 2386 (Part-1) – 2016 [19]
- Specific Gravity of fine aggregate - IS: 2386 (Part-3) - 2016 [19]

C. *Test on Coarse Aggregates*

Coarse aggregate (20 mm downsize) confirming to IS: 383 – 2016 [14] was used for the experimental work and the following test was conducted as per the standard procedure:

- Sieve Analysis of Coarse Aggregate - IS: 2386 (Part-1) – 2016 [19]

D. *Test on Red Mud*

Red Mud was procured from locally available source. The following test was carried out:

- Specific Gravity of Cement- IS: 4031 (Part-11) – 2005[18]

E. *Test on Fly Ash*

Fly Ash was procured from locally available source. The following test was carried out:

- Specific Gravity of Cement- IS: 4031 (Part-11) – 2005[18]

VI. RESULTS AND DISCUSSION ON MATERIALS TESTED

A. *Normal Consistency of Cement*

The normal consistency of cement was found to be 31%.

Discussion: As per Reference [18], the percentage of water required for preparing a cement paste of standard consistency is 26% to 32%. The obtained value is within the limits as per the standard.

B. *Initial Setting Time of Cement*

The initial setting time of Ordinary Portland Cement was found to be 67 minutes.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 12, December-2018

Discussion: As per Reference [18], the initial setting time for ordinary Portland cement should not be less than 30 minutes, which is as per the standard.

C. Final Setting Time of Cement

The final setting time of Ordinary Portland Cement was found to be 209 minutes.

Discussion: As per Reference [18], the final setting time for ordinary Portland cement should not be less than 600 minutes, which is as per the standard.

D. Specific Gravity of Cement

The specific gravity of Ordinary Portland Cement was found to be 3.03.

Discussion: As per Reference [18], the specific gravity of cement should lie between 3.12 – 3.19. The obtained value is within the standard limits.

E. Sieve Analysis of Fine Aggregates

The fineness modulus of sand was found to be 2.57.

Discussion: Sand with Fineness Modulus value between 2.6-2.9 is categorized as medium sand and belongs to Zone 2 according to Table 4 of IS : 383 – 2016 [14].

F. Silt Content in Fine Aggregates

Average Silt Content in River Sand was found to be 2.43%.

Discussion: As per Reference [14], silt content in river sand should not exceed 3%.

G. Specific Gravity of Fine Aggregates

The Specific Gravity of Fine Aggregate was found to be 2.4

Discussion: As per Reference [14], specific gravity of fine aggregate should be between 2.66 – 2.7. The obtained value is within the standard limits.

H. Specific Gravity of Coarse Aggregates

The Specific Gravity of Fine Aggregate was found to be 2.5

Discussion: As per Reference [14], specific gravity of fine aggregate should be between 2.66 – 2.7. The obtained value is within the standard limits.

I. Specific Gravity of Red Mud

The Specific Gravity of Red Mud was found to be 3.25.

J. Specific Gravity of Fly Ash

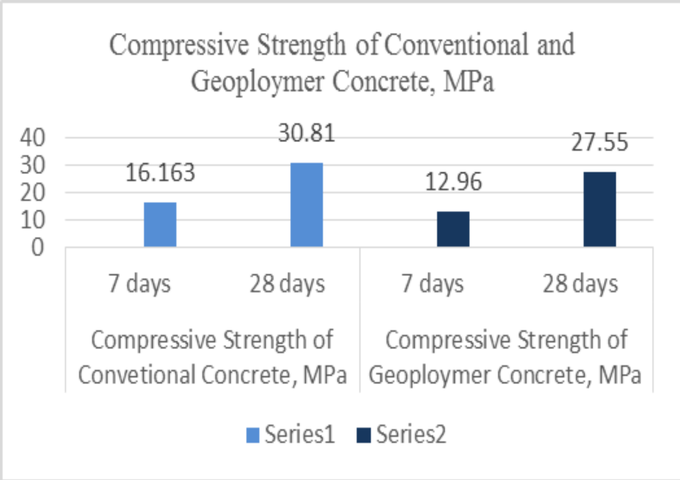
The Specific Gravity of Fly Ash was found to be 3.106.

VII. TEST RESULTS ON HARDENED CONCRETE

A. Compressive Strength of Conventional and Geopolymer Concrete for 7 days and 28 days as per IS 516: 1959 (Reaffirmed 1999) [20]

Table 1: Compressive Strength of Conventional and Geopolymer Concrete, MPa

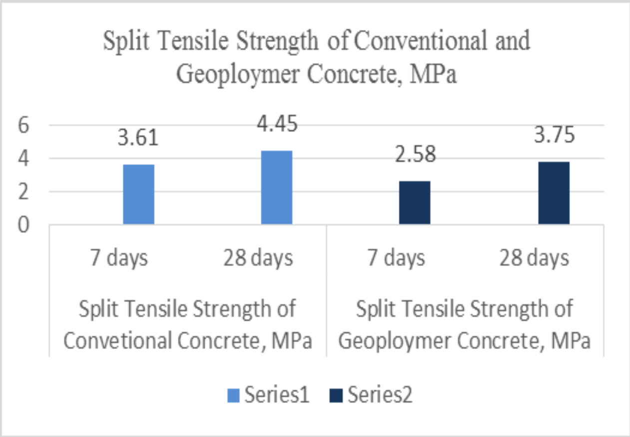
Specimen No.	Compressive Strength of Conventional Concrete, MPa		Compressive Strength of Geopolymer Concrete, MPa	
	7 days	**28 days**	**7 days**	**28 days**
1.	16	30.22	13.33	26.13
2.	16.89	31.55	12.77	28.22
3.	15.6	30.66	12.77	28.31
Average Value	**16.163**	**30.81**	**12.96**	**27.55**



