PERFORMANCE OF RECYCLED ALKALI ACTIVATED SLAG PLAIN AND REINFORCED CONCRETE IN TERMS OF MECHANICAL PROPERTIES WITH EMPHASIS ON SIZE EFFECT OF 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 as a a sole binder in the production of concrete. The overall aimof the study was to investigate the potential of alkali activated slag as the sole binder in producingconcrete.

The performance of alkali-activated slag concrete with sodium silicate, with hydrated lime, sodium hydroxide, sodium carbonate as activator are used at 4% Na_2o(by weight of slag) and 4% of hydrated lime by weight of solid binder content if used as retarder. The scope of the work coveredfour mixes: a normal OPC mix, three AAS slag mixes of the same binder content and the same water binder ratio.

The fresh concrete properties studied were setting time and workability in terms of slump. The engineering properties studied were compressive, split tensile strength was measured in 7,12,28 days and flexure and punching shear strength was compared in 12 days only.

The AAS concrete with different activators investigated was found to achieve very good workability which was higher or comparable with that of OPC. The addition of hydrated lime to AAS mix was resulted in decrease in workability. Water-glass(Solid powder form), NaoHactivated 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. L.S.S. was the best; Na_2co_3 was the second; and NaOH was third in terms of compressive, tensile strengths and NaOH was best; Na_2co_3 was second; and Na_2sio_3(Solid powder form) was third in terms of flexure and punching shear strength.

Keyword: - *workability, ggbfs, Compressive Strength, Flexural Strength, tensile strength, punching shear strength, and alkali activated slag etc.….*

1.INTRODUCTION

Although the greenhouse effect is a natural phenomenon, where the gases in the atmosphere trap the radiation of earth maintaining an average temperature of 15 degree centigrade, the extra greenhouse effect by human activity is a big problem, because as per the Environmental scientists, the Global warming caused by greenhouse effect lead to flooding and other climatic changes by the increase in earth's temperature. The concentration of "green house gases" has been increasing continuously for the last three decades. Representatives for more than 160 Governments met in Kyoto protocol that called for developed countries to reduce emissions of greenhouse gases on average by 5.2% below 1990 levels by the years 2008-2012.Carbon dioxide is among these green house gases.

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 decarbonisationof 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, anapproximately equal amount of carbon- dioxide is released into the 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-furnaceslag (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 water glass (Na_2SiO_3), sodium carbonate (Na_2CO_3) and sodium hydroxide (NaOH). There are many slags 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 extentbut 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, whichis 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.

1.1 Objectives and Scope of Work – Activated Slag as a Binder

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. Related information regarding the concrete engineeringand durability properties of AAS concrete is limited. Therefore this study is an attempt to add to the knowledge at this level.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 water glass, sodium carbonate (Na_2CO_3) and sodium hydroxide(NaOH) with a dosage of 4% Na_2O. The normal water curing was used.The overall aim of the project was to investigate the potential of AAS as a sole binder in structuralgrade concrete by studying its main properties and performance in comparison with Portland cement and slag by activating with different alkalis and from those alkalis choosing the better alkali for activating the given slag as concrete for structural grade.

The main objectives of the work:

1. Study the properties of alkali -activated slag concrete using Water-glass, sodium carbonateand sodium hydroxide as activators including the fresh concrete properties(setting time and workability in terms of slump) and Engineering properties(compressive strength, splitting tensile strength, flexural strength, punching shear strength, non-destructive tests which include ultrasonic pulse velocity). All the engineering properties are studied at normal water curing and at three different age(1 day, 7 day and 28 day) except flexural strength and Punching shear test at 12 days only.

2. LITERATURE REVIEW

The purpose of this chapter is to review and discuss the available literature on alkali-activated slagconcrete, studying the research done on different variables related to its application and constrainsto its use.

2.1 *Blast-furnace slag*

Blast Furnace

Definition—Blast-furnace slag is a nonmetallic combination of crystalline silica and other materials that form in a molten condition on the surface of molten iron being produced in a blast furnace. When the molten slag is poured into pits or banks and permitted to cool and solidify slowly under atmospheric conditions, the result is air-cooled slag. When molten blast-furnace slagis rapidly agitated with a controlled amount of water, or when it is injected

with a controlled amount of water, steam, or water-bearing compressed air, the result is expandedblast-furnace slag. When the molten slag is suddenly quenched in water, the result is granulated slag. However it is cooled, slag can be crushed and screened into a variety of sizes. Only air-cooled and expanded blast furnace slag are used as concrete aggregates. Ground granulated slag is groundto a fine powder and used as a cementations material.

Slag are by-products of the metallurgical industry and consist mainly of lime and calcium– magnesium alumina silicates. The most common Slag produced are from the iron and steel industry, called blast-furnace slag which is defined as the glassy granular material formed when molten blast-furnace slag is rapidly chilled as by immersion in water.

Due to its high content of silica and alumina in an amorphous state, ground blast-furnace slag shows pozzolanic and binding properties in an alkaline medium. Blast-furnace slag has been widely utilized as an ingredient in cement or concrete.

Marketed blast furnace slag's are of three main types—air-cooled, granulated, and pelletized (or expanded). Air-cooled blast furnace slag is formed by allowing the molten slag to cool relatively slowly under ambient conditions; final cooling can be accelerated with a water spray. The cooled material is hard and dense, although it can have a vesicular texture with closed pores, and is especially suitable for use as aggregates. Granulated blast furnace slag (GBFS) is formed by quenching molten slag in water to form sand-sized particles of glass. The disordered structure of this glass gives the material moderate hydraulic cementitious properties when very finely ground (GGBFS). However, if GGBFS can access free lime during hydration, its cementitious propertiesbecome strong.

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. Reactioncontinues if the pH is kept sufficiently high. The pore solution of a Portland cement, which is essentially one of the alkali hydroxides, is a suitable medium. The supply of K+ and Na+ ions arelimited, but these ions are only partially taken up by the hydration products, and the presence of solid calcium hydroxide ensures that the supply of OH- is maintained. Similarly the slag can be activated by the supply of OH- ions in other ways, such as the addition of sodium silicate or hydroxide (Taylor, 1997). This show that slag can be activated not only by OPC but also chemical alkalis introducing the concept of alkali-activated slag (AAS). AAS cement is composed of ground slag and an alkali component. The slag may be granulated blast furnace slag, electro thermal furnace phosphorous slag and steel slag. Of these granulated blast furnaces slag is most common type of slag used. The alkalis can be any sort of alkali hydroxide (MOH), silicic salts of $M_2O.(n)SiO_2$ and non silicic salts of weak acids (M_2CO_3, M_2S, MF) type as well as combinationsof these, where M stands for an alkali metal such as Na, K, Li. Of these alkalis, sodium silicate (Na_2SiO_3) is the most effective activator (Wang et al., 1995).

Alkali-activated slag cements using granulated blast-furnace slags were invented by Glukhovsky and patented in 1958. A review given by Glukhovsky (1980) commented that alkali-activated slag cements had been introduced into construction practice in the USSR in 1960 and in Poland in 1972. Alkali-activated slags have been employed on a limited scale as oil well cements and as a roof support system in mine applications in South Africa and Canada. Industrial experience of precastproducts utilizing these cements is widespread in Eastern Europe, Finland and France (Talling andBrandstetr, 1989). Research in China has confirmed the high strength of these systems (Wang, 1991).

2.2 *Factors Affecting Slag Activation*

The factors affecting slag activation are

1. Type of slag
2. Fineness of slag

3. Type of activator
4. Method of adding activator
5. Dosage
6. Influence of curing

2.2.1 *Type of Slag*

The chemical composition of the slag plays a major role in its hydraulic activity and consequentlythe microstructure and properties of hardened concrete produced. Neutral or alkaline (basic) is much preferred over acidic slag. The high alumina content results in high early strength where as greater amount of slag is reacted and quick setting occurs. Therefore the Al_2O_3/SiO_2 ratio is considered to be the quality modulus and slags with 12 to 15% of Al_2O_3 are preferred. Minor constituents in slag such as P, F, S, Mn and Ti often have significant influence on slag quality. The increasing content of Fe_2O_3 decreases the reactivity of the slag (Wang et al., 1994).

2.2.2 *Fineness of Slag*

The reactivity of ground slag depends on the fineness of grinding and more precisely on the particlesize distribution and specific surface area (Talling and Brandstetr, 1989). (Bougara et al., 2007 and Wang et al., 1994) reported that increasing the fineness of GGBS improves the strength and decreases the setting time of slag mixes. (Wang et al., 1994) suggests values of slag fineness for alkali activated slags in the range of 400-500m^2/kg (Blaine).

Alkali activated concrete are formulated with 300, 400, 500 kg slag per m^3 of fresh concrete and their performance is compared with reference concretes. Higher binder content leads to increased strength in both AASC and OPC at 28days. However at 90 days, the performance penalty for lowbinder content is more significant in the OPCC than AASC samples. Permeability water absorption and carbonation resistance properties are improved at higher binder content. (Susan A. Bernal et.al.2010)

2.2.3 *Type of Activator:*

(Douglas et al., 1990) reported that slag mortars activated with alkaline reagents such as NaOH, $Ca(OH)_2$ and sodium silicates, yielded compressive strengths comparable to or higher than those made with Portland cement alone. He activated slag mortars with 1% of Na_2SO_4 and small additions of lime or Portland cement and concluded that the 1 day compressive strengths were comparable to those of Portland cements mortars. (Malolepszy and Petri., 1986) found that water glass was the best activator in most cases which is in agreement with several researchers (Glukhovsky, 1980; Wang et al., 1994; Douglas et al., 1991) but Na_2CO_3 was suitable for slag richin C_2MS and NaOH for slag rich in C_2AS.

