

EXPERIMENTAL STUDY ON AASC USING PS BALL AS FINE AGGREGATE AT THE HIGHER CONCENTRATION OF SODIUM SILICATE

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Abstract

The second largest production of cement is India with 455 Million Tonnes (MT) annually, by 2020 it may reach up to 550MT. In India, the increased demand for construction industry required to meet the needs for infrastructure development. However, the production of Portland cement, releases the significant amounts of CO₂ to the atmosphere. Therefore, it is necessary to look for sustainable solutions for future concrete construction as next generation construction materials, by the use of the Secondary Cement Replacement Material (SCRM). The alternative replacement for Ordinary Portland Cement (OPC) can be Ground Granulated Blast Furnace Slag (GGBS), Fly-ash, Silica fume, Rice-husk ash, which are the various industrial by-products. In this present work, an attempt was made to develop Alkali Activated Slag Concrete (AASC) using Precious Slag (PS) ball as fine aggregate. The development of AASC was made with GGBS as the principal binder. Mixes were developed with binder content 443 kg/m³, Na₂SiO₃/ NaOH ratio (1,1.5,2 and 2.5) and their performance when exposed to ambient temperature were studied. Alkali binder ratio (0.3) and Molarity of 8M was kept constant for all the AASC mixes. The test results showed that the slump values for the different mixes developed herein to be greater than 25mm with conventional slump cone satisfying the MoRTH guidelines for concrete pavements. Results showed that all AASC mixes have higher 28-day compressive strength of the order 24-58 MPa. The fatigue life of AASC mixes has improved by the addition of PS ball, at the higher concentration of sodium silicate, indicating better performance of AASC mixes.

Keywords: - AASC, PS Ball, Molarity, Sodium silicate etc...

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1. INTRODUCTION

The OPC production is associated with emission of large amount of carbon di-oxide into the atmosphere, each year 12 billion tons of concrete produced by the construction industry by consuming 1.6 million tons of cement. In addition to consuming the natural resources and energy, the cement industry is extremely energy intensive, as it consumes 4GJ per ton of energy, for the production of one-ton cement releases nearly 1 ton of carbon- di-oxide into the environment [20]. The only method to produce concrete with lower carbon footprints by use of alternative binder material by the gainful utility of Fly-ash (FA) and GGBFS as Geopolymer Cement, which involves zero cement in its production by converting the currently treated waste to a useful and valuable product [22]. Purdon (1940s) initially started working on the alkali activated binders, where the GGBFS is activated by NaOH solution [20]. Further Glukhovskiy (1960s) invented an alkali activated system, came out with Calcium Silicate Hydrate (CSH) and alumina-silicate phases [16]. Davidovits (1972) coined the term Geopolymer, formed in the lower temperature by describing the tri-dimensional structure of alumina-silica complex from the Kaolin [8]. Geopolymerization is the continuous polymerization reaction, where the alumina-

silica mineral reacts with alkaline solution, which involves the exothermic reaction [14, 21].

The AASC technology attracted a lot of attention recently and considered as the next generation construction material. When pozzolanic material such as fly-ash, the Si and Al as major constituent reacting with alkaline solution satisfying the various engineering properties. The fly-ash based Geopolymer concrete, when heat cured the production cost is 10-30% cheaper than Conventional concrete [15, 12]. Although the development of AASC had gained its importance in current trend, it poses some problems which are limiting its application by rapid setting [11]. As per Brough et al. 2000 and Chang, J.J. 2003, Malic acid and phosphoric acid, were reported to have a good retarding effect [3, 5]. Collins and Sanjayan (1999) reported the workability and strength of AASC using ultra-fine materials and slag as the binder [7]. Collin and Fernandez et al. (1999) reported that the strength development of AASC depends on the type of activator and its concentration [4, 10].

Sand is critical for development and construction, much of global economy relies on it, sand reserves being depleted; industrial sand and gravels are the world's most extracted materials. Indiscriminate extracting of sand has severe environmental, social, economic and geopolitical inputs.

This paper centers on using the precious slag ball as the most viable alternative for fine aggregate in the AASC mix for application in rigid pavements.