B. Split Tensile Strength of Conventional and Geopolymer Concrete for 7 days and 28 days as per IS 516: 1959 (Reaffirmed 1999) [20]

Table 2: Split Tensile Strength of Conventional and Geopolymer Concrete, MPa

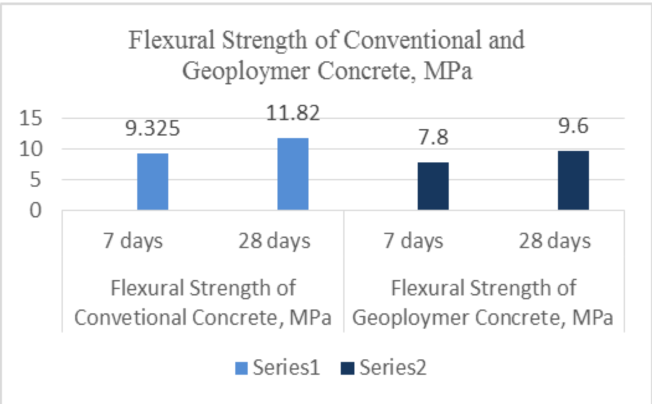
Specimen No.	Split Tensile Strength of Conventional Concrete, MPa		Split Tensile Strength of Geopolymer Concrete, MPa	
	7 days	**28 days**	**7 days**	**28 days**
1.	3.5	4.14	2.82	3.84
2.	3.82	4.46	2.78	3.62
3.	3.5	4.14	2.14	3.78
Average Value	**3.61**	**4.45**	**2.58**	**3.75**



C. Flexural Strength of Conventional and Geopolymer Concrete for 7 days and 28 days as per IS 516: 1959 (Reaffirmed 1999) [20]

Table 3: Flexural Strength of Conventional and Geopolymer Concrete, MPa

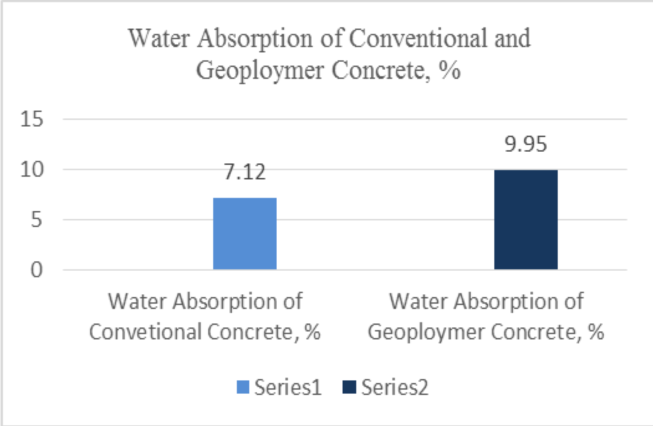
Specimen No.	Flexural Strength of Conventional Concrete, MPa		Flexural Strength of Geopolymer Concrete, MPa	
	7 days	**28 days**	**7 days**	**28 days**
1.	9.3	11.77	7.67	9.42
2.	9.375	11.62	7.83	9.65
3.	9.3	12.07	7.9	9.725
Average Value	**9.325**	**11.82**	**7.8**	**9.60**



D. Water Absorption of Conventional and Geopolymer Concrete for 7 days and 28 days as per IS 1199: 1959 (Reaffirmed 1999) [21]

Table 3: Water Absorption of Conventional and Geopolymer Concrete, %

Specimen No.	Water Absorption of Conventional Concrete, %	Water Absorption of Geopolymer Concrete, %
1.	7.01	9.60
2.	7.30	10.02
3.	7.05	10.23
Average Value	**7.12**	**9.95**



VIII. CONCLUSIONS

- From the experimental results it can be concluded that geopolymerization of red mud, fly ash and GGBFS can be used as sustainable alternative material for conventional concrete.
- Compressive strength of geopolymer concrete is found to be 89.4% of conventional concrete.
- Split tensile strength of geopolymer concrete is found to be 84.26% of conventional concrete.
- Flexural strength of geopolymer concrete is found to be 81.21% of conventional concrete.
- Water absorption of geopolymer concrete is found to be greater than of conventional concrete.
- To concrete the feasibility of usage of geopolymer concrete durability studies of the geopolymer is to be carried out.
- Specimens can also be tested for long term to check the strength achieved in comparison to conventional concrete.

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