2.2.4 *Method of Adding Activator:*

Addition of alkali to slag can be done in three ways: in solid state ground together with slag, in solution and in solid state where the alkali activator is added separately as one of the mix constituents. The addition of alkali in the solid state not only results in much lower strengths thanthe solution form but also provides much fluctuation in test results which can be attributed to lowersolubility in the mix and availability of alkali for reaction (Saud, 2002). The solid alkali might absorb moisture during storage, which will inhibit its activating action. Using hydrous water-glass/sodium met silicate (containing chemically bound water) in the solid form produces very low or even zero strength under normal curing conditions. When Na_2CO_3 is used, some results show that grinding Na_2CO_3 together with slag gives high strengths similar to the addition in solution form. When steam/autoclave curing is used the variation in strength with the method of adding thealkali is somewhat reduced. NaOH as an activator works in two ways, solution and solid due to itshigh solubility. (Collins and Sanjayan., 1999; Saud, 2002) reported that using solid sodium silicate powder provides better workability and minimal slump value compared to liquid sodium silicate solution.

2.2.5 *Dosage*

Alkali dosage can be expressed in 1. % by weight of slag

2. % of Na_2O content with respect to slag

The more Na_2O used the higher the strength. However, when Na_2O% reaches certain value (depending on slag, activator), the strength no longer increases with higher dosages but some detrimental properties such as efflorescence and brittleness are increased because of the presence of more free alkali. (Wang et al., 1994) recommended dosage of 3.0-5.5% Na_2O with water glassas an activator. LSS with a SiO_2/Na_2O ratio (modulus, M_s) of 0.75 and a 4% sodium concentrationwas recommended for use in alkali-activated Slag concrete by (Bakharev et al., 2001). For the LSSmortar at a constant sodium concentration, there is an optimum value for SiO_2/Na_2O ratio (M_s) at which the compressive strength becomes the highest. The optimum M_s value is lower at higher sodium concentrations (Atis et al., 2007). (Atis et al., 2007) used Sodium concentration in the mixture proportions as 4%, 6%, and 8% for both sodium carbonate(SC) and sodium hydroxide(SH) for Turkish slag and found SC slag mortar developed equivalent flexural tensile strength to PC mortar for 8% sodium concentration and SH activated mortar developed lower flexural tensile strength than that of PC mortar. In case of L.S.S activated slag mortar (Atis et al., 2007) reported that at modulus of silica 0.75 and 8% of Na_2O content by weight of slag giving maximum compressive strength at 28 days when compared to 4% and 6% of Na_2O dosage wherefor all dosages (4, 6 and 8% of Na_2O dosage) the initial set is almost same and are not comparablewith OPC mortar.

2.2.6 *Influence of Curing*

Since temperature is a reaction accelerator most of the researches have been done in a high temperature curing regime, but Cioffi et al. (2003) and Lee et al. (2003) found acceptable results curing at room temperature. The temperature range goes from 20^o C (Lee at al. 2003) to 85^o C (Cioffi et al., 2003; Palomo et al., 1999). Although temperature improves strength, curing for long periods of time at elevated temperature appears to weaken the structure, suggesting that small amounts of structural water need to be retained in order to reduce cracking and maintain structuralintegrity (Van Jaarsveld et al., 2002). The exact limit of the time and temperature of curing is still unknown and possibly depends on others characteristics of the cement paste, such as type of alumino-silicate and type of activator.

Using steam curing, (Hogan and Meusel, 1981) reported increased strength development in slag containing mortars. (Kutti et al., 1982) used autoclave curing with NaOH activated slag mortars and found an increase in compressive strength compared to normal water cured mortars. (Wang etal., 1994) state that the hydration of slag in AAS cements systems is sensitive to curing temperature, where high temperature leads to the formation of some crystalline products, whereasthe hydration products of AAS at normal temperature are generally amorphous. In their study they compared accelerated curing of AAS cement with normal cured OPC and concluded that the effectiveness of accelerated curing is more pronounced with acid and neutral slags or weaker alkaline activators. For example, an AAS cement based on phosphorous slag (acid or neutral in nature) and water-glass having a strength of 30 MPa under normal curing can reach 62 MPa aftersteam curing and 71-76 Mpa after autoclave curing, whereas an AAS cement based on granulatedblast furnace slag (GGBS, basic in nature) and L.S.S whose strength is 80 MPa under normal curing can only go up to 85-95 Mpa after steam or autoclave curing. Using finely ground slag or astrong activator such as NaOH reduces the effectiveness of accelerated curing.

1.1 *Recycled Aggregates*

When concrete pavements, structures, sidewalks, curbs, and gutters are removed, they become waste or can be processed for reuse. The resulting concrete must either be disposed of in landfills,or crushed for subsequent use as aggregate base material or as aggregate in new concrete. Crushingthe material and using it as coarse aggregate in new concrete makes sense because it reduces wasteand reduces the need for virgin aggregate. Recycled aggregate may be of better quality than somevirgin aggregate. While recycled aggregate is handled similarly to new aggregate, some differences between new and recycled aggregate must be addressed.

It is desirable to maximize the amount of coarse aggregate produced when concrete is recycled. Recycled fine aggregate normally accounts for approximately 25% of the finished recycled material. New concrete mixtures can contain both fine and coarse recycled aggregate. While up to100% of the coarse aggregate can be recycled material, the percentage of fine aggregate is usually limited to 10 to 20%, with the remainder being virgin material. This is because of the high absorption of recycled fine aggregates.

Absorption of recycled aggregates—Due to the cement mortar attached to the particles, the absorption of recycled aggregates is much higher than that of otherwise identical virgin aggregates,typically 2 to 6% for coarse aggregate and higher for fine aggregate. This high absorption can make the resulting fresh concrete less workable. To offset this, recycled aggregate should be sprinkled with water before the concrete is mixed, or extra water should be added to the mixture. Because fine aggregate made by crushing concrete is very angular and has a high absorption, it is generally necessary to limit it to approximately 10 to 20% of the total amount of fine aggregate in the mixture. Conservation of natural resources and preservation of environment is the essence of any modern development. The use of recycled aggregate concrete (RAC) is one such an attempt and is one way to solve some of the problems in construction engineering. The concept of using RAC is now gaining popularity and research in this field has gained some momentum. In fact, large amount of experimental work has been carried out in the past. Previous investigators mainly engaged themselves in the processing of demolished concrete, the mixture design, the physical and the mechanical properties as well as the durability aspects.
The ratio of the recycled to the total aggregates (by weight) is termed as the RCA replacement percentage (r). However, for the concrete with cylinder compressive strengths staying in the range of 25–30 MPa, the modulus of elasticity of concrete containing the RCA is only 3% lower than that of the normal concrete Rahal K. Build Environ 2007. In terms of the flexural strength, it hasbeen reported that the RCA content has insignificant influence on that (Xiao J, Li J.). It is observedthat 25% RCA does not influence the strength of concrete. In addition, it is found that for a givenimpact energy (the energy imparted by the hammer per blow) the reactions and strains of RAC with 50% and 100% RCA are significantly lower and higher respectively than those of normal concrete and RAC with 25% RCA (M. Chakradhara Rao). ascertained that the load carrying capacity and deflections of RAC beams and columns are relatively lower and higher respectivelythan those of normal concrete and the failure phenomena was slower in case of RAC, as a result of more ductility. (Sato et al). the recycled coarse aggregates are relatively weaker than the natural coarse aggregates and therefore the properties of recycled aggregate concrete are also relatively lower than that of normal concrete. However, 25–30% recycled coarse aggregate has no significant influence on the properties of recycled aggregate concrete (RAC). A Few researchers were examined the structural behaviour of RAC under static loading. (Ajdukiewicz and Kliszczewicz).also conclude that the concrete with 100% RCA as the coarse aggregate has been graded as ‘‘poor’’ in the oxygen permeability index (OPI). This phenomenon is mainly due to the cracks and fissures created within the micro and macro structures of the RCA during the crushing process. However, the permeability of the RAC is possible to be refined through alonger curing duration. These kindsof shortcomings of the RAC could also be enhanced by the incorporation of pozzolonic materials like fly ash and blast furnaces slag as in the conventional concrete (Abbas A).

2.3 Bond Behavior between Recycled Aggregate Concrete and Steel Rebar

Three recycled coarse aggregate (RCA) replacement percentages (i.e., 0%, 50% and 100%)and two types of steel rebar (i.e., plain and deformed) were considered Based on the test results, the influences of both RCA replacement percentages and the rebar surface on the bond strength between the RAC and steel rebar were investigated. It was found that under the condition of the equivalent mix proportion and compared with that of normal concrete, the bond strength between the recycled aggregate concrete and the plain rebar decreases by 12% and 6% for an RCA replacement percentage of 50% and 100%, respectively; while the bond strength between the recycled aggregate concrete and the deformed rebar is similar, irrespective of the RCA replacement percentage. For the case of the same compressive strength, the bond strength between the recycled aggregate concrete with r = 100% and steel rebar is higher than the one between normal concrete and steel rebar. For the recycled aggregate concrete, the bond strength between deformed steel rebar and concrete is approximately 100% higher than the one between plain steel rebar and concrete, and the coefficient of variation for the bond strength of the plain steel rebar is much higher than the one for the deformed steel rebar. Medium compression strength (30–45 MPa)concrete made with 25% of recycled coarse aggregates achieves the same mechanical properties as that of conventional concrete employing the same quantity of cement and the equal effective w/c ratio. Medium compressive strength concrete made with 50% or 100% of recycled coarse aggregates needs 4–10% lower effective w/c ratio and 5–10% more cement than conventional concrete to achieve the same compression strength at 28 days. The modulus elasticity is lower thanthat of conventional concrete. However, the tensile strength of recycled aggregate concrete can be higher than that of conventional concrete (concrete using raw aggregates).

