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# Effect of Alkali Activated Slag on Punching Shear

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**Abstract:** ***The need to meet a sustainable development is now an important challenge to the cement industry. The production of OPC is responsible for about 7% of the world"s $CO_2$ emission, a major contributor to the green house effect which is implicated in global warming and climatic changes, lead to the search for more environmentally viable alternative to cement. One of those alternative material is alkali activated slag (AAS) where ground granulated blast furnace slag is used not as partial replacement to cement but also as a sole binder in the production of concrete. The overall aim of the study was to investigate the potential of alkali activated slag as a sole binder in producing concrete. The performance of alkali-activated slag concrete with sodium silicate, sodium hydroxide, sodium carbonate as activator are used at 4% $Na_2O$(by weight of slag) and 4% of hydrated lime by total weight of solid binder content if used as a retarder. The scope of the work covered four mixes: - Normal OPC mix and three alkali activated slag mixes of the same binder content and the same water binder ratio. The fresh concrete properties studied were setting time and workability and the Engineering properties studied are compressive strength was measured in 1,7,28 days, split tensile strength was measured in 7,28 days and flexure, punching shear strength was compared in 12 days only. The AAS concrete with different activators investigated was found to achieve good workability comparable with that of OPC. Sodium silicate, sodium hydroxide activated slag mixes sets very quickly. AAS concrete is much more sensitive to curing where if there is no addition of retarder (hydrated lime) to the mix. Among AAS mix sodium silicate was the best; sodium carbonate was the second; and sodium hydroxide was third in terms of compressive, split tensile strengths and in terms of flexure strength and punching shear strength sodium hydroxide was best; sodium carbonate was second; sodium silicate (water glass) was third.***

**Keywords**: Alkali Activated Slag (AAS) Concrete, Ground Granulated Blast Furnace Slag, OPC, Compressive Strength, Split Tensile Strength, Flexure Strength and Punching Shear Strength.

## 1. Introduction

Portland cement clinker is made from calcinations of limestone and siliceous material where de-carbonation occurs according to reaction:

$$CaCO_3 \rightarrow CaO + CO_2$$

The total emission of $CO_2$ per kg of cement clinker produced is 0.53 kg from the decarbonisation of calcite, plus 0.33 kg from the burning process plus 0.12kg from the generation of electrical power required, making a total of 0.98kg. Therefore, for every ton of cement clinker produced, an approximately equal amount of carbondioxide is released into atmosphere (Davidovits, 1991). The world cement industry contributes some 7% to the total man made $CO_2$ emission (Malhotra, 1999). This leads to the search for more environmentally viable alternatives to Portland cement. One of these alternative materials is alkali-activated slag (AAS), in which ground granulated blast-furnace slag (GGBS) is used not as a partial replacement for cement but as a sole binder itself in the production of concrete. This will produce an environmentally friendly concrete. The use of slag cement has advantages due to its excellent cementations properties over Ordinary Portland cement (OPC). Various studies had investigated ways to enhance the reactivity of the slag. One of the economic ways of activation is alkali activation. The alkalis that are going to be used in this dissertation are sodium silicate ($Na_2SiO_3$), sodium carbonate ($Na_2CO_3$) and sodium hydroxide (NaOH). There are many slag like granulated blast-furnace slag, electro thermal furnace phosphorous slag and steel slag but GGBS is generally used. Slag has latent hydraulic properties. If GGBS is placed in water alone, it dissolves to a small extent but a protective film deficient in $Ca^{2+}$ is quickly formed, which inhibits further reaction. The reaction continues if the $P^H$ is kept sufficiently high. The pore solution of a Portland cement, which is essentially one of alkali hydroxides, is a suitable medium. The supply of K+ and Na+ ions is limited, but these ions are only partially taken up by the hydration products, and the presence of calcium hydroxide ensures that the supply of $OH^-$ ions is maintained. The slag can be similarly activated by $OH^-$ ions supplied in other ways such as addition of sodium hydroxide or silicate. Alkali activated slag is not a widely known and used construction material. Most of the research has been done at the material development stage dealing with paste and mortar specimens to study the material chemistry and microstructure. The scope of the work covers a normal strength OPC control mix, AAS mixes with the same binder content and the same w/b ratio. The AAS concrete comprise three mixes with slag as the sole binder activated with three alkalis sodium silicate, sodium carbonate and sodium hydroxide with a dosage of 4% $Na_2O$. The normal water curing was used.

