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An experimental investigation on self-compacting alkali activated slag concrete mixes

Manjunath R.*, Mattur C. Narasimhan

Department of Civil Engineering, National Institute of Technology Karnataka, Surathkal 575025, Mangalore, India

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ABSTRACT

In present work, an attempt has been made to develop self-compacting, alkali activated slag concrete mixes, using steel slag sand as fine aggregate and EAF (Electric Arc Furnace) slag as coarse aggregate. The study investigates the properties such as compressive strength, splitting tensile strength and water absorption of these mixes. Development of Self-Compacting Alkali Activated Slag Concrete mixes (hereafter referred to as SCAASC mixes) was made with GGBFS (Ground Granulated Blast Furnace Slag) as the binder, with its content varying between 700 kg/m^3 and 900 kg/m^3 of fresh concrete. The net W/B (water to binder) ratio of the mixes was varied between a narrow 0.47 – 0.48 range. The alkaline solutions had Na_2O percentages in the range 7 – 9%, but a constant activator modulus was maintained at 1.0 in all the mixes. In order to optimise the number of trial mixes to be tested, Taguchi's design of experiments methodology was adopted. A total of nine mixes were formulated using Taguchi orthogonal L9 array. Results showed the slump flow values for the mixes greater than 700 mm, with their L–Box ratios and V-Funnel values ranging between 0.90 and 0.95 and 9 – 11 s respectively, satisfying the EFNARC guidelines. Results also showed good compressive strengths (65–80 MPa), split-tensile strengths (2–4 MPa) and low water absorption values in the range of (2%–3%). The microstructural studies such as SEM, EDX and XRD analysis were also carried out, showing denser morphologies clearly indicating effective activation of slag by the alkaline solution.

1. Introduction

Concrete is one of the most important and widely used construction material in the world. Due to continued increase in the use of cement concrete for infrastructure development and its relative importance in the context of global environmental issues, special attention is being taken towards its role in sustainable development. It has now become more inevitable to consider OPC-based concrete production at such larger scale. Based on the survey carried out by International Energy Authority (IEA), cement industry is responsible for the production of approximately 6–7% of global CO_2 emission to the atmosphere [1].

One of the methods to produce sustainable concrete with lower carbon foot print is to minimize the use of Portland cement (PC) in the production of concrete. Geopolymers are a new class of concrete mixes, with no Portland cement, and are produced through the reaction of aluminosilicate-rich materials with an alkaline solution [2]. Fly ash, Rice husk ash, GGBFS, Metakaolin is some of the materials being used for cement replacement. Again some of these materials are pozzolanic in nature [3].

Fly ash and GGBFS are the most commonly used cement-replacement materials, due to the higher percentage of alumina and silica in them. Finely ground slag itself can be used as a sole-binder in the production of concrete, if it is activated by an alkaline solution of higher pH such as Sodium Hydroxide (NaOH) and/or Sodium Silicate (Na_2SiO_3) [4,5]. These binder- systems have the potential of using of large volumes of GGBFS, which otherwise may lead to safe disposal problems, leading to more economy and proving themselves more eco-friendly.

The production of one tonne of fly-ash based geopolymeric cements estimated to release about 0.184tonnes which is about 80% lower than that in Portland cement production. Again it is estimated that the production cost of fly ash-based, heat-cured, geopolymer concrete is about 10–30% cheaper than the normal concrete [6,7]. Partial replacement of fly ash with GGBFS in these concrete mixes has further proven to be more effective by avoiding heat curing [8]. This has led to the production of Alkali activated slag concrete mixes which have exhibited higher mechanical strengths and also greater resistances to aggressive environments [9–12]. These properties of Alkali activated slag concrete mixes have made them very promising alternatives to OPC concrete mixes taking into account sustainability issues also

* Corresponding author.
E-mail address: rmanju301@gmail.com (R. Manjunath).

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Table 1
Chemical composition of GGBFS.

Constituent	CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	Na_2O	K_2O	SO_3	LOI
Oxide content (% by weight)	33.7	16.7	1.20	32.42	9.65	0.16	0.07	0.88	0.04

Fig. 1. Slag sand.

Fig. 2. EAF slag.

Table 2
Physical properties of aggregates.

