

Engineering Properties of Alkali Activated Slag Concrete Under Ambient And Heat Curing

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Abstract - This paper presents an investigation into the engineering properties of alkali activated slag concrete (AASC) made with ground granulated blast furnace slag (GGBS) as sole binder. Four mixes of AASC were prepared using different Alkaline to GGBS ratios (0.4 and 0.5), Na₂SiO₃ to NaOH ratios (2.33 and 1.0) with concentration of NaOH solution as 12M and 16M. Specimens were cast and cured under ambient and heat curing (24 h at 60°C) conditions after undisturbed for 24 h in moulds at room temperature. Their performance was discussed and compared with conventional concrete (M20) produced using ordinary Portland cement. Engineering properties like compressive strength, flexural strength, splitting tensile strength and stress strain behaviour were evaluated as part of this study. The test results show that S-0.4-2.33-16M mix is better in compressive and splitting tensile strengths whereas S-0.5-2.33-16M mix exhibited higher flexural strength and S-0.5-1.0-12M mix has the highest toughness index.

Key words: Alkali activated slag concrete, conventional concrete, compressive strength, flexural strength, splitting tensile strength, stress strain

1. Introduction

The need for the world's infrastructure growth has been increasing every year where Portland cement is conventionally used as the primary binder for manufacturing concrete. The cement industry produces around 5% of global CO₂ emissions into the atmosphere [1]. Therefore, the focus is made on development of innovative, eco-friendly binding material which causes low CO₂ impact. Alkali

activated materials have been used as alternative binders offer advantages in terms of mechanical strength[2], chemical durability[3-5], thermal resistance[6]. The raw material used for alkali-activation is GGBS. The alkali activation of slag will produce a CaO-Al₂O₃-SiO₂ gel (C-A-S-H) resembling the C-S-H gel in Portland cement paste[7]. The alkaline activators used are sodium hydroxide and sodium silicate solution due to their activation capabilities with GGBS producing a high strength [8-13].

Most of the research on alkali activated materials has been centred by using various aluminosilicates materials such as GGBS, fly ash, Metakolin etc. as the source materials [14]. The study on alkali activated slag concrete is very still limited and needs systematic study

Therefore, the main aim is to investigate the engineering properties of alkali activated slag concrete (four mixes) along with conventional concrete mix subjected to heat curing and ambient curing. Compressive strength, flexural strength and splitting tensile strength tests are performed. The stress strain behaviour is also studied.

2. Experimental procedure

2.1. Materials

2.1.1. Ground granulated blast furnace slag

Ground granulated blast furnace slag conforming to BS: 6699-1992[15] has been used. The physical properties and chemical analysis of GGBS are shown in Table 1.

Table1 Physical properties and chemical analysis of GGBS (as furnished by the supplier)

Particulars	Test results	Requirements as per BS:6699:1992
Fineness (m ² /kg)	335	>275.0
Soundness-Le Chatelier Expansion(mm)	Nil	< 10.0
Initial setting time (min)	150	>of OPC
Insoluble residue (%mass)	0.60	< 1.5
Magnesia content(%mass)	9.12	< 14.0
Sulphide content (%mass)	0.60	< 2.0
Sulphite content (%mass)	0.56	< 2.5

Loss on ignition (%mass)	Nil	< 3.0
Manganese content (%mass)	0.58	< 2.0
Chloride content	0.018	< 0.1
Moisture content	0.20	< 1.0
Compressive strength(N/mm ²)		
• 7 days	26.0	> 12.0
• 28 days	46.0	> 32.5
Chemical moduli		
a. CaO+MgO +SiO ₂	78.56	> 66.7
b. (CaO +MgO) / SiO ₂	1.00	> 1.0
c. CaO/ SiO ₂	0.98	>1.4

2.1.2. Cement

Ordinary Portland cement of 53 grade conforming to IS: 12269-1987 [16] has been used. The physical

properties and chemical analysis are shown in table 2 and 3.