Strength will not be much altered till 15% of virgin aggregate is replaced with recycled coarse aggregate. There is some problem associated with porosity of recycled aggregate concreteso in order to reduce the porosity high fine silica fume can be used to decrease the porosity .Whenusing high fine slag there is no need to use silica fume. The humidity content in recycled coarse aggregates must be high. Concrete crushed by an impact crusher achieves a high percentage of recycled coarse aggregates without adhered mortar. Due to the high water absorption the used RCAs were pre-soaked by additional water before mixing, the water/cement ratio was kept.Recycled concrete is 10–15 percent lighter in weight, resulting in reduced transportation costs. Recycled concrete compacts faster—up to two to three times as fast as non stabilized naturalroad base. Recycled concrete aggregates can also have disadvantages: They are often composed of material with highly variable properties.

2.3.1 *Conclusions on Recycled Aggregates from Previous Literature*

Recycled coarse aggregates obtained by crushed concrete were used for concrete production. Four different recycled aggregate

1. Strength will not be much altered till 15% of virgin aggregate is replaced with recycledcoarse aggregate.
2. There is some problem associated with porosity of recycled aggregate concrete so in orderto reduce the porosity high fine silica fume can be used to decrease the porosity.
3. When using high fine slag there is no need to use silica fume.
4. The humidity content in recycled coarse aggregates must be high.
5. Concrete crushed by an impact crusher achieves a high percentage of recycled coarse aggregates without adhered mortar.
6. Due to the high water absorption the used RCAs were pre-soaked by additional waterbefore mixing, the water/cement ratio was kept.
7. Recycled concrete is 10–15 percent lighter in weight, resulting in reduced transportationcosts.
8. Recycled concrete compacts faster—up to two to three times as fast as non- stabilized natural road base.
9. Recycled concrete aggregates can also have disadvantages: They are often composed of material with highly variable properties.

1.2 *Properties of Alkali Activated Slag Concrete*

2.4.1 *Fresh Concrete Properties*

2.4.1.1 *Setting Time:*

Various reviewed literature presented rapid setting as a practical problem associated with AAS concrete. Many authors reported that the initial setting of these systems can be as low as 15 min (Chang 2003; Cheng and Chiu 2003; Saud 2002). According to Chang (2003) an increase of alkali concentration and reduction of the water-solids can significantly decrease the setting time. However, many successful attempts to retard the initial set have been investigated and it is now known that chemicals such as lime and phosphoric acid may be used as retarding agents (Bakharevet al., 1999; Douglas et al., 1991; Saud, 2002; Wang et al., 1995). The retarders, known to be effective with Portland cement, have no effect with alkali-activated slag due to the different chemical composition of slag cements. (Bakharev et al., 2000) noted in their work that using a super plasticizer caused a quick set in the concrete. The reason for this, according to the authors, is the polar molecule of the super plasticizer that can be adsorbed rapidly on charged particles. This increases the zeta-potential of the hydrating particles and promotes a quick set.

(Atis et al., 2007) reported that the initial and final setting of LSS and SH activated Turkish slag paste occur much earlier than with PC paste and Slag paste activated with SC showed similar setting times to PC paste when no retarding agents are used. Similar findings were published by (Puertas et al., 2003). (Atis et al., 2007) concluded that the final setting times of alkali-activated Turkish slag paste reduced with increase in the sodium concentration of the activator. Moreover, final setting times of LSS activated slag paste reduced with increase in SiO_2/Na_2O ratio (from 0.75to 1.5).

(Vladimír Živica., 2006) concluded Sodium silicate, sodium hydroxide and sodium carbonate in the dosages of 3, 5 and 7 wt% of Na_2O accelerate the setting and decrease the workability of AAS cement mixtures and sodium silicate is an activator unsuitably accelerating the setting, this effect presents a potential for the limited practical use this activator when a no retarder is used.
Wang (1991) stated that alkali activated slag cements will start to set in 15 minutes when producing concrete of >70 MPa compressive strength without using admixtures. He also reported that attempts were made in China to retard the setting time of alkali-activated slag cement using surface active agents, dispersants and water reducers often used in Portland cement but these attempts were not successful.

Quing-hua & Sarkar (1994) tested water-glass activated slag pastes and concluded that adding hydrated lime can increase the setting time where the setting time is less for higher Na_2O dosage. Other researchers (*Douglas et al., 1991; Gifford and Gillot 1996; Collins and Sanjayan, 1999*) have also used hydrated lime successfully to control the setting time.

(*Talling et al., 1989*) recommended slaked (hydrated) lime with the recommended amount of 2- 5% $Ca(OH)_2$ of ground slag in suspension together with alkaline solution to have retarding effect. They also pointed out that an increase in water to binder ratio would obviously have a retarding effect.

2.4.1.2 Workability

Workability is another issue related to alkali activated systems. Since rapid setting is a problem faced with the use of AAS concrete, workability will also suffer as the time progresses. The slumpdecreases with the increase in the dosage of activator or with the use of higher modulus in the caseof water-glass activated concrete. It can be noted that initial slump might be acceptable due to the mixing action but a quick loss of slump will occur (*Talling and Brandstetr., 1989*). The use of hydrated lime to control setting and helps to provide acceptable workability in terms of slump (*Douglas et al., 1991; Gifford and Gillot, 1996; Collins and Sanjayan, 1999*). (*Collins and Sanjayan, 1999; Saud, 2002*) reported that using sodium silicate powder provides better workability and minimal slump compared to liquid sodium silicate solution since powdered silicates have a slower release of alkalis. *Vladimír Živica (2006)* reported that the increase of temperature of the mixtures (20-31) °C shows the acceleration of setting and decrease of workability and for the sodium silicate activated slag mortar a continuous effect was observed as temperature was increased. But with sodium hydroxide and sodium carbonate a sudden acceleration of the setting, and workability decrease were observed, when the temperature reachedthe values 24–29°C.

2.4.2 Engineering Properties

High compressive strength can be achieved with AAS concrete using optimum conditions in termsof activator dosages and quality control. Strengths of AAS concrete from 60 MPa to 150 MPa canbe achieved without chemical additives. High early strength can be achieved with AAS systems (*Wang et al., 1994*). (*Atis et al., 2007*) concluded that slag mortar activated with LSS results withcomparable or higher compressive and flexural tensile strength than that of PC mortar, dependingon SiO_2/Na_2O ratio module and sodium concentration. Slag mortar activated with SH developed comparable compressive and lower flexural tensile strength than that of to PC mortar strength. Depending on sodium concentration, slag mortar activated with SC developed equivalent or comparable compressive and flexural tensile strength to PC mortar. The compressive strength of the slag mortars increases as the sodium concentration of the activator increases. This finding is valid for each curing (*Atis et al., 2007*). Strength variations occur due to the sensitivity of this typeof concrete to different variables that make the control of mix quality difficult and no standard orempirical method of design has been agreed as yet.

Collins and Sanjayan (1999) reported achieving higher compressive strength with AAS concrete than OPC concrete for the same water/binder ratio and the same binder content and also higher flexural strengths. (Douglas et al., 1991) reported a high one day compressive strength, for example 40 MPa after one day reaching 60 MPa at 28 days.

Strength development of AAS concrete is difficult to control compared to OPC concrete. Strength variations occur due to the sensitivity of this type of concrete to different variables that make the control of mix quality difficult and no standard or empirical method of design has been agreed asyet.

The alkali activated slag concrete has many advantages in its beneficial use in terms of saving energy and as an environmentally viable alternative to OPC concrete. The best alkali activator is Water glass (Na_2SiO_3) with Ms between 0.75 and 1.5 and Na_2O dosage between 4-8 % in terms ofcompressive strength and flexural tensile strength. Sodium carbonate is best activator for comparing fresh concrete properties(setting time, workability) and engineering properties(strengthand drying shrinkage) with dosage of 4,6 and 8% of Na_2O with respect to slag when there is no retarding agent (lime) used. The setting rate of water-glass activated slag paste is high when compared to the NaOH activated slag paste and Na_2CO_3.

2.4.3 *Conclusions of AAS Concrete From Previous Literature*

1. The alkali activated slag concrete has many advantages in its beneficial use in terms of saving energy and less CO_2 emissions and viable alternative to OPC concrete.
2. The best alkali activator is Water glass (Na_2SiO_3) with Ms between 0.75 and 1.5 and Na_2O dosage between 4-8 % in terms of compressive strength and flexural tensile strength.
3. Sodium carbonate is best activator for comparing fresh concrete properties(setting time, workability) and engineering properties(strength and drying shrinkage) with dosage of 4,6 and 8% of Na_2O with respect to slag when there is no retarding agent (lime) used.
4. Replacing OPC with GGBS by 60% can achieve 40 MPa compressive strength at 28 days with a lower water requirement than the OPC concrete of the same grade.
5. Water-glass activated concrete mix with the addition of lime (SS8L4) showed less shrinkage than the same water-glass activated concrete at same Na_2O dosage, Ms and without addition of lime (SS8).
6. Slag requires less water for the same workability level. Therefore the slag replacement mix had higher slump compared with an OPC control of the same w/c ratio and the samebinder content.
7. Water-glass 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.
8. The concrete incorporating GGBS as a replacement of OPC develops strength at a slowerrate compared to the OPC and AAS mixes with the same w/c ratio.
9. Curing is a very important factor in the engineering properties of concrete in general, but AAS concrete is much more sensitive to curing where if there is no addition of retarder hydrated lime to the mix. In case lime is added then effect of curing in strength loss in case of AAS is comparable or even less than normal OPC concrete. Strength of concreteof dry cured samples is lower than that of concrete that is water cured samples for all typesof concrete.
10. L.S.S was the best; Na_2CO_3 was the second; and NaOH was the third in terms of compressive, tensile and flexural strength of concrete studied. Replacing 60% of OPC byGGBS results in an increase in porosity compared to the OPC mix of the same w/c ratio while it results in lower porosity when compared to the OPC mix with the same workability level.

