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THE EFFICACY OF VARIOUS ALKALI ACTIVATORS IN SLAG

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Research Article
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Abstract: The cement industry currently faces a significant challenge in meeting the demand for sustainable development. The hunt for more ecologically sound alternatives to cement was prompted by the fact that OPC production accounts for approximately 7% of the world's CO_p emissions, a significant contribution to the greenhouse effect that is involved in climate change and global warming. As an example of a non-traditional material, alkali activated slag (AAS) uses powdered granulated blast furnace slag as both a cement substitute and the only binder in concrete. The overarching goal of the research was to find out how well alkali activated slag may work as a standalone binder in concrete production. Utilising sodium silicate, sodium hydroxide, and sodium carbonate as activators at a rate of 4% Na2O (by weight of slag) and 4% hydrated lime (by total weight of solid binder component) as retarders improves the performance of alkali-activated slag concrete. All four mixes were included in the scope of work: the normal OPC mix, three alkali activated slag mixes, and one water binder ratio. All four mixes had the same binder concentration. The engineering parameters that were examined were compressive strength at 1,7,28 days, split tensile strength at 7,28 days, and flexure and punching shear strength at 12 days. The fresh concrete properties that were examined included setting time and workability. Good workability, on par with OPC, was achieved by the AAS concrete with the various studied activators. Activated slag mixtures containing sodium silicate and sodium hydroxide set rapidly. The absence of a retarder, such as hydrated lime, makes AAS concrete considerably more curing sensitive. According to the compressive, split tensile, flexure, and punching shear strengths, sodium hydroxide ranked first, sodium carbonate second, and sodium silicate (water glass) third among the AAS mixes. Sodium carbonate came in second.

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

INTRODUCTION

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

$$CaCO_3 \rightarrow CaO + CO_2$$

Carbon dioxide (CO2) emissions per kilogram of cement clinker produced amount to 0.98 kilograms; this includes 0.53 kilograms from calcite decarbonisation, 0.33 kilograms from burning, and 0.12 kilograms from producing the necessary electrical power. So, about the same amount of carbon dioxide is emitted into the environment for every metric tonne of cement clinker that is manufactured (Davidovits, 1991). About seven percent of all man-made carbon dioxide emissions come from the cement industry (Malhotra, 1999). This prompts the quest for Portland cement substitutes that are less harmful to the environment. One of these substitute materials is alkali-activated slag (AAS), which uses ground granulated blast-furnace slag (GGBS) as the sole binder in concrete instead of only half cement. An eco-friendly concrete will be the result of this process. Because of its superior cementation qualities compared to OPC, slag cement is a useful material. Increasing the slag's reactivity had been the subject of several investigations. Alkali activation is one of the activation methods that is cost-effective. The dissertation will make use of sodium silicate (Na2SiO3), sodium carbonate (Na2CO3), and sodium hydroxide (NaOH) as alkalis. The most common type of

slag is GGBS, although there are many others, such as phosphorous slag from electrothermal furnaces, steel slag, and granulated blast-furnace slag. Slag possesses dormant hydraulic capabilities. When GGBS is mixed with water, it dissolves somewhat but forms a protective coating that blocks further reactions because it is lacking in Ca2+. Maintaining a high enough pH keeps the process going. An appropriate medium would be the alkali hydroxide-containing pore solution of Portland cement. Although there is a scarcity of potassium and sodium ions, the hydration products use up some of these ions, and the presence of calcium hydroxide keeps the supply of hydroxide ions constant. Other sources of OH-ions, such as sodium hydroxide or silicate, can also activate the slag. Not many people know about or utilise alkali activated slag as a building material. Paste and mortar specimens have been the primary focus of research on the microstructure and chemical composition of these materials during their development. The study encompasses a standard strength OPC control mix as well as AAS mixes that share the same binder content and weight-to-boundary ratio. The three-component AAS concrete consists of slag as the only binder and three alkalis—sodium silicate, sodium carbonate, and sodium hydroxide—each with a 4% Na2O dose. Curing in water as usual was employed.