Table 2 Physical properties of ordinary Portland cement

Properties	Results	Permissible limit as per IS:12269-1987
Fineness (% weight of residue left IS 90 μ Sieve)	2	< 10
Normal consistency (%)	33	-
Specific gravity	3.10	-
Setting time (minutes)		
Initial	145	> 30
Final	215	< 600
Soundness-Le Chatelier Expansion (mm)	2	< 10
Compressive strength (MPa)		
3 days	29.5	> 27
7 days	39.8	> 37
28 days	57.2	> 53

Table 3 Chemical analysis of ordinary Portland cement (as furnished by the supplier)

S.No.	Description	Result
1.	Lime Saturation Factor (LSF)	0.91
2.	Alumina/ Iron oxide	1.28
3.	Insoluble residue (% by mass)	1.10
4.	Magnesia (% by mass)	0.80
5.	Sulphur Anhydride (% by mass)	1.84
6.	Total Loss on ignition (% by mass)	1.06
7.	Alkali content	Nil
8.	Chloride (% by mass)	0.012

2.1.3. Alkaline solution

The alkaline solution is the combination of sodium silicate and sodium hydroxide solution. Sodium silicate with alkali modulus of 2.0 approximately (15.8% of Na₂O and 32.2% of SiO₂) is used. The alkaline solution was prepared 24 h prior to use for AASC specimens. Sodium hydroxide solutions of two different concentrations 12M and 16M were prepared in accordance with the procedure suggested by Rajamane and Jeyalakshmi [17] and

left it for one day. Sodium silicate solution is added to the NaOH solution one hour before casting.

2.1.4. Fine aggregate

River sand conforming to Zone III of IS: 383-1970[18] having specific gravity 2.54 and fineness modulus 2.13 was used.

2.1.5. Coarse aggregate

Coarse aggregate of two fractions 20 mm and 10 mm are used. The specific gravity 2.74 and fineness modulus 7.02 was used.

2.2. Mix proportions

Table 4 shows the mix proportions of conventional concrete and alkali activated slag concrete. The conventional concrete (M20) mix design was carried out according to IS: 10262-2009[19] and the same was adopted to alkali activated slag concrete mix. These four AASC mixes are having Alkaline to GGBS ratios 0.4 and 0.5 for Na₂SiO₃ to NaOH ratios 2.33 and 1.0 with concentration of NaOH solution as 12M and 16M.

Table 4 Mix proportions of CC and AASC specimens

Mix*		CC	S-0.4-2.33-16M	S-0.5-2.33-12M	S-0.5-1.0-12M	S-0.5-2.33-16M
Cement (kg/m ³)		320	-	-	-	-
GGBS (kg/m ³)		-	320	320	320	320
Fine aggregate (kg/m ³)		708.5	708.5	708.5	708.5	708.5
Coarse aggregate (kg/m ³)	20 mm	831.3	831.3	831.3	831.3	831.3
	10 mm	415.7	415.7	415.7	415.7	415.7
Water [#] (l)		160	160	160	160	160
Alkaline to GGBS ratio		-	0.4	0.5	0.5	0.5
Na ₂ SiO ₃ to NaOH ratio		-	2.33	2.33	1.0	2.33
Molarity of NaOH solution (M)		-	16	12	12	16

Note:

*Within mixture designation

S represents slag,

0.4 and 0.5 represent Alkaline to GGBS ratio, 2.33 and 1.0 represent Na₂SiO₃ to NaOH ratio and

12M and 16M represent Molarity of NaOH solution.

represents total water content including water in sodium hydroxide and sodium silicate.

2.3. Mixing, casting, curing and testing

The mixing of AASC and CC specimens are performed using pan mixer of 40 l capacity. Cube (150 mm x 150 mm x 150 mm), prisms (500 mm x 100 mm x 100 mm) and cylindrical specimens (150 mm diameter and 300 mm height) are casted using the mixer. The mixture kept in the mould are vibrated for sufficient time to ensure that no voids were present in the specimens casted. After casting, one set of specimens were left at room temperature (ambient curing) until time of testing. Another set of specimens were allowed to set for one day and then kept in the oven for 24 h at 60°C (heat curing). Then the specimens were brought down to room temperature before testing. Three specimens of

each mix were tested for compressive strength, flexural strength and splitting tensile strength at 7, 28 and 56 days of age. Compressive strength and flexural strength tests are conducted according to IS 516-1959 [20] whereas splitting tensile strength is conducted according to IS 5816-1999 [21]. Three specimens of each mix were tested at 28 days using compressive testing machine to study stress strain behaviour.