1.3 PUNCHING SHEAR

1. Since the late 1950s, numerous experimental investigations have been undertaken to study the behavior of laterally-restrained slabs which, relative to unrestrained slabs, typically exhibited a large increase in load-carrying capacity.

2. Kinnunen and Nylander(1960):**Aurelio Muttoni(August 2008)**: A mechanical explanation of the phenomenon of punching shear in slabs without transverse reinforcement is presented on the basis of the opening of a critical

shear crack. It leads to the formulation of a new failure criterion for punching shear based on the rotation of a slab. This criterion correctly describes punching shear failures observed in experimental testing, even in slabs with low reinforcement ratios. Parametric studies demonstrate that it correctly predicts several aspects of punching shear previously observed in testing as size effect (decreasing nominal shear strength with increasing size of the member). Accounting for the proposed failure criterion and load-rotation relationship of the slab, the punching shear strength of a flat slab is shown to depend on the span of the slab, rather than on its thickness as often proposed.

3. **ZdenekP.Bazant and Zhiping Cao (FEB 1987):** Done punching shear test of geometricallysimilar reinforced concrete slabs of different size are carried out. The nominal shear stress atfailure is not constant as assumed in the current design formula, but decrease as the slab size increase. The observed size effect in punching shear strength is approximately described by an improved design formula which uses the size effect law for brittle failure due to distributedcracking. Applicability of this law is further supported by measurement of deflection diagrams.

4. **D. Tuan Ngo (2001):** studied on the use of high-strength concrete in reinforced concrete slabs is becoming popular in Australia and other countries. The study was the experimental results from 4 research studies are used to review the existing recommendations in design codes forpunching shear failure of slabs. Design codes referred in this study are AS3600 and CEB-FIPMC 90. In AS3600 the punching shear strength is expressed as proportional to $fc^{1/2}$. Howeverin CEB-FIP MC 90 punching shear strength is assumed to be proportional to $fc^{1/3.}$

5. **Stefano Guandalini, Olivier L. Burdet, and Aurelio Muttoni (FEB 2009):** The test was conducted by punching behavior of slabs with varying flexural reinforcement ratios and without transverse reinforcement are presented The aim of the tests was to investigate the
6. behavior of slabs failing in punching shear with low reinforcement ratios. The size of the specimens and of the aggregate was also varied to investigate its effect on punching shear. Measurements at the concrete surface as well as through the thickness of the specimens allowed the observation of phenomena related to the development of the internal critical shearcrack prior to punching. The results are compared with design codes and to the critical shearcrack theory. From that comparison, it is shown that the formulation of ACI 318-08 can leadto less conservative estimates of the punching strength for thick slabs and for lower reinforcement ratios than in the test results. Satisfactory results are, on the other hand, obtained using Eurocode 2 and the critical shear crack theory.

7. **H. SudarsanaRao, N.V. Ramanab and K. Gnaneswarao (2009):** The overall paper can divide into two parts.

8. **Part1** is test was conducted on restrained SIFCON two way slabs were described and the load-deflection responses under flexural loading were reported. Three different types of slabs
9. i.e. **SIFCON slabs**, FRC slabs and PCC slabs were investigated. It was found that flexural performance of SIFCON slabs is quite superior when compared to FRC and PCC slabs.

10. **Part2** the effect of various volume percentage of steel fiber in SIFCON slab specimens subjected to punching shear was studied. The punching shear load was applied to simulate a column-footing connection. From experimentation, the failure loads, deflection and crack patterns in punching shear were studied.

11. **J. Sagaseta*, M. Fernández Ruiz** & A. Muttoni(2009):**the phenomenon of non- symmetrical punching shear is revised according to the Critical Shear Crack Theory (CSCT) and compared with other design approaches suggested in codes such as EC2, BS8110 and ACI-318.

12. **Prof, chang-chihchen, Ph.D&chung-yanLi(1996):** An experiment was conducted to investigate the punching shear strength and failure behavior of concrete slabs strengthen withglass-fiber-reinforcement-plastic (GFRP). He conducted variables of concrete compressive strength, ratio of the reinforcing steel and amount of GFRP. The results indicated that the presence of GFRP substantially increased the punching shear capacity of slab-column connection.

M. H. Harajli, D. Maalouf& H. Khatib(1994): The test to investigate the effect of fiber reinforcement on the punching shear resistance of flat slabs. The results are indicated that the use of hooked steel fibers improves substantially the ductility of shear failure of slab-column connections, modifies their failure mode, favorably, from pure punching to flexural, and leadsto a significant increase in their ultimate shear capacity. The increase in ultimate shear resistance varied almost linearly with the steel fiber content. While polypropylene fibers increase. The ductility of shear failure, they are not as effective as steel fibers in increasing thepunching shear resistance.

MATERIALS

3.1 *Introduction*

This chapter describes the materials used and the experimental work carried out to study the performance of alkali-activated slag concrete mixes with 4% Na_2O dosage by weight of slag for three different activators (water-glass, sodium hydroxide, sodium carbonate) in comparison with OPC concrete and slag concrete.

The properties of materials used in this investigation to produce the different mixes are presented in detail, followed by the mix design which includes the selection of concrete making ingredients and blending proportions. The mixing procedure and curing regimes used are also presented. The overall experimental programme, which was implemented in the investigation, is given. The specifics of the tests carried out for each property studied are presented in their respective chapters. Finally a description of the means to study the interrelationships between the different variables inthe investigation is presented.

Materials

The same types of OPC, GGBFS, alkali activators, fine and coarse aggregates have been used throughout the investigation.

3.1.1 *Cement*

Ordinary Portland cement, conforming to the requirements of – IS 12269: 1987 was used in this investigation

Chemical composition of cement	**In %**
Sio_2	21.3%
Al_2o_3	4.5
Fe2O3	4.0
MgO	2.4
CaO	63.1

Na2O	0.1
K2o	1.2
So3	2.2

Table-3.1: show the Chemical composition of cement

3.1.2 Slag

The ground granulated blast-furnace slag (GGBS) used was obtained from the Toshali cementspvt. Ltd., It complied with BS: 6699-1992.

3.1.3 Alkali Activators

3.1.3.1 Sodium Silicate Powder (Water-glass)

DESCRIPTION	REQUIREMENT ASper B.S:6699-1992	TEST RESULTS
Mgnesium Oxide(% by mass)	**14.0 max**	**8.29**
Sulphur Content (% by mass)	**2.0 max**	**0.29**
Sulphide Sulpher(%by mass)	**2.0max**	**0.54**
Loss on Igition(% by mass)	**3.0max**	**NIL**
Insoluble Residue(%by mass)	**1.5max**	**0.46**
Chloride(%by mass)	**0.1max**	**0.014**
Moisture content(%by mass)	**1.0 max**	**0.48**
Manganese content(%by mass)	**2.0max**	**0.26**
Glass content (%by optical microscopy)	**67.0 min**	**94.00**
Chemical Moduli **a)** $CaO+MgO+SiO_2$ **b)** $(CaO+MgO)/SiO_2$ **c)** CaO/SiO_2	 **66.66% min** **>1.00** **<1.40**	 **75.86** **1.32** **1.06**
Finess(m^2/Kg)	**275 min**	**360**

Setting time by vicat Method **a)initial(Minutes)**	**>IST of OPC**	**280**
Soundness **a)Le-Chhatlier Expansion(mm)**	**10.0 max**	**NIL**

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.

3.1.1.1 *Sodium Hydroxide Pellets*

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

3.1.1.2 *Sodium Carbonate*

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

3.2.3.4. Water

Distilled water available at the laboratory was used throughout the investigation including in making the alkali solutions (NaOH and Na_2CO_3) and for changing the modulus of silica from 3.21 to 0.75 by adding NaOH solution which was made with solid pellets of NaOH and potable tap water.

3.2.3.5.. Aggregates

Medium graded sand and 10-mm natural round uncrushed gravel was used. The density of aggregates in different conditions is given in Table.

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

Table -3.3 properties of aggregates

CHAPTER 4

Experimental Design

4.1. *Alkali Solutions Preparation*

Three different alkali solutions were prepared as activators for slag concrete. The alkali solution consists of a sodium silicate powder. The activator was prepared firstly by mixing the sodium silicate powder in to water, stirring until all the powder dissolved . Considerable care was necessary while handling the solution not only due to its high alkalinity and potential of harm, butbecause after preparation the solution released a very high amount of fumes.

The second solution was a mixture of specific amounts of sodium hydroxide pellets and water. The third solution was a mixture of specific amounts of sodium carbonate pellets and water. The retarding agent hydrated lime was added to the mix (AAS mix) during the preparation of concretemix in the mixer in a slurry form of equal parts (by weight) of lime and water.

After preparation, the solution was kept into a sealed container for at least 16 hours. This procedurewas necessary to avoid using the activator while it was still warm.

The water/ solid binder ratios were kept constant at 0.48. The term "solid" means a sum of the weight of slag , dissolved solids present in the solution (Na_2O and SiO_2) and the solid hydrated lime(in case the retarding agent is used).

4.2. *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 designed to target strength of 36.6 mpa, of M30
Grade. Mix design is done according to Indian standard recommended method of concrete mix design IS 10262-1982.

4.3 *Alkali-Activated Slag Mixes*

The alkali-activated slag concrete mixes are mixed based on the second OPC control mix having the w/c ratio of 0.42. The activator dosage chosen in the recommended Na_2O range was 4% of Na_2O by weight of slag in case of water-glass activator with M_S=0.75. The same dosage 4% of Na_2O by weight of slag was used for NaOH and Na_2CO_3 activated slag concrete mixes. The mixture calculations were made to calculate the required amount of activator by weight, which will provide the chosen dosages. The weight of the solids ((Na_2O and SiO_2) in case of water-glassactivator and (Na_2O) in case of NaOH and Na_2CO_3 activators) is considered as part of the binder content and the water in the activator is also taken as part of the total mixing water.

