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Influence of recycled concrete aggregates on the engineering and durability properties of alkali activated slag concrete

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HIGHLIGHTS

- AAS concrete can be used as sustainable construction material.
- Engineering and durability properties were investigated.
- Curing under ambient temperature may enhance its application in cast in-situ conditions.
- AAS concrete with 50% RCA content shows superior mechanical and durability properties.
- AAS concrete made of 100% RCA content shows superior properties than OPC concrete.

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ABSTRACT

The environmental effects of production of cement have provoked to examine the growth of concrete with 100% replacement of cement with materials which are activated by alkali solutions. Alkali activated slag (AAS) concrete is eco-friendly and potentially deemed to be a division of sustainable process. As majority of the volume of concrete is consumed by aggregates, there is a necessary to decrease the utilization of natural aggregates resulting in reduction of exploiting natural resources and effective utilization of construction and demolition waste. The effect of recycled concrete aggregate (RCA) on the engineering and durability properties of alkali activated slag concrete (AASC) under ambient curing state has been investigated in this paper. Since, very few works were carried in the field of alkali activated slag concrete curing under ambient temperature state and the utilization of recycled aggregates, an investigation was performed in AASC mixes with varying RCA fraction to study their influence on strength (compressive, splitting tensile and flexural) and durability (absorption, sorptivity, chloride and sulphate exposure) properties of AASC. The outcome of the results concludes that the addition of RCA has no signification reduction in the properties of alkali activated slag concrete.

1. Introduction

The increasing demand for concrete due to the growing demands of infrastructure has led to the increased production of Portland cement (PC). With the intention of curtailing the utilization of PC as a binder, geological source materials with rich amount of silicon (Si) and aluminum (Al) content can be an alternative source or an industrial by-product like fly ash, ground granulated blast furnace slag, etc. to react with an alkaline solution and the chemical reaction shaped is of polymerization products termed as Geopolymers was first established by Davidovits in 1978. Lawrence [1] stated that 1tonne of carbon dioxide (CO_2) is released to the atmosphere in the manufacture of 1tonne of PC if carbon fuel is used as energy source. Conversely, the making of commercial through-products releases fewer amounts of green house gases (GHG) comparing to PC. Fly ash produces 80–90% [2] and slag produces 80% [3] less GHG emission to the atmosphere compared with PC. The mix of sodium or potassium hydroxide with sodium or potassium silicate has been broadly utilized as an alkaline activator arrangement [4–7]. The utilization of recycled concrete aggregate (RCA) in concrete is gaining momentum. Vast measure of devastated concrete is produced as waste and is arranged off by dumping it as landfill or off recovering the area. But the cost of transportation and the shortage of dumping grounds make disposal a major problem [8]. As a further scope towards the use of waste concrete, the concrete rubble is being used as a substitute for natural aggregate have shown that RCA can best be used as a substitute for coarse aggregate only [9]. As understood, the cement paste from demolished concrete can bind chlorides, however the

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existence of sulphates can hinder this process as they are powerfully bound [10], hence, RCA can add to binding of chlorides, yet the stability of this maintenance is essential, so RCA without chlorides and sulphates must be utilized. The curing temperature or the temperature at which the underlying response plays a crucial part in the improvement of strength that can be accomplished by curing it above room temperature [11–13]. The quality was enhanced at a curing temperature of 50-80 °C instead of at room temperature [14]. The polymerization response turns out to be exceptionally quick with expansion in curing temperature and the solid can pick up strength of 70% inside 3–4 h of curing [11,15] and the higher early strength was accomplished when curing at 65 °C and there was no critical increment in the strength following 28 days [16]. The compressive strength, elastic modulus and water permeability depends on solution to ash ratio and paste to aggregate ratio [17]. As there was a minimum study focused on the geopolymer concrete made of recycled concrete aggregate and cured under room temperature condition, this investigation was done to evaluate the influence of RCA on the engineering and durability characteristics of AASC cured under ambient temperature condition. The flexural behavior of reinforced geopolymer concrete (GPC) beams containing RCA was already studied by the authors [18] whereas the issues regarding strength and durability properties were not addressed. Hence, this paper at the inception provides an outline of the experimental investigation integrating materials & their characteristics, their proportioning and experimental mechanism. It was then pursued by an elaborated discussion on the obtained results, where the effect of addition of RCA on the engineering (compressive strength, splitting tensile strength & flexural strength) and durability (water absorption & volume of voids, sorptivity, resistance to chloride and sulphate attack) properties are offered in conjunction with added significant elucidations.