3. RESULTS AND DISCUSSIONS

3.1 Compressive strength

Fig.1 shows the compressive strength development of CC and AASC mixes at 7, 28 and 56 days under ambient and heat curing. Higher compressive strength is observed in AASC mixes than CC mix. The compressive strength increases with increase in age for all mixes except for S-0.5-2.33-16M mix under ambient and heat curing. This S-0.5-2.33-16M mix shows slight reduction in strength at 56 days i.e., 46.52 MPa (ambient curing) and 47.85 MPa (heat curing). A similar deteriorating behaviour of a specimen made by 100% slag material was observed by other researchers also [22-23]. The behaviour can be attributed to the growth of micro-cracking with time. At the age of 7 days, S-0.5-2.33-12M mix has shown the highest compressive strength of 37.77 MPa (heat curing). The 28 day compressive strength is highest for S-0.5-2.33-16M mix with 53.03 MPa (heat curing)

while at 56 days it is high for S-0.4-2.33-16M mix with 50 MPa (heat curing). However, the highest compressive strength is not observed for same

AASC mix at all ages. This mix S-0.4-2.33-16M shows better strength at all ages.

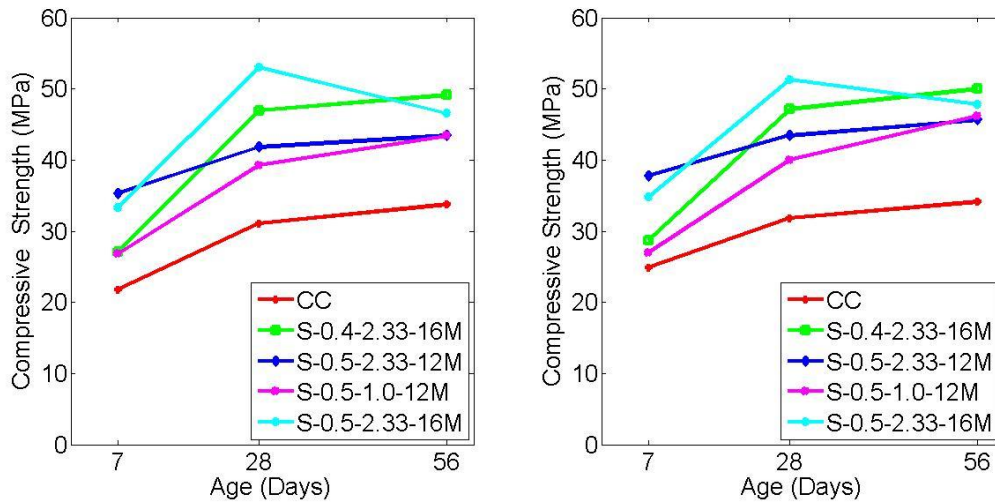


Fig.1. Variation of compressive strength of CC and AASC under ambient and heat curing

3.1. Flexural strength

The flexural strength of CC and AASC mixes at 7, 28 and 56 days under ambient and heat curing is shown in Fig.2. It is observed that S-0.5-2.33-16M mix under ambient curing is having highest flexural

strength at all ages. At 7 days the flexural strength for S-0.5-2.33-16M mix was 5.28 MPa while it was 5.72 MPa at 28 days and for 56 days it was 6.19 MPa. It is observed that flexural strength for S-0.5-1.0-12M mix at 7 days is more when compared to 28 days under ambient and heat curing.

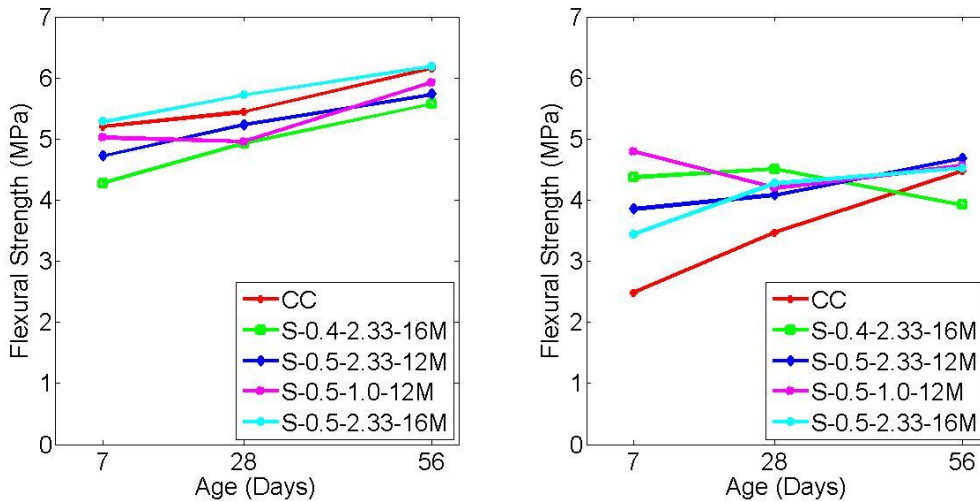


Fig.2. Variation of flexural strength of CC and AASC under ambient and heat curing