4.4 *Mix Proportions and Mix Notations*

The details of different mixes are presented in Table 4. The mortar and paste mixtures are designedto have the same mortar or paste fractions of the concrete mixes.

The notation for the mixes is as follows:

CM1: PC control mix with w/c=0.42.

SS4: sodium silicate powder -activated slag concrete mixture with Na_2O content of 4% by weightof slag with w/c=0.43

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

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

4.4.1 Concrete Mixtures:

Horizontal pan mixers were used according to the batching size. The mixing was done as just likepaste mixtures but in addition to the OPC and slag dry mix coarse aggregate and sand were also dry mixed in the first step. Dry mix the material in the order of coarse aggregate, OPC and slag, sand for 30 seconds. All the mixes are hand mixed.

4.5 *Casting and Curing*

After mixing, the concrete was placed in pre-oiled moulds. Curing is done by ordinary watercuring for 1,7,28 days respectively.

Table -4.1 Shows the Details mix proportions of different concretes

5. PROPERTIES OF THE FRESH CONCRETE:

Mix no	Type of binding material	Binding Material (kg/m^3)	Type of activator	Activator (kg/m^3) (4%)	Fine agg (kg/m^3)	Coarse agg +(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
SH4	Slag	420	NaoH	21.67	562.8	1209.6		0.43
SC4	Slag	420	Na_2CO_3	28.72	562.8	1209.6		0.43
SS4	Slag	420	Na_2SiO_3	16.8	562.8	1209.6	16.8	0.43

The rheological properties of concrete will be greatly influenced by the use of alternative cementitious materials, such as GGBS, whether in partial replacement of cement or as the sole binder in the case of alkali-activated slag. This chapter investigates the effect of using different alkali activators (with or without retarder lime) for activating slag concrete in case of slump test and for activating slag paste in case of setting time measurement, when compared to control mixes(OPC and OPC/Slag blended systems).

5.1 *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 isthe term traditionally been used in concrete technology to embrace all the necessary qualities.

According to *Tattersall* (1991), the fresh concrete must be of a suitable composition in terms of quality and quantity of cement, aggregate and admixtures and must also be capable of: flowing into all corners of the mould or formwork to fill it completely, being compacted to expel as much entrapped air as possible, being mixed satisfactorily, being transported satisfactorily and providinga good surface finish.

Workability Tests

There are different tests for the workability of concrete that are adopted in concrete practice. Theuse of any test is chosen based on the following inter-dependent factors:

- The concrete type: Properties and the desired level of workability of concrete, w/c ratioand use of admixtures.
- The application: whether used in floors or slabs or columns and the formwork used.

The location of the casting, which affects the means of delivering of concrete whether there, is aneed for pumping for high altitudes**.**The test used is slump test.

Activator	slump (mm)
CM1	**135**
SS4	**Collapse**
SH4	**110**
SC4	**Collapse**

Table no: 5.1 show the Slump at 5 minutes of different concrete mixes

Results 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 water-glass 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 water glass activated slag concrete is very high when the modulus is between 0.5 and 1.0. For the same modulus of water glass 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 additionof hydrated lime has lower workability but is comparable with the workability of control mixes.

5.2 *Setting Time*

The term ‘setting’ is related to a change from the fluid to the rigid state of a cement system. The time taken for cement paste or concrete to stiffen is known as setting time. It is arbitrarily divided into two stages: initial setting and final setting time. At the initial set, the stiffness of the paste or mortar starts to steadily increase and after this point the fresh material can no longer be properly handled and placed. At the final set, the material begins to develop useful strength and no further finishing can be carried. The reactions controlling these physical parameters are usually accompanied by a temperature rise.

5.2.1 *Test Procedure*

The mix procedure followed the steps described in section 3.4.1 and 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) ^{o}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 penetratesthe mortar to a depth of only 0.5 mm.

Figure 5.1 Vicat's apparatus used for finding the initial and final setting time

5.2.2 *Setting time of OPC Systems:*

The setting values are related to many variables such as cement composition and temperature andthe typical data on setting of different types of cement are shown in Table 4.2

cement type	Initial Setting(h: min)	Final setting(h: min)
OPC of 53 grade	0:30	3.10
SS4(sodium silicate activated slag)	0:20	0.50
SH4(sodium hydroxide activatedslag)	0:10	0.30
SC4(Sodium Carbonate Activatedslag)	1:00	2:15

Table-5.2 Typical setting time of cements, Slag mixes

IS-4031(part 5:1988) prescribes a minimum initial setting time for Portland cement: if the designed28 day compressive strength is 32.5 MPa, the initial setting time cannot be less than 75 min; if it is 42.5 MPa not less than 60 min; and if it is 52.5 MPa not less than 45 min.

5.2.3 *Results and Discussion*

The results in Figure 4.2 show that the OPC mix with higher w/c ratio had longer setting time compared to the other OPC control mix. Among the mixes of the same w/c ratio and binder contentthe 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 mortarmixes. From the Figure 4.2 it is evident that the addition of 4% hydrated lime by weight of slag prolongs the final setting time of water-glass activated slag by 50 minutes whereas the initial setting time by 5 minutes only. The effect of hydrated lime in controlling the setting time is reported and adopted by several researchers, reported earlier in the literature review. Among AASmortar SC8 mix holds good for the criteria of minimum initial setting time of 60 minutes prescribedby IS-4031(part 5:1988) for strength of 42.5 MPa. For SC8 mix no addition of lime is required as it shows comparable setting of OPC (CM) mix. (Atis et al., 2007) reported initial and final setting times of 20 and 65 minutes in case of water-glass activated slag pastes with 4% Na2O, with Ms=1 Here for the same activator (water-glass) with same concentration for the given slag it wasfounded 20 and 50 minutes as initial and final setting times respectively, in case of mortar mix. The changes might be because of difference in slag composition, w/b, properties of aggregates used etc.

CHAPTER 6

6. *ENGINEERING PROPERTIES*

In the field of construction practice and concrete design, the strength of cement paste and concrete are commonly considered as valuable properties. As there is direct relationship between the structure of the cement paste and strength, the strength gives an overall indication of the quality ofconcrete or cement paste. However, practically other characteristics such as permeability and porosity (durability related properties) may in fact be more critical in assessing the quality and performance of concrete.

This chapter reports on the engineering properties of concrete including the compressive strength, tensile strength, flexural strength and UPV of different concrete mixes including the control OPC, OPC/Slag and AAS mixes with different activators (water-glass, NaOH and Na_2CO_3) andactivator dosages. The influence of curing conditions (dry curing and water curing) at different ages is presented.

6.1 Compressive Strength

Compressive strength is an important criterion used to evaluate the quality of concrete. It is usuallythe value that the structural design of concrete is based on. This section gives details of the investigation carried out to evaluate the compressive strength of OPC, OPC/Slag and AAS concrete with different activators.

6.1.1 Test Procedure

150x150x150 mm cubes were prepared according to mix procedure given in Section 4.2. The compressive strength is determined by following (IS456:2000) and two samples were tested for each different age and curing except at the age of 7 day where only one sample is used. Cubes from the mixtures listed in Table 4 were tested for 1, 7 and 28 days, and the average results are reported. All the above-mentioned specimens were cured under water curing (WC) and dry curing(DC).
The compressive strength was calculated from following formula: $f_c = P/A$

Where: f_c is compressive strength in N/mm^2 (MPa) P is maximum load applied to the cube in NA is the area of concrete surface in mm^2

Age	**cement or slag mix**	**strength (mpa)**	**%28 days strength**
1	CM1	10	25
7	CM1	25	66
28	CM1	38	
1	SS4	12	40
7	SS4	23	74
28	SS4	31	
1	SH4	12	44
7	SH4	24	87
28	SH4	27	
1	SC4	6	20
7	SC4	20	69
28	SC4	29	