## 2. Materials

The materials used in this investigation are OPC, GGBS, Alkali Activators, Fine and Coarse Aggregates.

**A. Cement**

Ordinary Portland cement, conforming to the requirements of – IS 12269: 1987 was used in this investigation. The following Chemical properties are produced by the manufacturer.

**Table I:** Chemical Properties of Cement

| Description | In% |
|---|---|
| $SiO_2$ | 21.3 |
| $Al_2O_3$ | 4.5 |
| $Fe_2O_3$ | 4.0 |
| MgO | 2.4 |
| CaO | 63.1 |
| $Na_2O$ | 0.1 |
| $K_2O$ | 1.2 |
| $SO_3$ | 2.2 |

### B. Slag

The Ground Granulated Blast-Furnace Slag (GGBS) used was obtained from the Toshali Cements pvt. Ltd., It complied with BS: 6699-1992 and the Chemical properties are produced by the manufacturer.

**Table II:** Chemical Properties of Slag

| Description | In% |
|---|---|
| Magnesium Oxide | 8.29 |
| Sulphur Content | 0.29 |
| Sulphide Sulphur | 0.54 |
| Loss on Igition | NIL |
| Insoluble Residue | 0.46 |
| Chloride | 0.014 |
| Moisture Content | 0.48 |
| Manganese content | 0.26 |
| Glass content | 94.00 |
| Finess($m^2$/kg) | 360 |
| Soundness | NIL |

### C. Sodium Silicate Powder

Powder form of sodium silicate was used in the investigation. It has a molecular ratio $SiO_2$: $Na_2O$ (Ms) =3.21 with 29.2% of $SiO_2$ and 9.1% of $Na_2O$ by weight.

### D. Sodium Carbonate

Sodium carbonate powder. It is almost 99.5 % pure. The powder is used to make solution of required dosage in water.

### E. Sodium Hydroxide Pellets

Sodium hydroxide pellets. It is 97 % pure. The pellets are used to make solution of required dosage in water.

### F. Water

Distilled water available at the laboratory was used throughout the investigation.

### G. Aggregates

Medium graded sand and 20-mm natural round uncrushed gravel was used. The density of aggregates in different conditions is given in Table III.

**Table III:** Properties of Aggregate

| Relative density property | Sand | Gravel |
|---|---|---|
| Oven dried | 2.62 | 2.62 |
| Saturated and Surface dried | 2.63 | 2.63 |
| Apparent | 2.65 | 2.65 |

## 3. Mix Design Procedure

The proportioning of a concrete mixture is based on determining the quantities of the ingredients which, when mixed together and cured properly will produce reasonably workable concrete that has a good finish and achieves the desired strength when hardened. This involves different variables in terms of water to cement ratio, the desired workability measured by slump and cement content and aggregate proportions. The mix is M30 Grade. Mix design is done according to Indian standard recommended method of concrete mix design IS 10262-1982.

### A. Mix Proportions and Mix Notations

The notation for the mixes is as follows:

**CM:** Ordinary Portland cement (OPC) control mix with w/c=0.43.

**SS4:** Sodium silicate powder -activated slag concrete mixture with $Na_2O$ content of 4% by weight of slag with w/c=0.43.

**SH4:** Sodium hydroxide-activated slag concrete mixture with $Na_2O$ content of 4% by weight of slag with w/c=0.43.

**SC4:** Sodium carbonate-activated slag concrete mixture with $Na_2O$ content of 4% by weight of slag and with w/c=0.43.

