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Influence of recycled concrete aggregates on the flexural properties of reinforced alkali activated slag concrete

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HIGHLIGHTS

- AAS concrete can be used for sustainable structural design.
- Flexural properties of AAS concrete made with RCA were investigated.
- Compressive strength, water absorption and volume of voids were also discussed.
- Curing under ambient temperature may enhance its wider application in the field.
- Deflection and ductility properties improve with increase in the RCA content.

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ABSTRACT

Alkali-activated concretes are a novel invention for substituting conventional construction materials; their main variation from conventional Portland cement concretes is utilizing comparatively alkali-rich, clinker-free binder matrix namely alkali-activated slag or geopolymer. Alkali-activated concrete is an environmental friendly and possibly considered to be a part of the sustainable development. Since, aggregates constitutes the major part of the concrete, there is a need to reduce the use of natural aggregate thereby reducing the exploitation of natural resources. This paper explains the influence of recycled concrete aggregates derived from the demolished concrete waste on the mechanical properties of geopolymer concrete (GPC). Since, very few studies been conducted using recycled aggregates in geopolymer concrete under ambient curing, an experimental work was carried out involving mixes with varying proportion of recycled aggregates and their influence on the physical, mechanical and flexural characteristics of geopolymer concrete. The results infer that the inclusion of recycled aggregate improves the strength characteristics of geopolymer concrete.

1. Introduction

Cement manufacturing is the primary factor for the CO_2 emission which constitutes around 1.8GT every year [1] or about 7% of global CO_2 emission [2] and may increase rapidly upto 200% by 2050 than 2010 [3] due to the increase in the consumption of concrete. This has led to the evolution of geopolymer concrete in which industrial by-products which are rich in silica (Si^{4+}) and alumina (Al^{3+}) such as flyash, ground granulated blast furnace slag, etc. [4–7] can be used as a binder along with an activator solution. The activator solution is the mixture of sodium hydroxide with sodium silicate or potassium hydroxide with potassium silicate [8,9]. During the geopolymerization process, the reaction developed between aluminosilicate source material and alkali polysialates results in the development of 3-D polymeric chain and ring-like structure consisting of –Si–O–Al–O– bond [10,11]. The consumption of waste in various forms to accomplish inventive building material is the recent trend to utilize the enormous amount of wastes which are dumped every year. In general, concrete produced with RCA has typically shown a drop in the compressive strength as that with natural aggregates [12]. In converse, equivalent [13,14] and better [15] strength have also been acknowledged using RCA depending on the class of the recycled concrete aggregate (RCA) and mix proportion in addition to its workability and liquid–binder ratio. Concrete made with angular shaped RA shows better flexural strength as that of with round-shaped aggregates under reduced water–cement ratio. Regardless of the size and type of RCA, the concrete reveals analogous performance [16] provided that they show comparable physical properties at a given replacement level. As there was no study has been conducted to evaluate the influence of recycled aggregates in

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geopolymer concrete and minimum work has been conducted under ambient curing condition, this work is focused to study the influence of recycled aggregate content in geopolymer concrete under ambient curing condition. The paper at the outset offers a summary of the experimental program, incorporating materials used with their properties, mix proportioning and testing methodology. This is then followed with the results of the experimental program conducted and a detailed discussion on the results obtained, in which the influence recycled aggregate content on the compressive strength, split tensile strength, absorption characteristics and also their influences on the flexural behavior of the reinforced geopolymer concrete beams are presented along with added key experimental interpretations.

2. Materials and methods

2.1. Materials

2.1.1. Ordinary Portland Cement (OPC)

Ordinary Portland Cement of grade 53 blended cement with a specific gravity of 3.05 obtained from the local supplier with the chemical composition listed in Table 1 has been used in this work.

2.1.2. Ground Granulated Blast Furnace Slag (GGBFS)

Unlike flyash, Ground Granulated Blast Furnace Slag (GGBFS) leans to be added consistent in physical properties and chemical composition [17] and hence more likely to confer consistent results. GGBFS from the local steel plant with a mean particle size of 29 μm, specific gravity of 2.90 and a specific surface area of 438 m^2/kg was used as the alumino-silicate source material. The chemical analysis has been carried out using X-ray fluorescence spectrometry and the results are detailed in Table 1. From the chemical composition, the basicity coefficient has been calculated as 0.98 (less than 1) and the slag has been classified as acidic which is suitable as a starting material for AAS binder. GGBFS can be suitable to use as binder as the ratio CaO/SiO_2 is 1.18 (between 0.5 and 2.0) and Al_2O_3/SiO_2 is 0.56 (between 0.1 and 0.6) [18]. The hydration modulus is calculated as 2.04 which is the influencing factor for the degree of hydration and should exceed 1.4 [19]

2.1.3. Aggregates

Locally available graded river sand was taken as fine aggregates with a nominal maximum size of 4.75 mm and crushed granite as coarse aggregate with a maximum size of 16 mm. The demolished concrete waste arrived from the nearby demolished construction was ground into aggregate with a nominal maximum size of 16 mm. Test results for the aggregate used in the mixes are shown in Table 2. The RCA have the adhered mortar to the natural aggregates leads to lower density and specific gravity with greater absorption.