3.2. Splitting tensile strength

Fig.3. shows the splitting tensile strength of CC and AASC under ambient and heat curing at the age of 7, 28 and 56 days. It can be seen that the splitting tensile strength of AASC mixes are higher than that

of CC mix at all ages under heat curing. But for ambient curing the splitting tensile strength of CC mix is equivalent to S-0.4-2.33-16M mix at 7 and 56 days. Therefore, the highest splitting tensile strength is observed for CC under ambient curing at all ages. At 7 days the strength is 2.55 MPa whereas at 28 days it is 2.64 MPa and for 56 days it

is 2.83 MPa. It is also observed that the same strength is observed for both CC and S-0.4-2.33-

16M at 7 and 56 days under ambient curing.

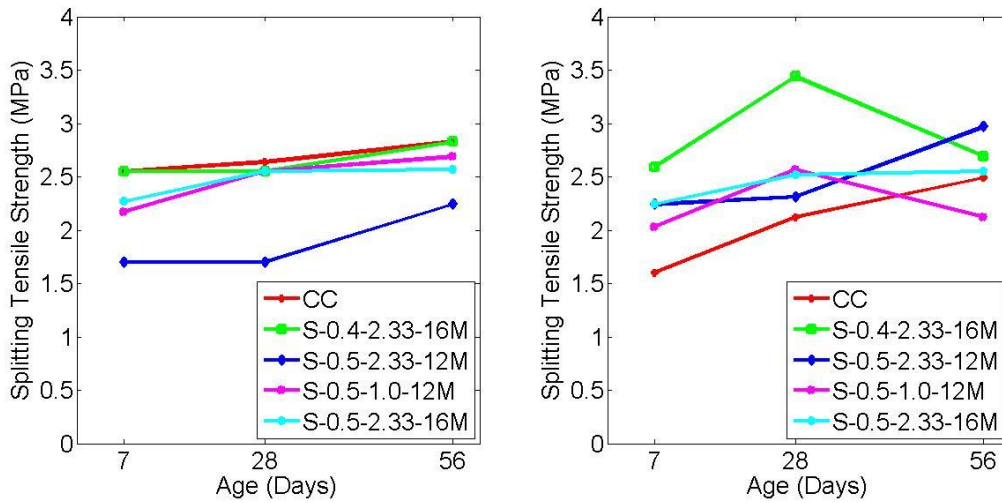


Fig.3. Variation of splitting tensile strength of CC and AASC under ambient and heat curing

3.3. Stress – strain behaviour

3.3.1. Under Ambient curing

Fig.4. shows S-0.5-1.0-12M mix gives high toughness value compared to other AASC and CC mix. The peak ultimate stress observed for this mix is 24.05 N/mm². Among S-0.5-1.0-12M and S-0.5-

2.33-16M mixes, there is significant decrease in peak stress by 12.5% in S-0.5-2.33-12M mix. With regards to strain S-0.5-2.33-12M mix shows prominence value (0.003) than other mixes while S-0.4-2.33-16M and CCmixes shows lesser stress and strain values.