**Table IV:** Details of Mix Proportions

| Mix No | Type of Binding Material | Binding Material (kg/$m^3$) | Type of Activator | Activator (kg/$m^3$) -4% | Fine Aggregate (kg/$m^3$) | Coarse Aggregate+(10% RCA)(kg/$m^3$) | Lime (kg/$m^3$) 4% by weight of slag | W/b |
|---|---|---|---|---|---|---|---|---|
| CM | OPC | 420 | | | 562.8 | 1209.6 | | 0.43 |
| SS4 | Slag | 420 | NaOH | 21.67 | 562.8 | 1209.6 | 16.8 | 0.43 |
| SH4 | Slag | 420 | $Na_2CO_3$ | 28.72 | 562.8 | 1209.6 | 16.8 | 0.43 |
| SC4 | Slag | 420 | $Na_2SiO_3$ | 16.8 | 562.8 | 1209.6 | 16.8 | 0.43 |

## 4. Workability

The workability of concrete describes the homogeneity and the ease of mixing, handling, placing, compacting and finishing of the concrete (or mortar). Workability or rheology of fresh concrete is the term traditionally been used in concrete technology to embrace all the necessary qualities. The test used is slump test.

**Table V:** The Slump at 5 Minutes

| *Activator* | *Slump(mm)* |
|---|---|
| CM | 135 |
| SS4 | 145 |
| SH4 | 110 |
| SC4 | 125 |

### A. Result and Discussion

The results from above Table show acceptably workable concrete with the CM, having the lower slump than AAS concrete which has same w/c ratio. From the results displayed in above Table it can be concluded that the workability of sodium silicate activated slag concrete at Ms=1 when there is no addition of lime has high workability when compared with the addition of lime slurry mixed water glass activated slag concrete, which is in agreement with the results published by Shi et al., (2006) where they also found the workability of sodium silicate activated slag concrete is very high when the modulus is between 0.5 and 1.0. For the same modulus of sodium silicate and at the same dosage, but with the addition of 4% lime by weight of slag resulted in loss of workability from collapse to 145 mm in terms of slump, which shows that due to the addition of lime slurry there exists loss of workability. This finding is in agreement with the work done by Chen and Liao, 1992. The sodium carbonate activated slag also shows high workability when compared to the control mixes. Among AAS concrete, sodium hydroxide activated slag concrete with the addition of hydrated lime has lower workability but is comparable with the workability of control mixes.

## 5. Setting Time

### A. Test procedure

The test was carried out in accordance to IS4031 (part 5)1988 using the vicat"s apparatus. The apparatus consists of steel needle which acts under a prescribed weight of 300 ± 1 g to penetrate the mortar. The penetration was repeated for every 10 min and during the interval the sample was kept in a chamber under a controlled temperature (20 ± 2) °C and 90% relative humidity. Two different needles were used to determine the initial and final setting. The initial set needle was a right cylinder of diameter 1.13 ± 0.05 mm. The initial setting time was recorded when the sample is sufficiently stiff so that the needle penetrates no deeper than 4 ± 1 mm from the bottom. The final set needle is a similar needle with an attachment that helps to identify when it penetrates the mortar to a depth of only 0.5 mm. The setting values are related to many variables such as cement composition and temperature and the typical data on setting of different types of cement are shown in Table below.

**Table VI:** Setting Time of Mixes

| *Cement Type* | *Initial Setting (h:min)* | *Final Setting(h:min)* |
|---|---|---|
| OPC (CM) | 0:30 | 3:10 |
| SS4 | 0:20 | 0:50 |
| SH4 | 0:10 | 0:30 |
| SC4 | 1:0 | 2:15 |

### B. Result and Discussion

Among the mixes of the same w/c ratio and binder content the addition of slag prolongs the setting time. The sodium silicate activated slag mortar with modulus of silica (Ms=1) and 4 % $Na_2O$ dosage has shorter setting time of all the mixes and $Na_2CO_3$ activated slag mortar exhibited longer setting times (Initial and Final) among AAS mortar mixes. From the above table it is evident that the addition of 4% hydrated lime by weight of slag prolongs the final setting time of sodium silicate activated slag by 50 minutes.