I. 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

II. MIX DESIGN PROCEDURE

When mixing and curing concrete, the goal is to obtain a combination with the right proportions of materials so that it is relatively workable, has a nice finish, and hardens to the necessary strength. A number of factors must be considered, including the ratio of water to cement, the amount of aggregate, and the slump and cement content that are considered important for the appropriate workability. M30 Grade is the mix. The concrete mix design is carried out in accordance with the Indian standard, 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

III. 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

Based on the data in the table, it can be concluded that CM produces usable concrete with a

reduced slump compared to AAS concrete with the same water-to-cement ratio. The results shown in the table indicate that at Ms=1, without lime, sodium silicate activated slag concrete has a high workability compared to activated slag concrete with lime slurry, water, and glass. This is in line with the findings of Shi et al. (2006), who also discovered that at modulus values between 0.5 and 1.0, sodium silicate activated slag concrete has a very high workability. Loss in workability from collapse to 145 mm in terms of slump was seen by adding 4% lime by weight of slag to the same dose and modulus of sodium silicate. This indicates that the addition of lime slurry causes a decrease in workability. Results from the study by Chen and Liao (1992) are consistent with this conclusion. In comparison to the control mixtures, the sodium carbonate activated slag demonstrates excellent workability. The workability of AAS concrete with hydrated lime has a lower level than control mixes, but it is still equivalent to that of sodium hydroxide activated slag concrete.

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)ºC 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.