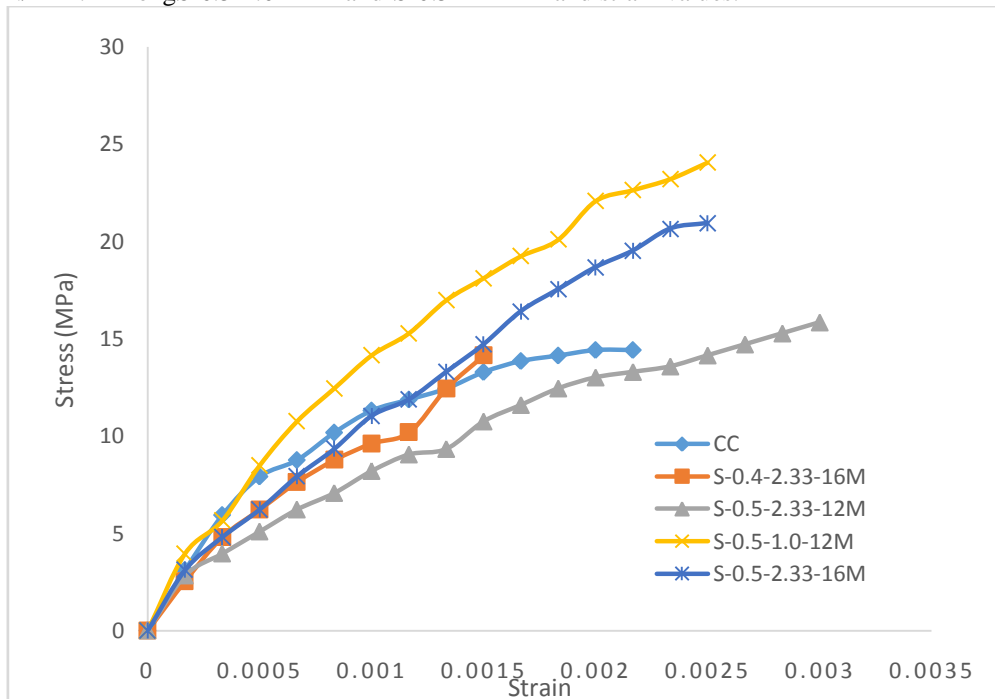


Fig.4. Stress-Strain curves of CC and AASC under ambient curing

3.3.2. Under heat curing

In Fig.5 mix S-0.5-2.33-16M has highest peak stress (23.2 MPa) whereas, S-0.5-2.33-12M and S-0.5-

1.0-12M mixes are having highest strain values (0.0033). But when compared with regards to toughness S-0.5-1.0-12M mix has highest value followed by S-0.5-2.33-12M mix. S-0.4-2.33-16M

and CCmixes are having lowest strength values when compared to other mixes of AASC.

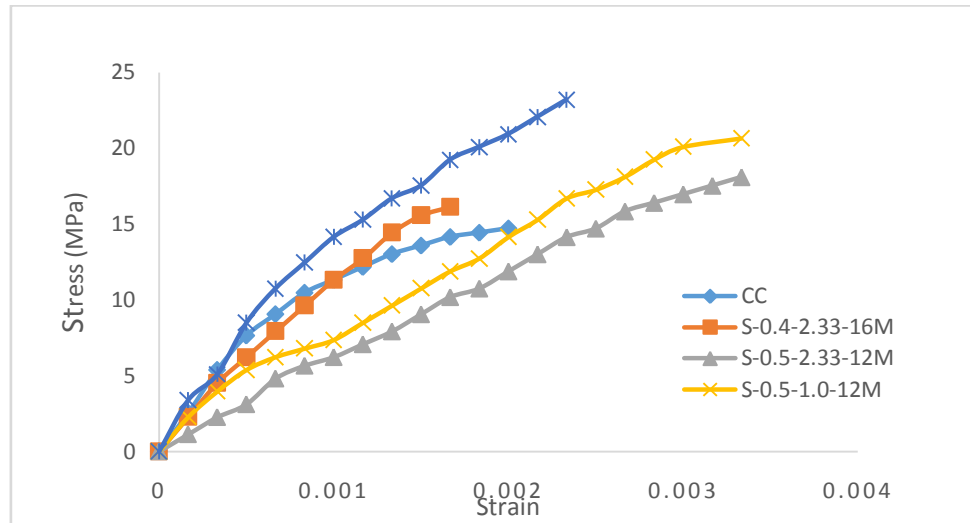


Fig.5. Stress-Strain curves of CC and AASC under heat curing

4. Conclusions

In this paper, the engineering properties of AASC and CC under ambient and heat curing were studied at 7, 28 and 56 days. The following conclusions are drawn:

1. S-0.4-2.33-16M mix has been found to be the best mix under ambient as well as heat curing with respect to compressive behaviour.
2. The flexural strength is maximum for S-0.5-2.33-16M mix under ambient curing.
3. The splitting tensile strength is observed to be high for conventional concrete mix under ambient curing but S-0.4-2.33-16M mix is also having almost strength at 7 and 56 days.
4. The S-0.5-1.0-12M mix shows high toughness value when it is subjected to ambient or heat curing.

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