Table 1: Chemical Composition of Ground Granulated Blast Furnace Slag

Chemical Constituent	Percentage (%)	
CaO	37.34	
Al ₂ O ₃	14.42	
Fe ₂ O ₃	1.11	
SiO ₂	37.73	
MgO	8.71	
MnO	0.02	
Sulphide sulphur	0.39	
Loss on Ignition	1.41	
Insoluble Residue	1.59	
Glass content	92	
Chemical moduli:		The presence of major oxides with granulated slag shall satisfy at least one of the equation
1. CaO+Mgo+1/3Al ₂ O ₃	1.1	
2. CaO+Mgo+ Al ₂ O ₃	1.6	

They are made by a procedure that includes the atomizing of fluid steel slag utilizing an advanced, innovative called Slag Atomizing Technology (SAT). The fluid steel slag stream is changed over to round slag chunks of different sizes by the super cooling technique for liquid slag, utilizing quick warmth trade of the falling fluid steel slag in fast wind current. Amid this procedure, free CaO and Fe₂O₃ are scattered to shape a strong PS ball and hence delivered in a steady Spinel Structure. PS Ball is non-lethal and contains no free silica. They are earth benevolent as the material is without contamination and non-poisonous, which has a characteristic trademark hardness. Its Spinel structure causes strength in physical and synthetic piece, wiping out any reasons for the contamination. As contrasted and sand, it has prevalent attributes of compressive quality, hardness and against weathering properties. PS Ball is a financially savvy material when contrasted with other mineral materials. PS Ball it has molded in a steady and safe frame, not a contamination and harder than of Copper or Sand. Lower levels of perilous contaminants, for example, asbestos (olivine) and arsenic (copper slag). As an answer for this, different choices, for example, copper slag, steel slag, slag sand, rock sand is considered. Copper slag has appeared to be a reasonable and a successful substitution of stream sand, up to 100% bearing great mechanical properties and strength properties [19]. AASC blends created utilizing two modern waste-steel slag sand and Electric Arc Furnace (EAF) slag as coarse total at 100% substitution are fulfilling the EFNARC rules of stream capacity and other designing properties [17]. Directed studies in the past have revealed the utilization of steel slag as totals to be favorable in traditional cement [1, 18 and 23]. In this study, the effect of sodium silicate concentration on AASC mixes was evaluated by incorporating PS Ball as aswap for stream

sand, aiming to satisfy the requirements as per IRC 58:2011 for its application in rigid pavements.

Table 2: Chemical composition of Precious Slag (PS) Ball

Chemical constituent	Percentage (%)
CaO	29.99
Al ₂ O ₃	11.24
Fe ₂ O ₃	32.95
SiO ₂	18.32
MgO	6.13
SO ₃	0.058
Na ₂ O	0.29
K ₂ O	0.16

2. EXPERIMENTAL PROGRAMME

2.1 Materials

2.1.1 Ground Granulated Blast Furnace Slag (GGBFS)

GGBFS is used as binder for AASC, Obtained from M/s, Jindal Steel Works, Bellary. The slag has a Blaine's fineness of about 370 m²/kg and specific gravity of 2.90. The chemical composition of GGBFS used is arranged in Table1. With a computed basicity coefficient (ratio of basic content and acidic content) of 1 which can be delegated an acidic slag [24].

2.1.2 Alkaline Solution

From the practical application point of view commercial grade sodium hydroxide (NaOH) flakes having a purity of 97% and Liquid Sodium Silicate (LSS) solution containing 14.7% Na₂O, 32.8% SiO₂, 52.5% H₂O by mass and density 1570 kg/m³ were used in the arrangement of an alkaline activator solution. In the present study, binder of 443 kg/m³ was selected with fixed Molarity of 8M, Sodium Silicate (SS) to Sodium Hydroxide (SH) ratio of 1,1.5, 2 and 2.5 is selected, keeping the constant alkaline liquid to binder ratio as 0.3 for all mixes. The total mass of Na₂O present in the alkaline solution is equal to the sum of Na₂O present in NaOH. The consumable water accessible in the laboratory was utilized for preparing the alkaline solution. The alkaline solution prepared is allowed to cool for 24 hours prior to mixing so that ions can dissociate, to reduce the heat liberated and to prevent the quick setting of fresh concrete during mixing.

2.1.3 Aggregates

In the present study, Crushed stone pieces of maximum nominal size of 20mm down were used as coarse aggregates. The specific gravity and water absorption of coarse aggregate are 2.68 and 0.45% respectively. Precious Slag (PS) ball is used as replacement for river sand. The

specific gravity and water absorption of PS ball used is 3.45 and 0% (Nil) respectively. The PS ball used satisfies the requirements of zone-1 specified for the fine aggregates.