## 6. Engineering Properties

The Engineering properties of concrete including the Compressive Strength, Split Tensile Strength, Flexural Strength and Punching Shear of different concrete mixes OPC and three AAS mixes with different activators. The influence of curing conditions at different ages is presented.

### A. Compressive Strength Test

Compressive Strength is an important criterion used to evaluate the quality of concrete. The Compressive Strength is done as determined in IS456:2000 and two samples were tested at 1, 7 and 28 days, and the average results are reported.

**Table VII:** Compressive strength at different ages

| Cement or Slag mix | 1- Day Strength (Mpa) | 7-Day Strength (Mpa) | 28-Day Strength (Mpa) |
|---|---|---|---|
| CM | 9.5 | 25.08 | 38.10 |
| SS4 | 12.46 | 22.87 | 31.09 |
| SH4 | 12.04 | 23.66 | 27.32 |
| SC4 | 05.73 | 20.03 | 29.15 |

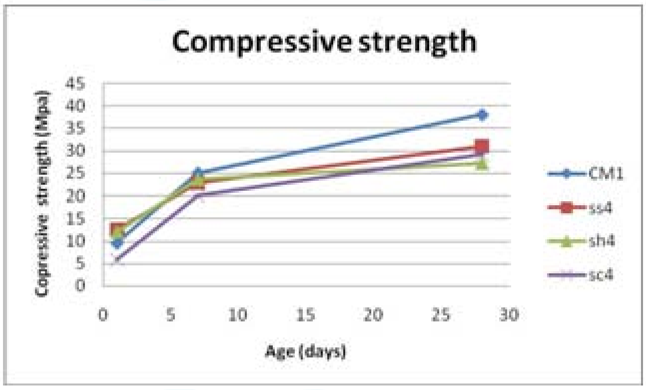


**Figure 1:** Compressive Strength Result in Graphical Representation

### B. Result on Compressive Strength

It can be seen in Fig.1 that $Na_2SiO_3$(SS4) with a dosage of 4% $Na_2O$ by weight of slag achieved higher compressive strength (31.09 MPa at 28 days respectively in water curing) in comparison with all the other mixes. $Na_2CO_3$(SC4) activated concrete exhibited second highest compressive strength (29.15 MPa at 28 days) among alkali-activated concrete mixes. NaOH (SH4) activated slag concrete mix has compressive strength 27.32 Mpa at 28 days.

### C. Split Tensile Strength Test

The Splitting Tensile Test is a simple test to perform and it is believed that it leads to a close value of direct tensile strength. The test was performed as described in IS 5816: 1999 and three samples were tested at the ages 7 and 28 days for water curing and average values are reported.

**Table VIII:** Split Tensile Strength at Different Ages

| *Cement or Slag mix* | *7-Day Strength (Mpa)* | *28-Day Strength(Mpa)* |
|---|---|---|
| CM | 2.31 | 2.8 |
| SS4 | 1.87 | 2.59 |
| SH4 | 1.79 | 2.16 |
| SC4 | 1.83 | 2.47 |

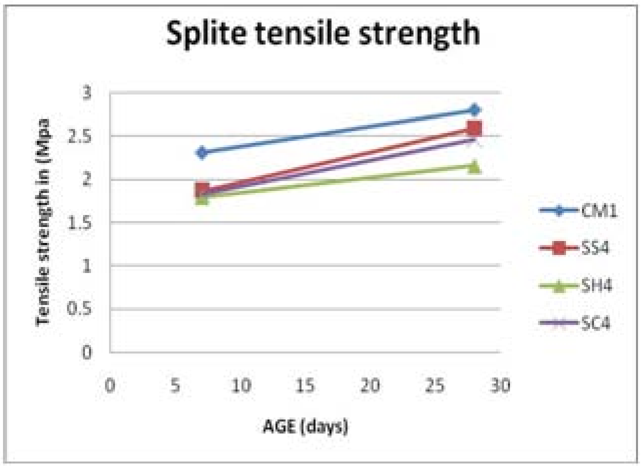


**Figure 2:** Split Tensile Strength Result in Graphical Representation

### D. Result on Split Tensile Strength

The results in above table show that among AAS concrete mixes, SS4 showed the highest value of tensile strength around 2.59 MPa at 28 days followed by SC4 (2.47 MPa). SH4 showed the lowest value (2.16 Mpa).