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

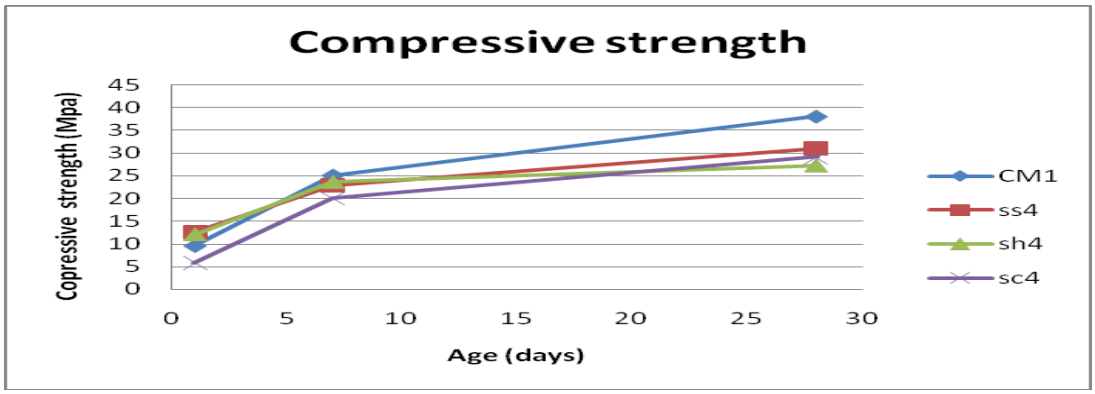


Fig. 1 Compressive Strength Result in Graphical Representation

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

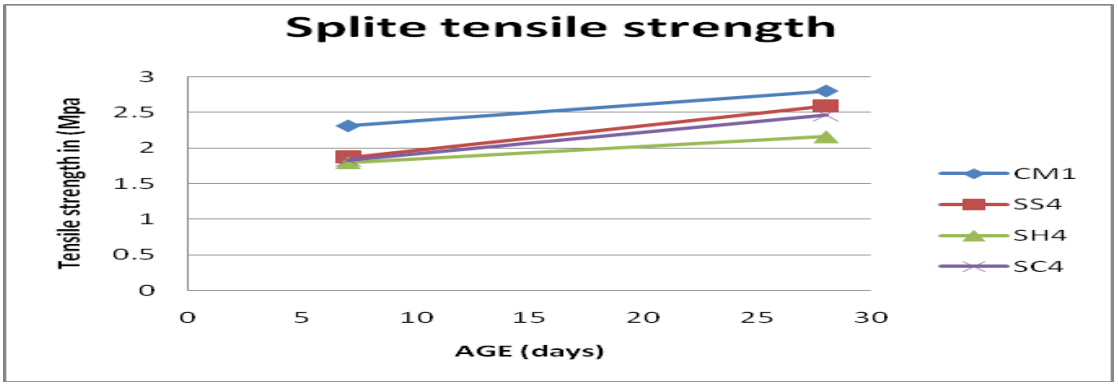


Fig. 2 Split Tensile Strength Result in Graphical Representation

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

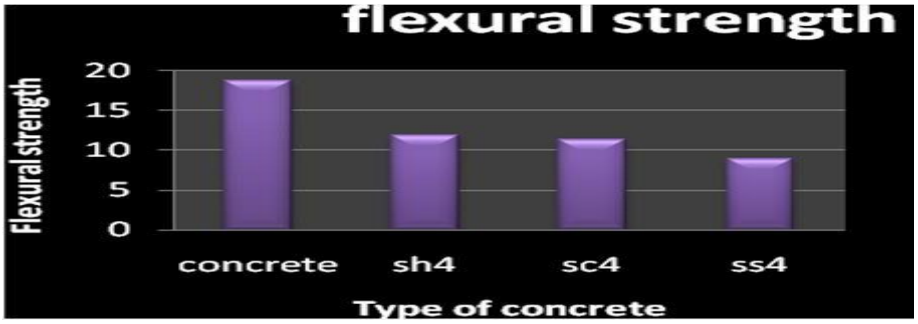


Fig. 3 Flexure Strength at 12 day curing

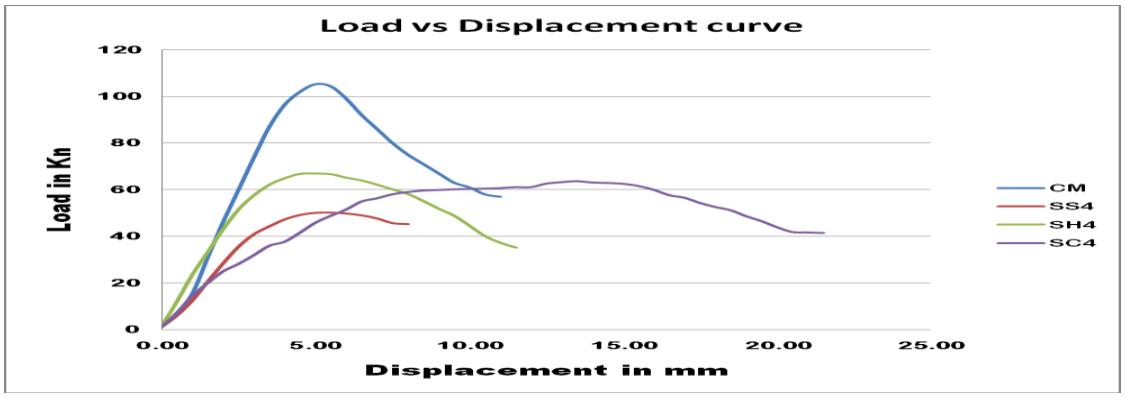


Fig. 4 Load Vs Displacement of Flexure Strength

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

Punching shear strength was determined by subjecting micro concrete specimens to a battery of tests. The process involved casting, curing, and loading three circular slabs to failure, one for each of the three thickness„d" values. The cement-to-concrete ratio: weight-wise, the proportions of sand, gravel, water, and 1.34 to 2.88 to 0.43 were as follows. The aggregate can't be more than 20 mm in size.The specimens are 400 mm in diameter and 200 mm in height, with the proportion between the two being one fourth of the specimen's diameter. According to the

requirements of the IS code, the concrete is mixed in one mixer while the AAS concrete mixes are mixed in separate machines (BS 1881: part 125: 1986). It took up to twelve days for the specimens to cure. The variance in punching shear for various concrete mixers at certain cylinder specimen sizes is illustrated in the following graphical images.