2.1.4. Activator solution

A series of alkali activators has been used and the majority of the past research proved that the activation by sodium silicate ($Na_2O{\cdot}\gamma SiO_2$) [20] blended with sodium hydroxide results in high strength. The alkaline activation of GGBFS was done by using commercially available sodium hydroxide flakes (99% purity) and sodium silicate solution ($Na_2O{\cdot}\gamma SiO_2{\cdot}nH_2O$) composed of 28% SiO_2, 11.2% Na_2O and 60.8% H_2O by mass. The silica modulus (the ratio between SiO_2 and Na_2O) was found to be 2.5.

2.1.5. Superplasticizer

The problem of rapid setting of geopolymer concrete and low workability because of RCA can be greatly reduced by employing superplasticizers which may even enhance the mechanical properties of geopolymer concrete [21]. In this regard, polycarboxylic ether (PCE) type superplasticizer, which is light brown liquid with a relative density of 1.08 at 25 °C, chloride ion content <0.2% and pH value 6 was utilized as it can exhibit the best plasticizing effect among other commercial superplasticizers for geopolymers activated with sodium hydroxide and sodium silicate [22].

Table 1
Chemical composition of OPC and GGBFS.

Oxide	CaO	SiO_2	Al_2O_3	MgO	SO_3	Fe_2O_3	Na_2O	K_2O
OPC (%)	63.12	24.52	6.88	2.16	1.43	3.51	0.44	0.63
GGBFS (%)	36.77	30.97	17.41	9.01	1.82	1.03	0.69	0.46

Table 2
Properties of aggregates used in the mixes.

Properties	Fine aggregate	Coarse aggregate	
		Natural aggregate	Recycled aggregate
Maximum size (mm)	4.75	16	16
Bulk density (kg/m^3)	1696	1485	1269
Specific gravity	2.58	2.72	2.44
Water absorption (%)	1.37	0.77	3.92

2.1.6. Reinforcing steel

The steel bars of 12 and 8 mm diameter bars were used as the longitudinal reinforcement and 6 mm diameter bars were used as shear reinforcements in the beams and were tested under uni-axial tension and the results obtained from the average of three specimens are detailed in Table 3.

2.2. Preparation of the geopolymer mixes

As mentioned earlier [23,24], the recycled concrete aggregates were pre-wetted and saturated to make in the form of saturated surface dry (SSD) condition in order to thwart the consequence of rapid reduction in the workability of concrete with RCA and also provide a better bond with cement. Sodium silicate and sodium hydroxide were utilized as the solution component of the geopolymer mix. NaOH solution was prepared a day before casting and kept in room temperature conditions to eliminate the rapid setting of the geopolymeric specimens due to excessive heat evolved. This was then mixed with sodium silicate solution for the required alkaline concentration. The mixes were prepared with an alkaline ratio of 2.0 with a liquid–binder ratio of 0.50 and NaOH concentration of 14 M. At the beginning GGBFS and sand was mixed first to have homogeneity. Coarse aggregate of desired size and quantity was prepared separately. Prepared dry mix of GGBFS-sand was mixed with coarse aggregate and thoroughly mixed for three minutes. Then permissible quantity of super plasticizer was poured into prepared alkaline solution and stirred with the help of stirrer for two minutes to have homogeneity. Subsequently heap was formed in the dry mix and alkaline liquid-super plasticizer solution was gradually poured to get the cohesiveness of the mix in fresh concrete. The detailed mix proportions of the mixes are listed in Table 4. All the mixes were casted and cured under ambient condition at a relative humidity of 71% with a temperature range of 26–30 °C.

2.3. Test setup

The compressive strength of the mixes was calculated according to ASTM C39/C39M [24] using cylindrical specimens of 100 mm dia. and 200 mm height after 28 days of ambient curing condition. The reinforced geopolymer concrete beams were tested under 4-point flexure mechanism similar to ASTM C1161 [25]. The size of the beam specimens were taken as 1.50 m × 0.10 m × 0.15 m simply supported over an effective span of 1200 mm. All the beams were reinforced with 2 numbers of 12 mm dia. bars as tension reinforcement and 2 numbers of 8 mm dia. bars as hanger reinforcement provided with 6 mm dia. shear reinforcements placed at 100 mm c/c. The beams were tested monotonically in a universal testing machine of 1000 kN capacity using a four-point loading setup as shown in Fig. 1 until failure. The loads were applied symmetrically at 400 mm on either side of the midspan.

3. Results and discussions

3.1. Physical properties

3.1.1. Workability

The workability of the mixes was determined with the help of the Slump cone test in accordance with ASTM C143/C143M [26]. The workability results of the mixes are shown in Fig. 2, found to decrease with the increase in the RCA content. This may be due to the presence of voids in the RCA content. This reduction in the slump was greatly reduced with the inclusion of superplasticizer with the increasing amount of RCA.

Table 3
Reinforcing steel properties under axial tension.

Bar size	f_y (MPa)	f_u (MPa)	f_b (MPa)	Elongation (%)
12 mm	530	653	408	20.50
8 mm	554	684	409	16.00
6 mm	684	805	572	25.50

Note: f_y = yield strength; f_u = ultimate strength; f_b = bearing strength.