2.2 Mix Design

The mix design resulted in the mixture proportion of 443 kg/m³ of binder material, total aggregate content of 1824 kg/m³. All the mixes were proportioned based on the absolute volume method. The ratio of coarse to fine aggregate is 1:2, with constant alkaline liquid to binder ratio 0.3 and sodium silicate to sodium hydroxide ratio as 1, 1.5, 2 and 2.5 for various AASC mixes at fixed molar of 8M. A retarder dosage of 0.65% by weight of slag to provide an initial setting not earlier than 20 min. Alkaline liquids were prepared, one day prior to mixing based on the quantities required for different sodium silicate content. The mixing of all material was done in a ribbon type mixer with a horizontal shaft for better mixing. The resulting homogenous mix of concrete was subjected to workability test with slump cone. Then the cube specimens were cast using 100x100x100 mm mould for determining the compressive strength and water absorption test. Cylindrical specimens, 150 mm diameter x 300 mm height, were cast for split tensile strength test. Similarly, prism specimens, 500x 100x 100 mm mould for determining the flexural strength and fatigue analysis. The entire specimen was de-moulded after 24hrs and then subjected to ambient curing. Sufficient numbers of specimen were cast for facilitating compressive strength test at the age of 3-day, 7-day and 28-days.

Table 3: Details of Mix Proportions of Concrete Mix

Mix ID	Binder (kg/m ³)	Alkaline solution (kg/m ³)		Aggregates (kg/m ³)		Total wet weight (kg/m ³)
		Sodium silicate solution	Sodium hydroxide solution	Coarse aggregate	PS Ball	
M1	443	66.465	66.465	1167.36	656.64	2400
M2	443	53.172	79.758	1167.36	656.64	2400
M3	443	44.31	88.62	1167.36	656.64	2400
M4	443	38	95	1167.36	656.64	2400

3. RESULTS AND DISCUSSION

3.1 Workability of AASC Mixes

Generally, the Alkali Activated Concrete (AAC) is characterized by lower workability compared to the conventional concrete due to the presence of alumina and silica as major source reaction material in AAC. For the mixes with high NaOH content (SS: SH=1) the workability

decreased with increase in NaOH concentrations. The slump of mixes with 8M was 45, 42, 40 and 35 mm respectively. The increased Na₂SiO₃ concentration increased the viscosity of the mix by reducing the workability. The setting time of concrete is influenced by SS: SH ratio, for the mixes with high NaOH content (SS: SH=1), setting time decreased with the increase in Na₂SiO₃ concentration. The setting time of mixes with 8M for Na₂SiO₃/NaOH of 1, 1.5, 2 and 2.5 were 21, 17, 14 and 12 min respectively. At high NaOH concentrations, the setting time was controlled by geopolymerization [6]. At low NaOH concentrations, the setting was controlled by the presence of calcium, and the high concentration of NaOH hindered the dissolution of calcium and thus setting time was delayed [6]. Tri-sodium phosphate was chosen as an initial setting time retarder to reduce the stiffness consistency, introduced into alkali solution before mixing. The initial setting time of all the AASC mixes developed with Na₂SiO₃/NaOH of 1, 1.5, 2 and 2.5 has 42, 36, 29, and 22 min.

3.2 Tests on Hardened Concrete

3.2.1 Compressive Strength

The compressive strength at various stages 3-day, 7-day and 28-days were conducted as per IS 516:1999 and their results are shown in Figure-1. The compressive strength of AASC mix increased as Na₂SiO₃/NaOH ratio was increased, by accelerating the geopolymerization chain reaction process with greater dissolution of source material, which has similar observation made by Hardjito and Rangan (2005).

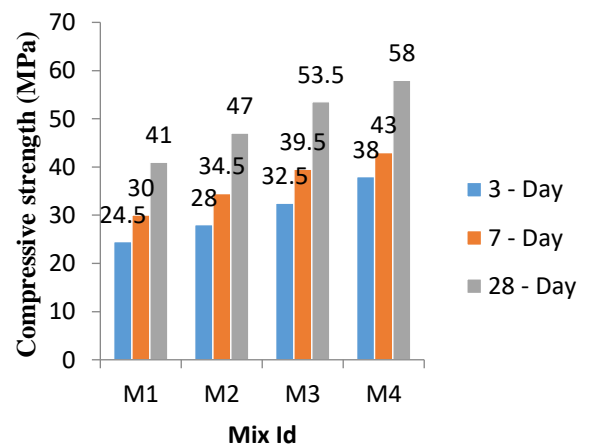


Fig 1: Compressive strength of AASC Mixes

Note - M1 is AASC mix with 8M at SS/SH=1, M2 is AASC mix with 8M at SS/SH=1.5, M3 is AASC mix with 8M at SS/SH= 2, M4 is AASC mix with 8M at SS/SH =2.5

AASC continued to gain strength from 3 to 28 days cured at the ambient temperature, due to continued polymerization reaction and availability of free water in the mix.