6.1- Compressive strength development of different mixes

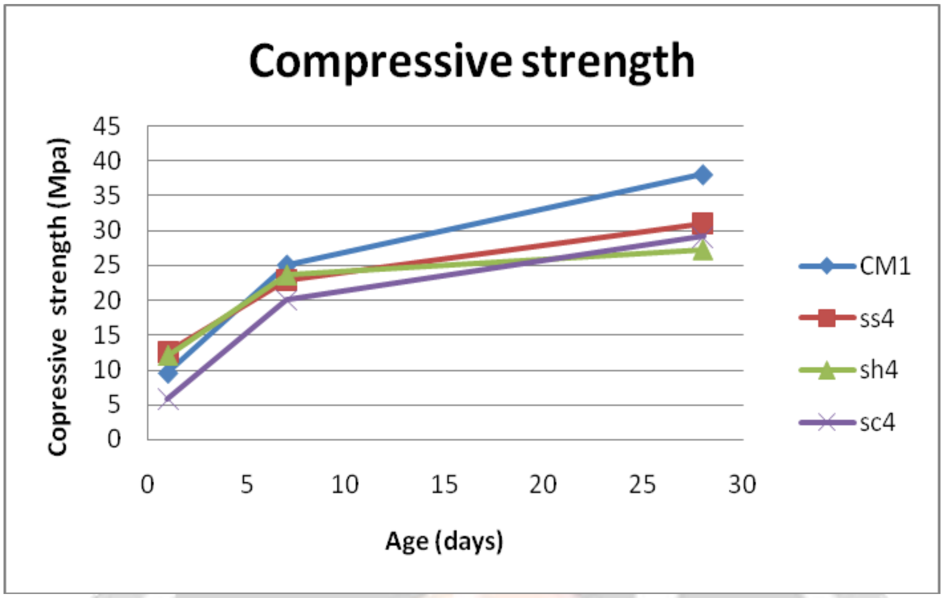

Figure 6.1 Compressive strength of different mix samples at different

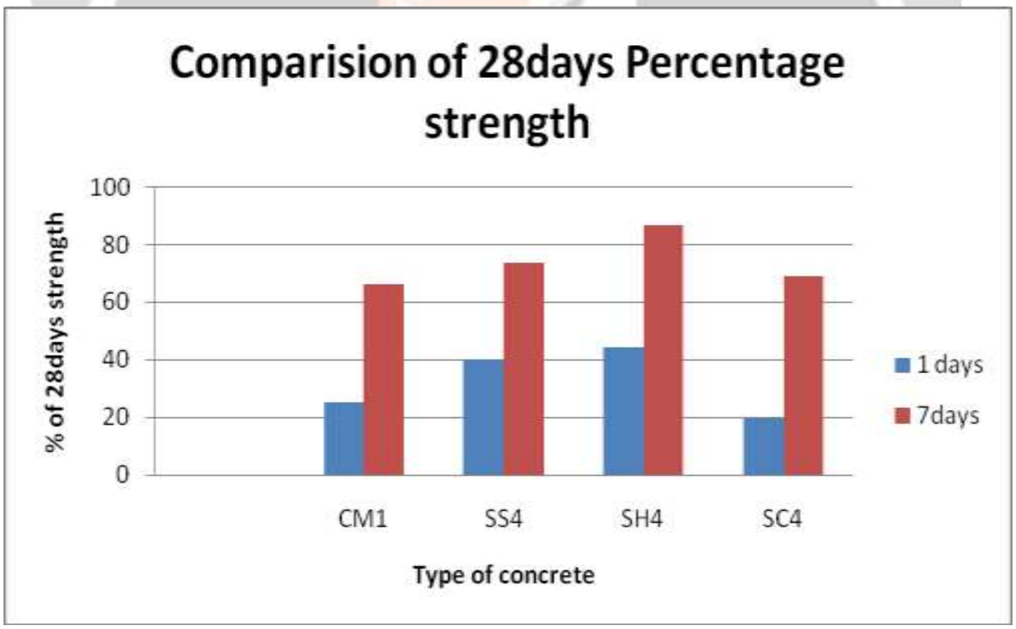

Figure 6.2 Shows the Comparison of 28 days % strength

6.1.2. Results on Compressive Strength:

It can be seen in Figure 6.1 that SS4 with a dosage of 4% Na_2O and SH_4 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. This finding is in valid with many authors like (Atis et al., 2007; Bakharev, 1999). Na_2CO_3 activated concrete exhibited second highest compressive strength (29.15 MPa at 28 days) among alkali-activated concrete mixes, which is lower than the two AAS mixes SS_4 and SH_4 which have 31.09 and 27.32 MPa strength in case of water cured samples. This is because of the presence of silica rich gel during hydration when compared to

NaOH and Na_2CO_3 activated slag concrete, which is reasoned by many authors like Palacios et al., (2007); Wang et al., (1994) and Shi et al., (2006). From the Table 5.1 it can be noticed that the addition of 4% lime by weight of total solid binder content along with L.S.S (SS_4mix) slightly improved strength at 28 days (31.09 mpa) when compared to NaOH (SH_4), which is in acceptance with the results published by (Shi et al., 2006). Of all the alkali activated concrete mixes, NaOH activated slag concrete mix with 4% by weight of slag (SH_4) has compressive strength 27.32 MPa, which is even higher than the strength given by Na_2CO_3 in case of water curing. The reviewed literature on AAS concrete (Douglas et al., 1991; Gifford and Gillot, 1996; Collins and Sanjayan, 1999; Atis et al., 2007) gave variable results with different AAS concrete depending on the concrete composition but the compressive strength achieved was comparable tothat of OPC control mixes.

6.2 *Splitting Tensile Strength:*

Concrete in general is known to be weak in tension leading to the use of steel reinforcement in structural concrete. Although concretes and mortars are not generally designed to resist tension, the knowledge of the tensile strength is significant to estimate the load under which the sample will crack.

There are three types of test for the tensile strength: direct tension test, flexure test and splitting tensile 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. However, it is stated that the splitting tensile test yields a lowresult for mortars (*Neville, 1995*).

As with compressive strength, the tensile strength of concrete obtained is related to the mix material composition and proportion of ingredients. It is greatly affected by curing conditions.

Test Procedure: The splitting tensile strength of all mixes was measured using 100 mmΦ X 300 mm long cylinders. The test was performed as described by (IS 5816: 1999) and three samples were tested at each of the ages 1 and 28 days for water curing whereas for 7 day age onesample was tested. The splitting tensile strength was calculated from the following expression:

$$f_{ct} = \frac{2P}{\pi LD}$$

Where:

f_{ct} is the splitting tensile strength (MPa);

P is the maximum load (N);

L is the length of line of contact of specimen (mm);

D is the diameter of cylinder (mm).

Age (days)	TYPE	Tensile strength
7	CM1	2.31
28	CM1	2.8
7	ss4	1.87
28	ss4	2.59
7	sh4	1.79
28	sh4	2.16
7	sc4	1.83
28	sc4	2.47

Table 6.2- Tensile strength development of different mixes

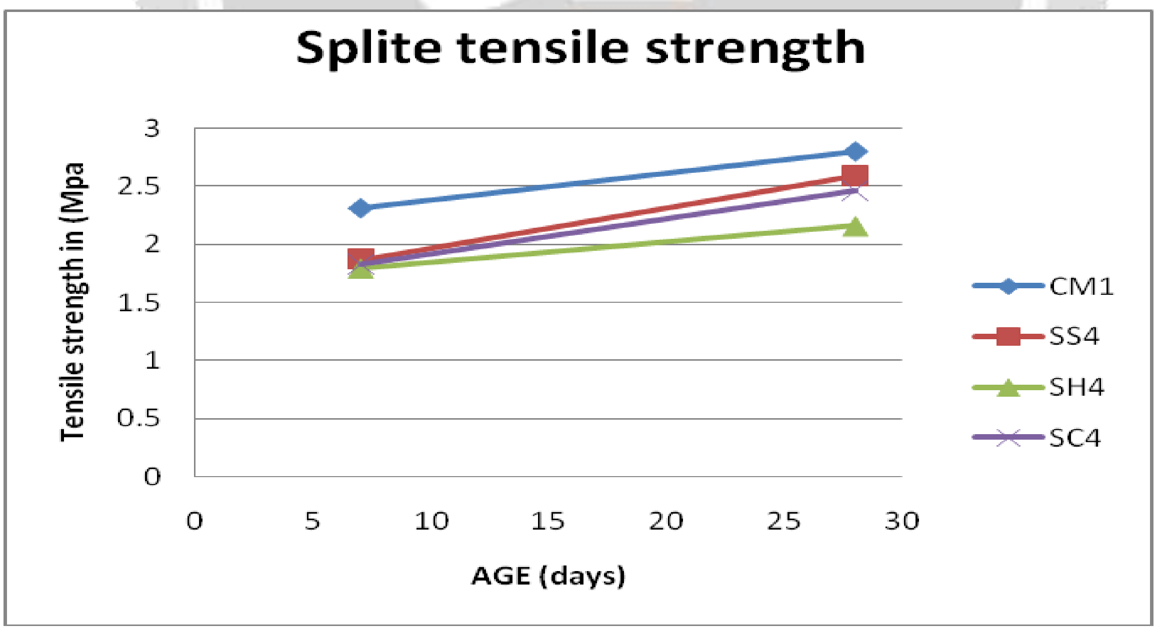

Figure 6.3 Tensile strength development of different mixes

The results in above table show that among AAS concrete mixes, SS_4 showed the highest value of tensile strength around 2.59 MPa at 28 days followed by SC8 (2.47 MPa). SH_4 showed the lowest value. Expect SH_4, all the other AAS mixes showed comparable values of tensile strength than control mix CM1.

5.1 Relationship Amongst Engineering Properties:

This section presents an attempt made to correlate engineering properties with each other. The relationships are empirical in nature and have certain limitations because a number of factors including age and curing, binder type, w/c ratio affect the relationships. Nevertheless, the relationships give some idea of development of the properties with age. The detailed descriptionsof the relationships developed in this investigation are presented below.

6.5.1 Punching Shear Test:

To find out the punching shear strength and size effect, 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) was1: 1.34: 2.88: 0.43. The maximum size of the aggregate is 20mm. the sizes of the specimens are 400mm, 200mm, 100mm.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 AASR concrete mixtures are done separately in different mixers BS 1881: part 125:1986.

A group of three specimens, one of each size, was cast one at time from same batch of concrete. Then each specimen was vibrated, and one day after casting the specimen were unmolded and placed for curing tank. The specimens were curing up to 12day.

The slab specimens were tested on the servo controlled dynamic testing machine under displacement rate control. The load is applied through the steel column. At every stage of loading,stroke reading were recorded which indicates the vertical movement of the column. The load atwhich punching shear failure occurred is recorded. The failure load and punching shear strengthcolumn specimens.

Figure 6.9 Show the punching shear test specimen and Experiment

.

6.5.1 *Formulas used from punching shear test:*

Punching shear stress in experimental formula (τ_p) = P/(πxdxh)Where P =
Ultimate load in (N)
d = Diameter of critical perimeter (mm)

h = Effective height of specimen (or) slab (mm)τ_p =
Punching shear stress (N/mm^2)

ACI code provisions:

ACI 318 code provisions (clause 11.12.2.1) for punching shear are derived from Moe's work onlow strength concrete[13]. The ultimate shear strength for slabs without pre-stress is given by

V_{uo} = ud (v_n)

Where,

u = length of the critical perimeter, taken at a distance of d/2 from the column, mm (See Fig..)

d = effective depth of slab, mm

vn = punching shear strength, MPa, shall be the smallest

where,

αs = 40 for interior columns, 30 for edge columns and 20 for corner columnsβc = ratio of longest column dimension to shorter column/capital dimension.