### E. Flexural Strength Test

The Flexural Strength of concrete mixes was measured according to I.S.9399:1979. Samples of 150x150x700 mm were cast in order to perform the Flexural Strength Test and two samples were tested for curing at the age of 12 day and average are reported.

**Table IX:** Flexure Strength at 12 Day Age

| *Cement or Slag mix* | *12-Day Strength(Mpa)* |
|---|---|
| CM | 1.87 |
| SS4 | 0.89 |
| SH4 | 1.18 |
| SC4 | 1.13 |

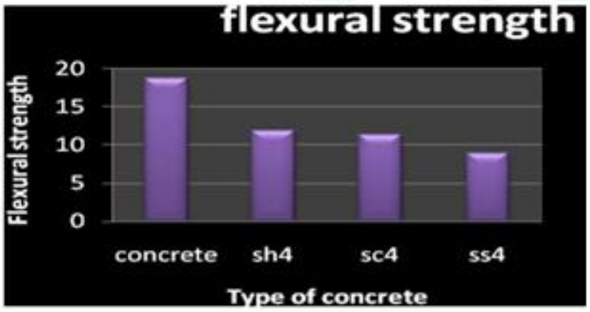


**Figure 3:** Flexure Strength at 12 day curing

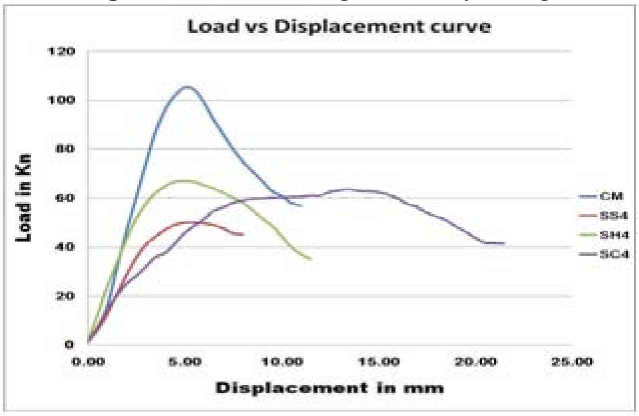


**Figure 4:** Load Vs Displacement of Flexure Strength

### F. Results on Flexural Strength

From the above figure we can observe effect of curing on all different mixes. The highest flexural strength is shown by concrete mix where the lowest flexural strength is shown by $Na_2SiO_3$ activated concrete mix (SS4). Almost all AAS concrete shows comparable values of flexural strength with concrete mixes. Among AAS concrete NaOH (SH4) shows higher flexural strength followed by $Na_2CO_3$ activated slag mix (SC4) and then finally the least flexural strength is given by $NaSiO_3$ (SS4).

### G. Punching Shear Test

To find out the Punching Shear Strength a series of tests of micro concrete specimens has been carried out. Three circular slabs for each three different thickness„d" were cast, cured, and loaded to failure. The concrete mix ratio of cement: sand: gravel: water (by weight) was 1: 1.34: 2.88: 0.43. The maximum size of the aggregate is 20mm.The sizes of the specimens are 400mm, 200mm and the height of the specimens they have a relation one fourth of the diameter of the specimen. The mix concrete is done by as per IS code provisions and AAS concrete mixtures are done separately in different mixers BS 1881: part 125:1986. The specimens were curing up to 12days. The below graphical figures, show the variation in punching shear for different concrete mixers at particular size cylinder specimen.