3.2.2 Split Tensile Strength

The split tensile strength tests were performed according to IS 5816-1999 and the results are as shown in Figure-2 for the various mixes, at 28-day curing period. The increased Na₂SiO₃/NaOH ratio, accelerated the geopolymerization process in turn the split tensile of AASC was related to the compressive strength. Duxson et al. 2007 reported that the Geopolymer produced by high hydroxide content and higher silicate solution tends to have higher Interfacial Transition Zone (ITZ) strength due to lower porosity in geopolymer paste [9]. In the AASC with the presence of high calcium compound, the voids in alumina-silicate matrix were filled with Calcium Silicate Hydrate (CSH) products resulting in increased strength [13].

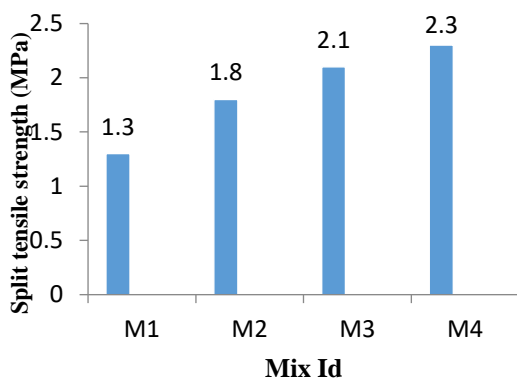


Fig -2: Split tensile strength of AASC Mixes at 28 days curing

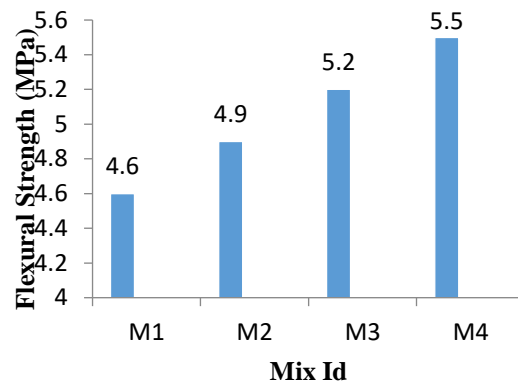


Fig 3: Flexural strength of AASC Mixes at 28 days curing

Table -4: Fatigue life of AASC specimens

Mix ID \ Stress Level	M1	M2	M3	M4
0.85	504	552	591	633
	534	582	624	669
	579	633	678	723
0.8	726	765	801	825
	762	798	843	852
	792	846	879	912
0.75	924	966	1122	1176
	975	1023	1233	1293
	1014	1059	1293	1323

3.2.3 Flexural Fatigue Behavior of Concrete Mixes

The flexural strength was determined as per IS 516:1959 for all the AASC mixes. The static flexural strength tests were conducted at 28-day of curing and the results are shown in Fig- 2. It is observed that the higher concentration of sodium silicate in AASC mixes increased the flexural strength at 28-day ambient curing, all the mixes achieved the minimum strength requirement of 4.5 MPa as per IRC 58:2011. The fatigue life analysis of AASC mixes is presented in Table 4. Irrespective of flexural failure load for all the mixes, a constant load (1125 kg) was selected to know the fatigue behavior of all the mixes, all the mixes display better fatigue performance due to the existence of highly dense interfacial transition zone in AASC mix [2], at the higher concentration of NaOH excess hydroxide ion concentration causing alumina-silicate gel to precipitate at the early stages, hindering the polymerization reaction resulted weak paste-aggregate interface thus initiating early crack formation and propagation leading to early fatigue failure under the action of repetitive cyclic loading.

As per IRC: 57-2002, for stress ratios above 0.7 repetitions reducing drastically. At 0.7-1970 cycles, 0.75- 477 cycles, 0.85-30 cycles so on. Therefore, this material is much more superior than the conventional cement concrete.

4. CONCLUSION

Based on the data obtained from the various experiments, the following conclusion can be drawn. The setting time of AASC mix decreased as the sodium silicate content increased, which has greater influence on the workability and strength. The AASC mixes with higher silicate content resulted in the lower workability due to incomplete geopolymerization by less alkaline activator reaction with slag. The compressive strength of AASC mix increments with increment in sodium silicate content, the higher convergence of Na₂SiO₃ accelerates the geopolymerization response with greater dissolution of the source material. The compressive strength of AASC is dependent on the NaOH concentration and Na₂O content present in alkali solution; in turn the split tensile and flexural fatigue behavior of AASC was related to the compressive strength. The AASC mix with AL/B proportion of 0.3, 10 M NaOH, and SS/SH proportion in the scope of 1 to 1.5 can be proposed as ideal blends in regards to the execution criteria of workability, setting time and compressive strength.

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