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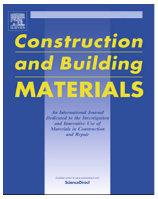

Enhancement of the properties of Ground Granulated Blast Furnace Slag based Self Compacting Geopolymer Concrete by incorporating Rice Husk Ash

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HIGHLIGHTS

- SCGC can be developed using GGBFS and RHA at ambient curing.
- The effect of RHA on workability and mechanical properties was analysed.
- Workability decreased with increase in percentage of RHA.
- Improvements on mechanical strength were recorded.
- Dense microstructure with better interlocking was resulted due to RHA.

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ABSTRACT

Rice Husk Ash (RHA) is an agricultural waste and plentifully accessible in rice-producing countries such as India. Use of RHA is achieving broader awareness because of its considerable impact on the mechanical and microstructural properties of concrete based on OPC as well as geopolymer binders. This paper presents the effect of RHA on the Fresh and Mechanical properties of Self Compacting Geopolymer Concrete (SCGC) blended by Ground Granulated Blast Furnace Slag (GGBFS). The SCGC was developed using GGBFS as the primary binder and GGBFS was replaced with 5%, 15% and 25% of RHA. The workability of fresh SCGC was assessed by slump flow, V-funnel, L-Box and J-Ring test methods as per EFNARC guidelines. Mechanical properties such as compressive strength, split tensile strength and flexural strength at 3, 7, and 28 days was tested. The results show that replacement of GGBFS with RHA results in loss of workability. The optimum replacement level of the RHA is 5% which results in 2.81% decrease in slump flow value but increases 3.02% compressive strength compare to results of 100% GGBFS SCGC mix. From SEM images, 5% RHA mix shows dense microstructure.

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1. Introduction

Nowadays, the primary interest of research is to control the environmental pollution. The major factors for environmental pollution are industrialization, urbanization and population growth. The utilization of cement is also increased up to 1 m^3 of concrete per year per person to meet the infrastructure development [1]. Growing demand for concrete using Ordinary Portland Cement (OPC) emitted lots of CO_2 (6–7%), and responsible for ecological imbalance because of continuous depletion of natural resources [2,3]. At the same time, it is required to protect the environment by avoiding dumping of waste or by-product materials in uncontrolled manners. Utilization of such by-products as an alternate material of cement has many benefits like the sustainability of resources, conservation of the environment and solves the issue of disposal of it. An effort in this inclination is the development of geopolymer concrete, which results in the eco-friendly and economical material with the identical mechanical properties which can be obtained from OPC.

Davidovits [4] developed the term 'geopolymer' in 1978 which is produced by polymerization process between aluminosilicate

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source material comprising silicon (Si) and aluminium (Al) and an alkaline liquid, resulted in an amorphous microstructure. Geopolymer concrete has become popular and attained the attention of researchers due to its environmental benefits, such as reduction of CO_2 emission and reduced use of natural resources. The raw material of geopolymers does not require high energy as the temperature calcinations process is not needed, which is a prime requirement of cement raw material production. It is proved that the geopolymer synthesis produces 5–6 times lesser CO_2 than Portland cement [5–7]. To achieve a suitable chemical composition of geopolymers, the preferable method is to blend Fly Ash with another high silica source like GGBFS, Rice Husk Ash, and Silica Fume etc. [8].

Li et al. [9] reported that the other waste material that is available in huge quantity in the world is GGBFS which is a by-product of the iron in a blast furnace and having calcium, magnesium silicates and aluminosilicates. Production of one tone of GGBFS releases only 70 kg of CO_2 which is only 7% of CO_2 emission of cement. The inclusion of GGBFS in Fly Ash based geopolymer showed reduced setting time and reduction in workability of paste. The calcium oxide (CaO) of GGBFS produces calcium silicate hydrates (C-S-H) with the aluminosilicate gel, enhancing the mechanical properties [10–21]. The partial replacement of GGBFS with FA, MK, and SF improved the setting time of geopolymer paste [22].

Rice Husk Ash (RHA) has not been extensively studied in geopolymer application [23]. The RHA is a waste by-product generated from rice milling plants produced by burning of Rice Husk under the controlled temperature. The main component of the RHA is amorphous silicon oxide (83–98%) with a minor quantity of CaO, MgO, K_2O, Al_2O_3, Fe_2O_3 and Na_2O [24,25]. The global production of paddy rice in 2014 was about 741.3 million tons (MT) as per the Food and Agricultural Organization (FAO) report. Therefore, the rice industries will remain sustainable in future and hence higher will be the amount of rice agricultural wastes [26]. India produces about 30 million tons of Rice Husk waste per year [27]. Concrete containing rice husk offer superior durability properties compared to concrete with other admixtures [28]. The inclusion of RHA in geopolymer developed higher compressive strength with a reduction in pore diameter up to 55%. It refined pore blocking effect and produced dense microstructure. The strength of geopolymer increases with the Si/Al ratio due to increase in stronger Si—O—Si bond [29–38]. The inclusion of 0–3% nano silica in Fly Ash based geopolymer with OPC and GGBFS developed dense and compact microstructure [39].