Indian code provisions:

The Indian code provisions are also based on the American code. As per the Indian code, theultimate shear strength for slabs without pre-stress is given by (clause 31.6.3.1 of the code)

V_{uo} = udτc
where,
τ_c= ks (0.25√ f ck)

ks = 0.5 +□c ≤ 1.0

6.5.2 *Results of punching shear stress:*

The below graphical figures, figure 6.11 Show the variation in punching shear for different concrete mixers at particular size cylinder specimen. In the above figures shows the punching shear stress results. These results are calculating by the experimental formulas and these results are comparing the ACI code and I.S codes. These two codes the ACI code results gives the very lowerwhen comparing to the I.S. code and experimental values. So these two codes ACI code will takethe factor of safety of the experimental values.

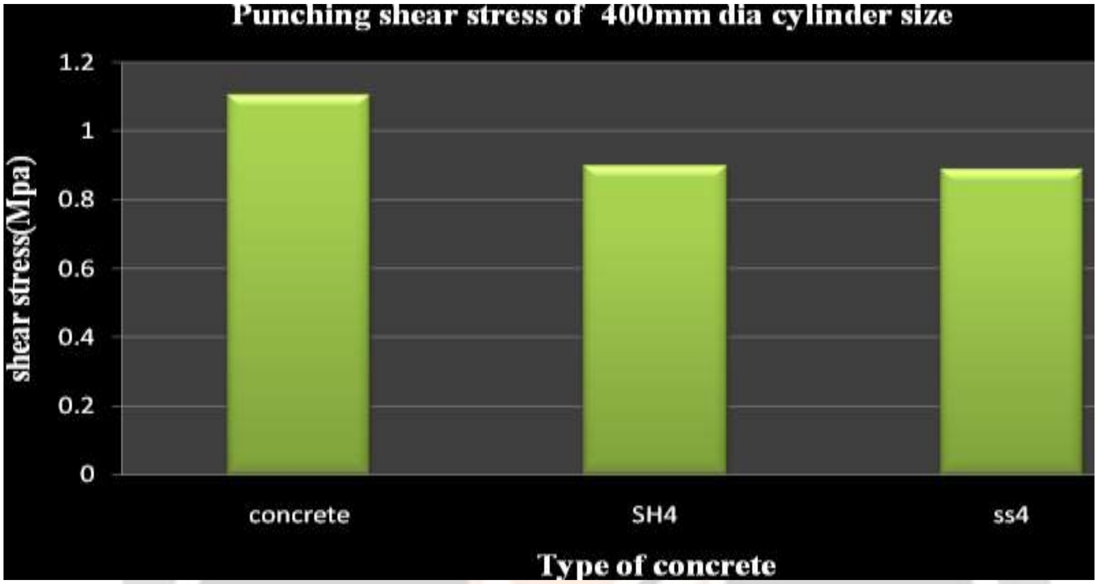

Figure6.11 Punching Shear Stress of 400mm Diameter Cylinder

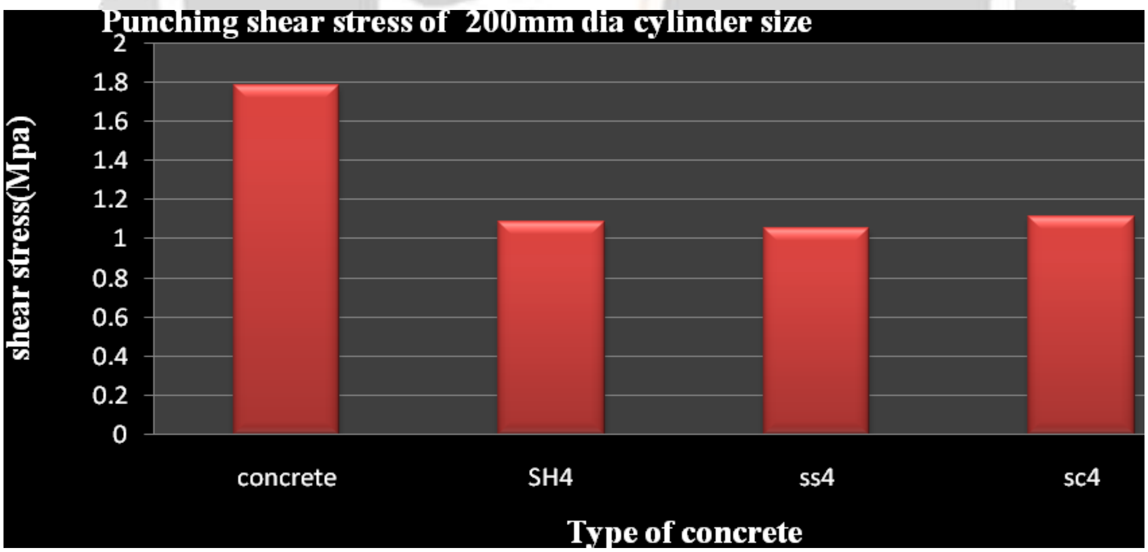

Figure 6.12 Punching Shear Stress of 200mm Diameter Cylinder

Figure 6.13 Punching Shear Stress of 100mm Diameter Cylinder

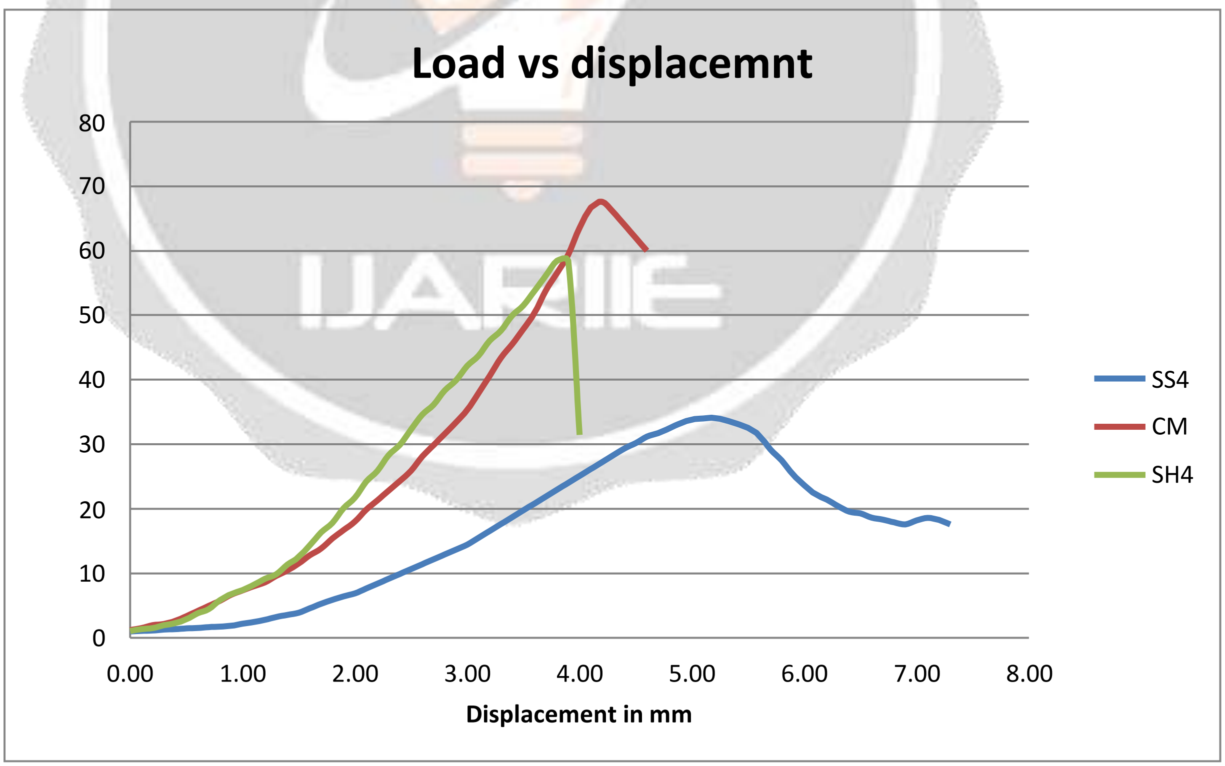

figure 6.14 Load vs Displacement of 400mm Diameter Cylinder

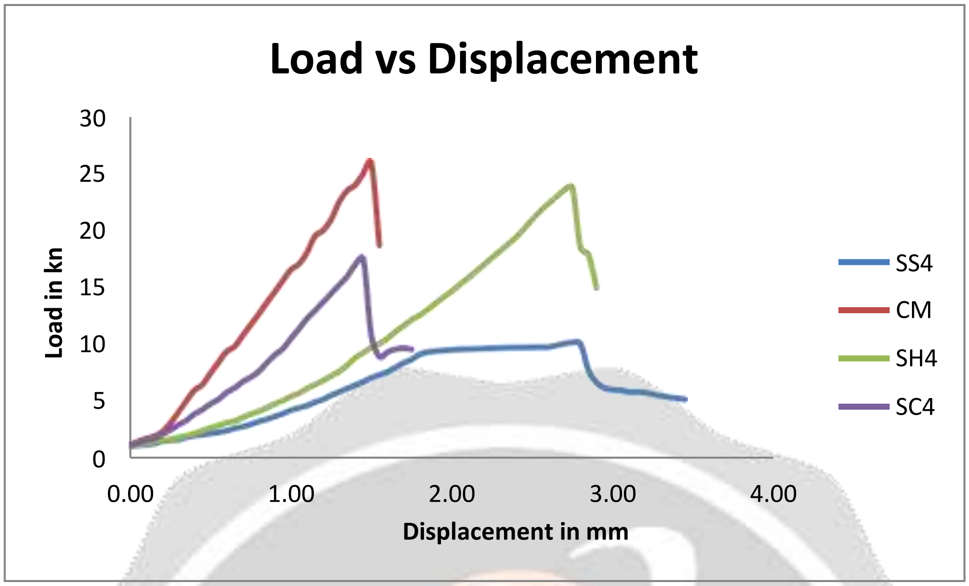

Figure 6.15 Load vs Displacement of 200mm Diameter Cylinder

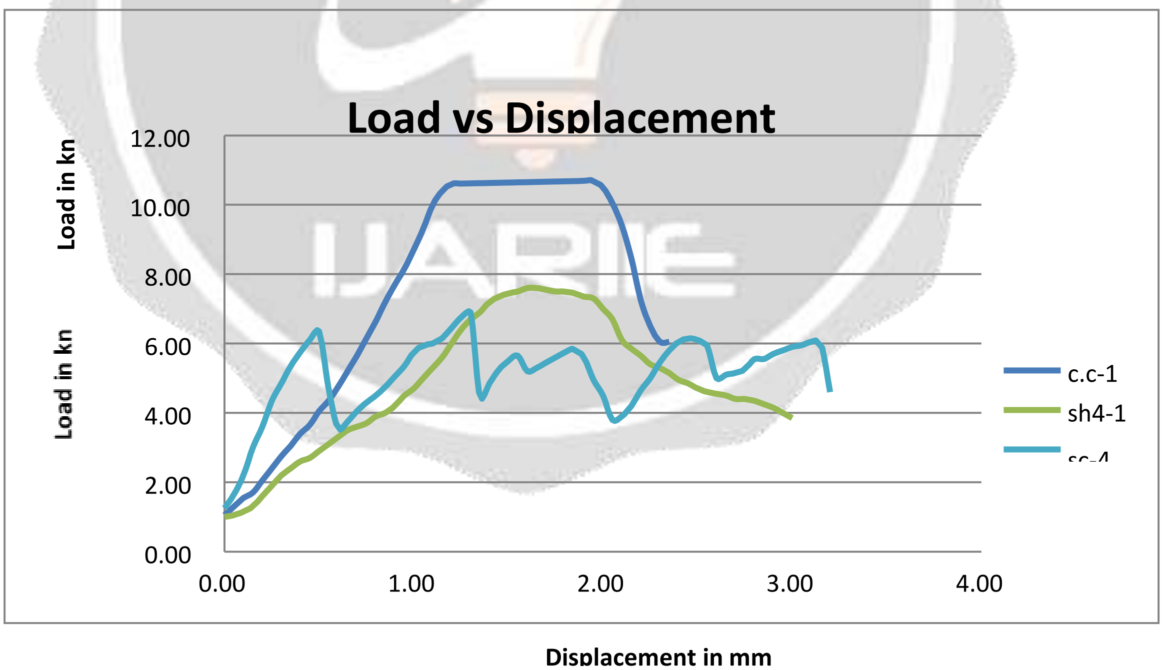

Figure 6.16 Load vs Displacement of 100mm Diameter Cylinder

6.6 SIZE EFFECT ON PUNCHING SHEAR STRENGTH:

If the stress in specimen is not constant with same material because the size of the specimen will vary the stress also vary this is called size effect. If the sizes of the specimen will increases the stress will decrease. The below figure show the size effect of the different concretes

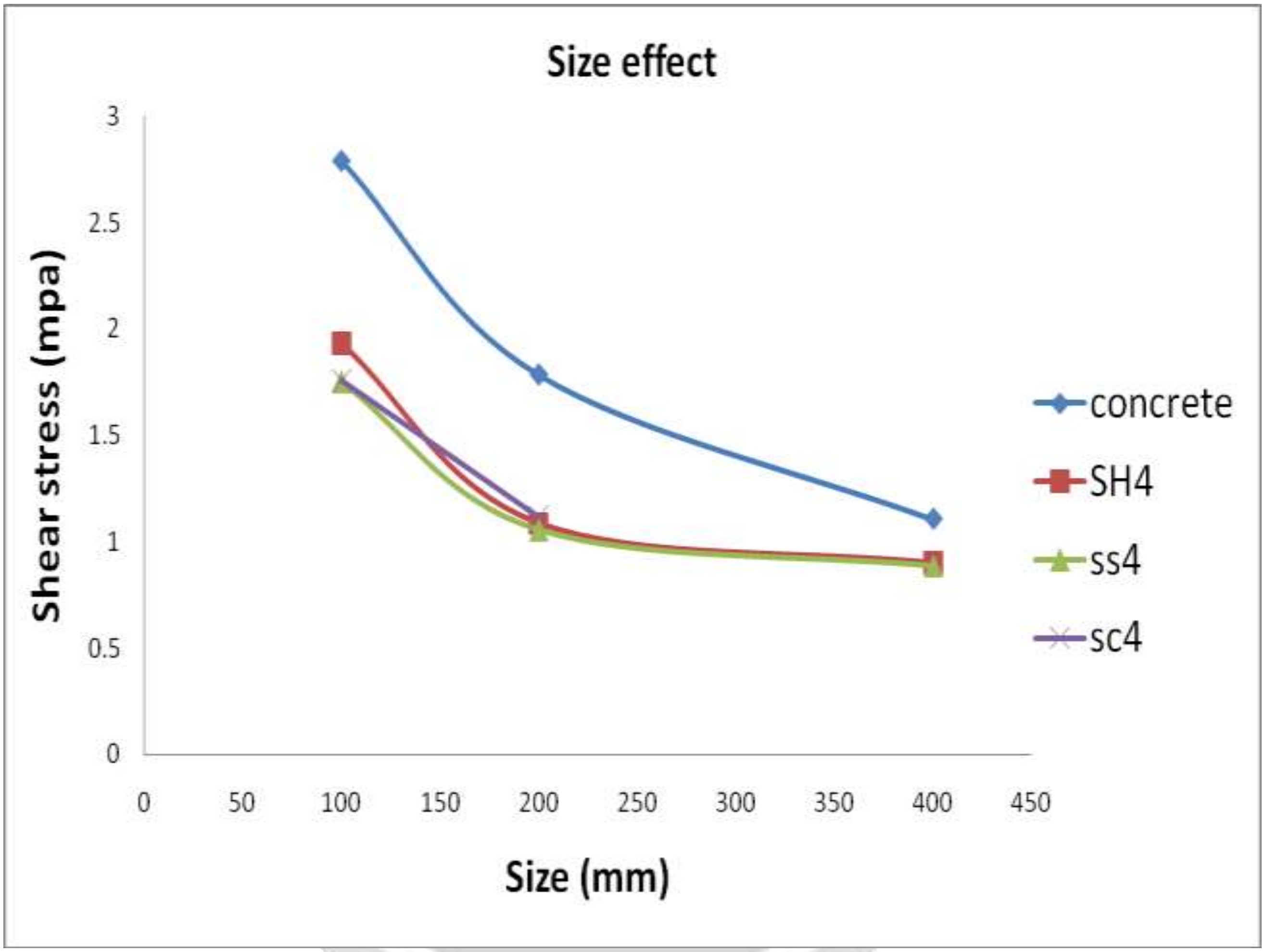

Figure 6.17 Size Effect of Punching Shear in Different Concrete Mixes.

The regression results for water cured samples are shown in Figure 6.4. The formulae arrived by regressionare as follows:

$y = 5E\text{-}06x^2 - 0.005x + 2.323$ (OPC, WC)

$R^2 = 1$

$y = -0.000x + 1.311$ (SC4, WC)

$R^2 = 1$

$y = 4E\text{-}06x^2 - 0.003x + 1.568$ (SH4, WC)

$R^2 = 1$

$y = -7E\text{-}07x^2 - 0.000x + 1.205$ (SS4, WC)

$R^2 = 1$

6.6.1 *Results and Discussion:*

In the above figure.. Show the different concrete and different sizes of specimens punching shearstress. In this graph 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 gives the higher strength when compare the Na_2CO_3 and Na_2SiO_3. And Na_2SiO_3 gives the vary lower value.

6. *CONCLUSIONS AND FUTURE WORK:*