Sl. No	Test	Slag sand	EAF slag
1	Specific gravity	2.65	3.0
2	Fineness modulus	2.75	6.9
	Dry bulk density (kg/m^3)		
3	a) Loose	1445	1678
	b) Compacted	1635	1710
4	Aggregate crushing value	–	26%
5	Los angeles abrasion value	–	28%
6	Aggregate impact value	–	17%
7	Flakiness index	–	13%
8	Elongation index	–	25%

Table 3
Chemical composition of slag sand and EAF slag.

Chemical constituents	Weight (%)	
	Slag sand	EAF slag
CaO	34.30	34.70
Al_2O_3	17.29	4.19
Fe_2O_3	0.73	24.2
SiO_2	36.01	19.12
MgO	6.20	6.2
Minor minerals	5.47	1.63
Insoluble residue	–	9.7
LOI	–	0.26

[13,14].

Alkali activated slag concrete mixes, however, tend to exhibit workability-related problems in that, due to the early activation of the slag, following mixing, they tend to stiffen at faster rates, quite often within 15–20 min. Several attempts have been made to increase the workability and to retain it for longer durations in AASC mixes, either by using certain ultrafine materials or by using different types of superplasticizers. However poly-carboxyl ether based admixtures and naphthalene based admixtures only showed a slight increase in workability [15]. Again, it has been observed that the increase in the fluidizing of the concrete which in term increases the workability also depends on the pH of the solution [16].

Natural resources, in the form of fine and coarse aggregates also, are being exploited to a very great extent, due to the enormous increase in the construction activities [17]. Hence in view of preserving the natural resources, many alternative materials have been used as aggregates in alkali activated concrete mixes. Among them, copper slag has been shown to be a viable and effective replacement for river sand, up to 100%, both in terms of good mechanical properties and durability characteristics [18]. Steel slag aggregates can also be used as coarse aggregates in AASC concrete mixes, which may perform better with respect to their mechanical strengths and durability properties as compared to AASC mixes with regular broken granite chips [19].

The microstructure of the alkaline activation of slag most often depicts C–(A)–S–H gel as the main reaction product [20], albeit with a lower Ca/Si ratio [21,22] and also differences in C-S-H structure depending on the activator type [23,24]. The development of microstructure and the mechanical properties in AASC systems are remarkably different from that in Portland cement concrete mixes, noted by the absence of portlandite in the hydration products and rapid strength development during early ages [25,26].

The present paper focuses on developing a new class of more sustainable AAS concrete mixes, which can be brought to practice in the construction industry. Herein, an attempt has been made for developing Self-compacting alkali activated slag concrete mixes incorporating steel slag sand (in lieu of river sand) as fine aggregates and EAF slag aggregates as replacement to broken granite chips (jelly) as the coarse aggregate. The present experimental work aims at achieving more economical AASC mixes with better mechanical properties as compared to the current, state-of-art AASC mixes.

2. Experimental program

2.1. Materials

2.1.1. Ground granulated Blast furnace slag (GGBFS)

Ground granulated Blast furnace slag is the most commonly used binder for AAS systems, due to its higher hydraulic activity when compared to other types [27]. In the present investigation, GGBFS, obtained from M/S Jindal Steel Works, Bellary, India, conforming to IS: 12089 −1987 was used. The slag had a Blaine's fineness of about 370 m^2/kg and specific gravity of 2.9. From the chemical composition of GGBFS presented in Table 1 **(**as provided by the manufacturer), it is found that the basicity coefficient (the ratio between the total basic contents and acidic contents**)** is found to be 0.9 (< = 1), there by categorising the slag to be of acidic nature which is best-suited as a starting material for AAS binders.

2.1.2. Alkaline solution

Commercial grade Sodium hydroxide (NaOH) flakes having (a purity of 97%) and Liquid sodium silicate solution **(LSS)** (containing 14.7% Na_2O +32.8 SiO_2 + 52.5% H_2O, by mass and with a density 1570 kg/m^3) are used in the preparation of an alkaline activator used herein. In the present study, mixtures of sodium hydroxide and sodium silicate solutions, keeping a constant activator modulus (ratio of SiO_2/Na_2O) as 1.0 but for three different percentages of Na_2O namely 7%,