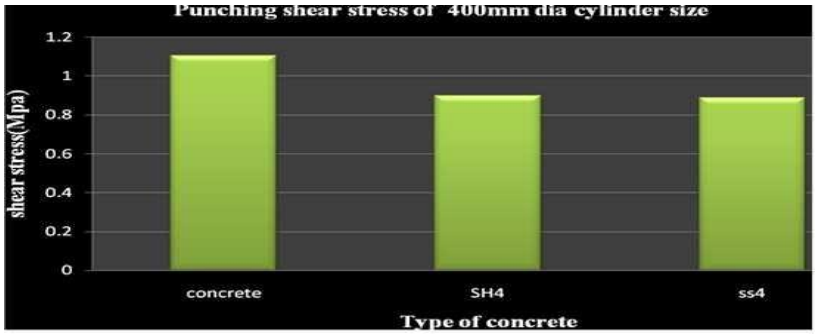


Fig. 5 Punching Shear Stress of 400mm Diameter Cylinder at 12 days curing

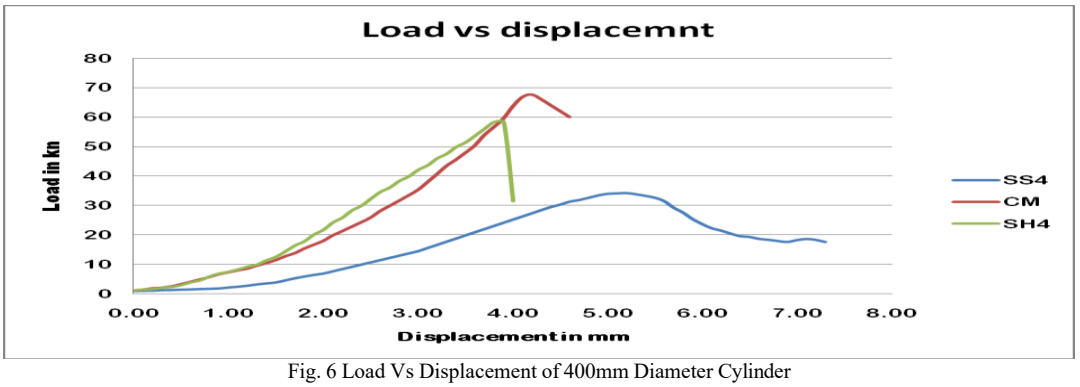


Fig. 6 Load Vs Displacement of 400mm Diameter Cylinder

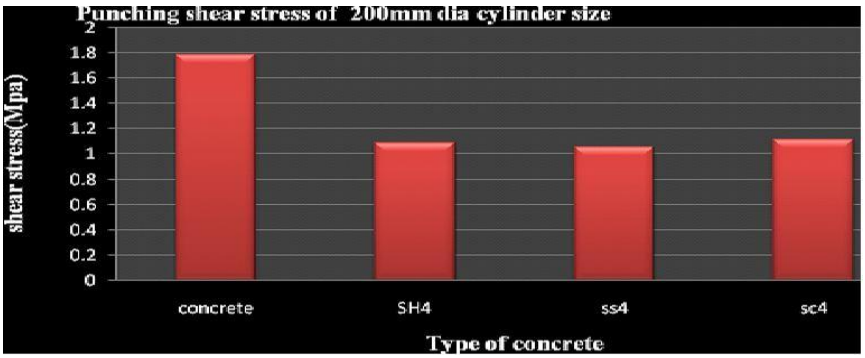


Fig. 7 Punching Shear Stress of 200mm Diameter Cylinder at 12 days curing

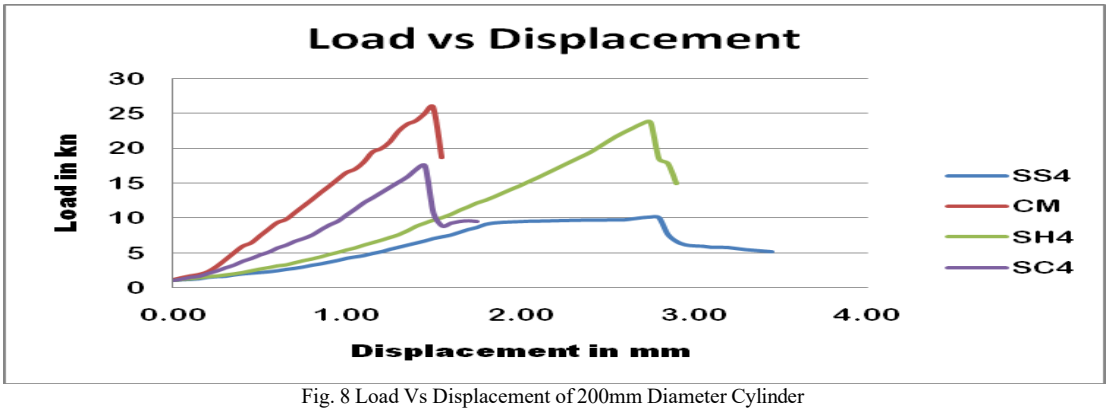


Fig. 8 Load Vs Displacement of 200mm Diameter Cylinder

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.

CONCLUSION

In sum, AAS concrete shows promise and offers an option to OPC that might lessen environmental impact via energy savings and reduced CO2 emissions. The setting time of sodium silicate activated slag concrete is reduced when the Na2O dose is increased. By adding hydrated lime to the mixture, the setting time can be extended. This results in a longer final setting time relative to the original setting time. The flexural and punching shear tests for the slag composition of the Vizag steel mill showed that of the three activators tested, NaOH performed the best, followed by Na2CO3, and Na2SiO3. Compressive testing shows that, in comparison to regular concrete, the early-stage strength increase rate is substantially higher. Results from flexure tests showing the relationship between load and displacement reveal that CM mixes have a higher load bearing capacity but poor ductility, whereas SC4 mixes have a lower load carrying capacity but excellent ductility. The ductility of AAS concrete is often higher than that of regular concrete. Therefore, in seismically active regions, or anywhere else ductile designs are required, AAS concrete is an excellent choice. Among the three AAS concrete mixes tested in the punching shear test, NaOH yields the highest punching strength. Among all the mixtures, Na2SiO3 has the weakest strength.

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