As per Liu et al. [40] and EFNARC [41], SCC offers advantages such as reduced construction time, enhancement of quality of concrete, placement of concrete through congested reinforcing bars, homogeneous, thoroughly compacted mix and increase in bond strength. It reduces noise levels due to the absence of vibration as well as reduces overall costs with providing safe working surroundings to masons. The use of RHA in SCC increases plastic velocity and yield stress. Up to 10% replacement of RHA reduces workability of geopolymer concrete and increases compressive strength [42–44].

Self Compacting Geopolymer Concrete (SCGC) is a new concrete that offers advantages of both SCC and geopolymer concrete. Memon et al. [45–49] were studied the compressive strength and fresh properties of low calcium Fly Ash based SCGC at an elevated temperature range from 60 °C to 90 °C. They have also investigated the effect of curing temperature, Superplasticizer, NaOH molarity as well as the effect of water to geopolymer solid ratio on fresh properties and compressive strength of SCGC blended with the Fly Ash only. The inclusion of GGBFS and silica fume enhanced the properties of SCGC due to the refinement of pore structure which finally developed dense microstructure [50–52].

1.1. Significance of research

Most of the investigations of SCGC have been done on Fly Ash as aluminosilicate source material. It was proved that the temperature curing is required to start the polymerization process for Fly Ash based geopolymer. The scope of such concrete is limited to the precast members only due to the constraint of the heat curing in cast-in-situ construction. Thus, the investigation is required to develop the geopolymer concrete cured at an ambient temperature. The currently available disposal method of pozzolanic waste material is by burning and dumping, which create environmental pollutions. RHA is a good quality source of reactive amorphous silica with lower bulk density. In the present study, GGBFS as an industrial waste and RHA as an agricultural waste are used as source material to synthesize the SCGC. The main objectives of this study are (i) to develop SCGC at ambient temperature curing for sustainability of environment by saving the energy of temperature curing and (ii) to investigate the effect of different percentage of RHA on fresh and hardened properties of SCGC blended with GGBFS.

2. Material and methods

2.1. Materials

GGBFS and RHA obtained from the local commercial suppliers in Ahmadabad were used as aluminosilicate source material in this study. The physical properties and chemical compounds of Fly Ash, GGBFS and RHA are as shown in Table 1 and Table 2.

River sand confirming zone II as per IS 383:1987 [53] with a specific gravity of 2.6 and fineness modulus of 2.73 was used as a fine aggregate. Locally available average size of 14 mm crushed coarse aggregates with a specific gravity of 2.87 was used. Alkaline solution plays a vital role in geopolymerization. Sodium hydroxide and sodium silicate were used as an alkaline solution. Sodium hydroxide with 98% purity in the flakes forms and sodium silicate in liquid form were obtained from the local manufacturer. To achieve higher workability and desired flowability of fresh concrete, a commercially available superplasticizer based on second-generation polycarboxylic ether, Master Glenium Sky 8784 supplied by BASF with relative density 1.10 was used.

2.2. Mix proportions

As standard mix design procedure is not available for geopolymer concrete, the mix design of SCGC is as per the EFNARC [41] guidelines of SCC. The target strength of SCGC was fixed 30 MPa. Total five mixes were prepared; two control mixes (Fly Ash and GGBFS) as a sole binder without RHA and remaining three mixes were prepared with different proportions of RHA. GGBFS was replaced with RHA at the percentages of 5%, 15% and 25% by mass. The total binder was fixed at 500 kg/m^3. For all mixes, the water to binder ratio by mass was maintained at 0.25. The sodium hydroxide molarity was fixed as 12 M, and the ratio of sodium silicate to sodium hydroxide was 2.5. The extra water of 25% and superplasticizer of 6% dosage by mass of the binder were used to satisfy the

Table 1
Physical Properties of Fly Ash, RHA and GGBFS.

Sample (%)	Specific gravity (g/cm^2)	Mean particle size (μm)	BET specific surface area (m^2/g)
Fly Ash	2.28	17.0	4.2
GGBFS	2.67	14.0	5.0
RHA	2.06	12.5	22.5

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