This work studied the properties of alkali activated slag concrete using three different alkalis (Sodium Silicate Powder with use of lime as retarder, NaOH and Na_2CO_3). The properties of alkali-activated slag concrete are compared with OPC concrete in terms of fresh and engineering properties.

- 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.
- Water-glass 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
- In flexural test, traditional concrete (M30) mix gives the higher resistance in flexure whencompared to AAS concrete at the dosage of 4 % of Na_2O by weight of slag using all activators. But the flexural strength of AAS is comparable with that of traditional M20, which can also be used as structural grade concrete which resulted at the dosage of 4 % ofNa_2O by weight of slag.
- From Load vs. displacement curve in flexure test results, the CM mix gives the higher loadcarrying capacity but less ductility whereas 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 seismicprone areas.
- In punching shear test, experimental test results gives the higher values when compared with the ACI and I.S code formulae, which is as expected. Since in design code of practice any strength parameter is underestimated by applying the factor of safety.
- ACI code punching shear strength is under estimated when compared to IS code punchingshear strength. So it is better to estimate punching shear strength using ACI code of practiceto be in safe side
- 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 strengthcompare to all mixes.

- The increase in size of the specimen decreases the punching shear stress experimentally but in code of practice (ACI and I.S code) there is no equation for punching shear strengthby considering the size effect
- Experimentally as the size of the specimen increases, the stress decreases

7.2. Recommendations for Future work:

1. Attempts should be made to standardize the mix design methods for AAS concrete and specify the activators as a construction material with recommended dosages and properties.

2. Investigate the use of Na_2SO_4 as an activator in activating GGBS to study the fresh, Engineering and Durability related properties of concrete.

3. Investigate the possibility of using different mixtures of alkalis as an activator, for examplethe combination of NaOH and Na_2CO_3, in AAS slag concrete to study the properties of concrete.

4. Developing the stress and strain blocks of AAS concrete is essential future work.

5. By using different fibers in AAS concrete finding out the punching shear values and size effect can be worked out.

6. The high tensile strength fibers such as AR (Aramid) and Carbon fibers can be suggested for study of compressive strength, flexural and punching shear behavior of the AAS concrete.

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