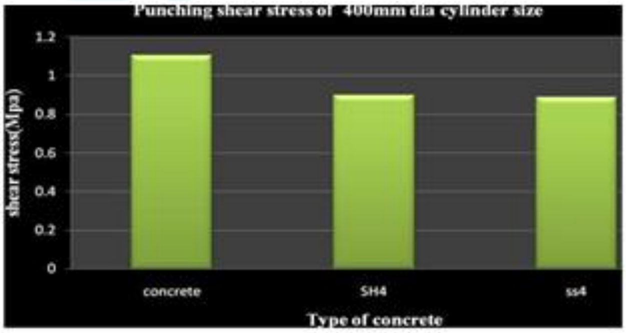


**Figure 5:** Punching Shear Stress of 400mm Diameter Cylinder at 12 days curing

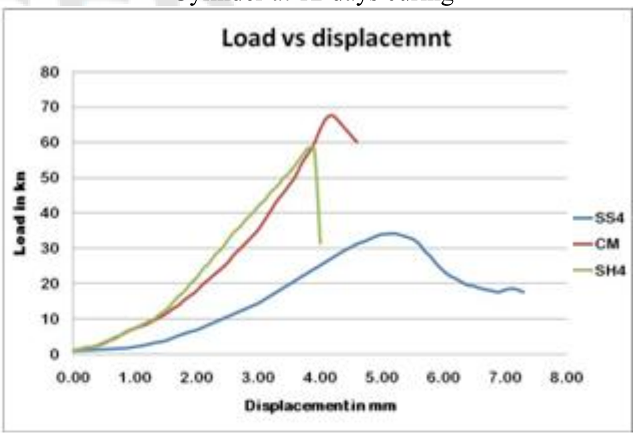


**Figure 6:** Load Vs Displacement of 400mm Diameter Cylinder


**Figure 7:** Punching Shear Stress of 200mm Diameter Cylinder at 12 days curing

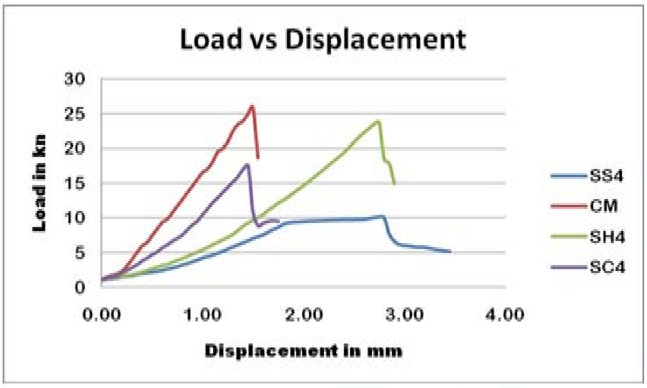


**Figure 8:** Load Vs Displacement of 200mm Diameter Cylinder

### H. Results on Punching Shear

The above figures show the different concrete and different sizes of specimens punching shear stress. In the above graphs the concrete gives the higher strength when compare the AAS concrete. The graph show the lower size specimen gives the higher strength when compare to the higher size specimen. All these three AAS concrete NaOH (SH4) gives the higher strength when compare the $Na_2CO_3$ and $Na_2SiO_3$ gives the very lower value.

## 7. Conclusion

Overall it can be concluded that AAS concrete has a great potential and presents a viable alternative to OPC to help in decreasing the effect on the environment in terms of energy conservation and less $CO_2$ emissions. Sodium silicate activated slag concrete sets rapidly with the higher $Na_2O$ dosage resulting in shorter setting time. The setting time can be prolonged by adding hydrated lime to mix, which increases the final setting time more when compared to initial setting time. Out of all these three activators NaOH is best ; $Na_2CO_3$ was the second; $Na_2SiO_3$ was the third in terms of flexural and punching shear test for the Vizag steel plant slag composition. In compressive test the strength growth rate in early age is high when compared to traditional concrete. From Load vs. displacement curve in flexure test results, the CM mix gives the higher load carrying capacity but less ductility where as SC4 mix shows lower load carrying capacity but very high ductility. Almost all the AAS concrete shows good ductility than traditional concrete. So AAS concrete is good to use where ductile designs are needed i.e., in seismic prone areas. In punching shear test, among all the AAS concrete mixes, NaOH gives higher punching strength when compared to the other two AAS mixes. $Na_2SiO_3$ gives the very less strength compare to all mixes.

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