2. Materials and methods

2.1. Materials

2.1.1. Ordinary Portland cement (OPC)

53 grade Ordinary Portland Cement (OPC) acquired from the local supplier was used in this study. The specific gravity was found to be 3.05 and its chemical composition is listed in Table 1.

2.1.2. Ground granulated blast furnace slag (GGBFS)

The most common cementitious material for AAS binder is GGBFS [19] as its hydraulic activity is high as compared with the other types [20,21] which can be measured by the basicity coefficient, which is the ratio between the total basic contents and acidic contents. GGBFS acquired from the nearby steel plant with 29 μm mean particle size, specific surface area of $1.56 m^2/g$ and specific gravity of 2.90 was used as geopolymer source material (GSM).

From the chemical composition of GGBFS presented in Table 1, the basicity coefficient was found to be 0.98 (less than 1) thereby the GGBFS was categorized under acidic nature can be best suited as a starting substance for alkali activated slag binder. The ratio of 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) [22] which makes GGBFS best suited as binder. The degree of hydration is mainly influenced by the hydration modulus, which was found to be 2.04 and should exceed 1.4 [23].

2.1.3. Activator solution

A variety of activators was utilized in the past research and the majority of them confirmed that the sodium silicate (Na_2SiO_3) [24] with sodium hydroxide (NaOH) activation fallout with superior strength. GGBFS was alkali activated by the use of commercially available sodium hydroxide in the form of flakes (99% purity) and sodium silicate solution (SiO_2-28%, Na_2O-11.2% by mass). The modulus of silica, which is the ratio between SiO_2 and Na_2O, was calculated as 2.5.

2.1.4. Aggregates

The fine and the coarse aggregates were equipped in accordance with ASTM C33/C33M [25] and their moisture condition was found to be in saturated surface dry (SSD) state. Graded river sand was used as fine aggregate with a nominal maximum size of 4.75 mm, coarse aggregate of crushed granite type natural aggregates (NA) and recycled aggregate derived from the laboratory cast concrete of 2 year old concrete waste with a nominal size of 16 mm were used as aggregates and their test results are given in Table 2. The mortar content present in the RCA samples was estimated by a modified acid treatment method as recommended in Akbarnezhad et al. [26]. In this technique, 1 kg of recycled aggregates were soaked in 2 M sulphuric acid solution for 5 days until the mortar present on the surface of the aggregates are completely removed, which is then washed and sieved through 4.75 mm sieve to separate the detached mortar from the aggregates. The mortar content can be measured by the rate of change of weight of the aggregates, which was measured to be in the range of 12 to 20% with a pH value of 11.5. The recycled aggregates used in the tests is shown in Fig 1 and the range of recycled aggregates were fixed such that the grading (Fig 2) of the natural and recycled aggregates is similar.

2.1.5. Superplasticizer (SP)

The use of superplasticizer has significant effect on overcoming the hitch in the reduction of workability of AASC when equipped with recycled aggregates and early setting time has been significantly reduced with the use of superplasticizer [27] resulting may improve the mechanical characteristics of GPC. The superplasticizers of polycarboxylic ether type has been employed in this work with a pH of 6, relative density of 1.08 at 25 °C with less than 2% chloride content, as it may be well suited for sodium activated geopolymers with their best plasticizing effect comparing with other commercial types [28].

2.2. Preparation of GPC mixes

To make RCA in surface saturated condition, they were prewetted and saturated [29,30] before mixing with the purpose of reducing the effect of reduced workability when employed with RCA as well as to afford an enhanced bond with cement. NaOH flakes were diluted in distilled water and kept under room temperature for 24 h to reduce the quick setting of the AASC mixes due to evolution of excessive heat. The concentration of NaOH solution was fixed at 14 M, which was then mixed with Na_2SiO_3 solution to have an alkaline ratio of 2.0. The NaOH concentration of 14 M

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