A Comparative Study on the Mechanical and Durability Properties of Concrete Blended with Shrinkage Reducing Admixture, Metakaolin and Monofibre under Different Curing Conditions

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***Abstact* - The use of Shrinkage compensating admixture in concrete has been proven to be an effective way to mitigate the shrinkage of concrete. The practice of using expansive agents has been recommended to manufacture shrinkage compensating concrete provided that an adequate wet curing is carried out. On the other hand, more recently the use of shrinkage reducing admixtures has been suggested to improve concrete performance in terms of low risk of cracking related to drying shrinkage. In this study, the mechanical properties and the durability of the shrinkage compensating concrete by addition of shrinkage reducing admixtures such as Plaster of Paris(0%, 2.5 % , 5 %, 7.5 % 10 % by weight of cement) in Metakaolin (5 %) and Polypropylene (0.3%) blended concrete will be tested and compared.**

Keywords- Metakaolin, polypropelene fibre, Plaster of Paris, Shrinkage

I. INTRODUCTION

A. *General*

Concrete, as the most commonly used construction material, is developing towards high performance, i.e., high strength, high toughness, high durability, and good workability. Shrinkage and permeability resistance of concrete are two important properties relating to durability. An important measure of improving concrete impermeability is to improve the capability of resisting shrinkage and cracking.

Shrinkage of concrete deserves special consideration when a concrete structure is designed, which may cause cracking if the concrete is restrained by internal steel bars or connected structural elements. The use of shrinkage-compensating admixture in concrete has been proven to be an effective way to mitigate the shrinkage of concrete. The negative volume change (shrinkage) of concrete is counteracted with some reactions that have swelling potentials via which the shrinkage is compensated. The start of research about shrinkage-compensating admixture dates back to about 60 years ago where a mixture of Portland cement, an expanding agent, and a stabilizer were used to make a concrete with controlled expansion. The expanding admixture is made by burning a mixture of gypsum, bauxite and chalk to form Calcium Sulphate and Calcium Aluminate (mainly C_5A_3). These compounds react with water to form Ettringite. The formation of Ettringite as the major source of expansion is commonly used in modern concrete to compensate the shrinkage.

While concrete can undergo dimensional changes for a variety of reasons, one of the most common is due to the loss of water during environmental exposure. Commonly referred to as drying shrinkage, this phenomenon can lead to cracking of concrete members, if not properly accounted for during the design and construction process. Typically, early-age moisture loss is minimized by specification of a curing regimen for the concrete. In addition to preventing evaporation and the accompanying drying-type shrinkage, good curing practices also maximize the degree of hydration achieved by the cement within the concrete, potentially leading to stronger and more durable concrete.

It is well known that the dry shrinkage of concrete is due to the evaporation of water from concrete and causes volume contraction. The measuring time for drying shrinkage is initiated after 7 days that a concrete specimen was immersed in water. Typically, concrete specimen is exposed to an environment with low humidity and high temperature. A major disadvantage of cement mortar and concrete is that they tend to crack on drying due to their considerable drying shrinkage and low tensile strength. For this reason, a concrete which will dry with a minimum of contraction has been desired. To counteract drying shrinkage, expansive admixture or expansive cement has been used extensively in practice for many years. In recent years, new shrinkage-reducing admixtures (SRAs) appeared in concrete engineering. According to some reports, SRA can reduce plastic shrinkage, autogeneous shrinkage, and especially drying shrinkage.

Expansive cements have also been used in prestressed concrete applications. The expansive cement is used to bring about self-stressing of steel reinforcing members contained within the concrete. Expansive cements are particularly useful for three-dimensional prestressing.

For concrete consisting of hardened cement, aggregates pore, and microcracks of different sizes, reinforcing effect of monofibre is limited. Hybrid fibre of different sizes and types may play important roles in resisting cracking at different scales to achieve high performance. It has been proven that incorporating fibre into cementitious materials can effectively improve their toughness and ability of resisting crack.

B. Mechanism of concrete shrinkage

Concrete shrinks as it dries under normal atmospheric conditions. Tensile stresses develop when the concrete is prevented from shrinking freely. The combination of high tensile stresses with the low fracture resistance of concrete often results in cracking. Cracks reduce load carrying capacity and accelerate deterioration, resulting in increased maintenance costs and reduced service life. Although free shrinkage measurements are useful in comparing different mixture compositions, they do not provide sufficient information to determine if the concrete will crack in service.

Water related shrinkage is a volumetric change caused by the movement and the loss of water. Drying is driven by the environmental conditions in which the relative humidity of the concrete structure strives to bring into balance with the humidity of the surrounding environment. Water is squeezed from the capillary pores resulting in the development of tensile stresses.
Drying shrinkage is by far the most common cause of shrinkage. Drying shrinkage occurs in hardened concrete as a result of water movement.

C. Objectives

- To develop a proper mix design for normal concrete.
- To study the workability of fresh concrete.
- To determine the mechanical properties and the durability of shrinkage compensating concrete by the addition of Plaster of Paris as admixture (0%, 2.5%, 5%, 7.5 % and 10% by weight of cement) blended with Metakaolin (5 %) and monofibre (0.3%).
- To compare the properties of the shrinkage compensating concrete under different curing conditions.

D. Methodology

- Literature survey
- Raw materials procurement from available sources.
- Determination of material properties.
- Development of mix design.
- Workability study of developed mixes.
- Casting the specimens.
- Testing the specimens.
- Comparison of results to arrive at conclusion.

II. EXPERIMENTAL INVESTIGATION

This chapter deals with the experimental programmes conducted in the present study which include the material properties, mix design, properties of fresh concrete and properties of hardened concrete.

A. Materials used

The various materials used in the experiment are

i. Cement
ii. Plaster of Paris
iii. Metakaolin
iv. Fine Aggregate
v. Coarse Aggregate of maximum size 20 mm
vi. Polypropylene Fibres
vii. Superplasticiser
viii. Water

B. Test on constituent materials

Cement :Ordinary Portland Cement of 53 grade, conforming to IS: 12269-1987 was used. Different laboratory tests were conducted on cement to determine standard consistency and initial and final setting time as per IS: 4031-1988. Tests were conducted in the laboratory. The specific gravity was obtained as 2.84 and standard consistency 35%. The initial and final setting time was obtained as 80 minutes and 450 minutes respectively.

Plaster of Paris :Plaster of Paris is a quick-setting gypsum plaster consisting of a fine, white powder, Calcium Sulphate Hemihydrates which hardens when moistened and allowed to dry. Plaster of Paris is prepared by heating Calcium Sulphate dihydrate or gypsum to 120°–180° C.

Fig 1 Plaster of Paris

Metakaolin :Metakaolin is a dehydroxylated form of the clay mineral Kaolinite. Rocks that are rich in Kaolinite are known as china clay or Kaolin, traditionally used in the manufacture of porcelain. The specific gravity of Metakaolin is 2.50.

Fig.2 Metakaolin

Fine Aggregate : Commercially available manufactured sand passing through 4.75mm IS sieve and conforming to grading zone II of IS: 383-1970 was used for experiment. Sieve analysis was done to determine the fineness modulus and grain size distribution of M sand.
Fineness modulus of fine aggregate was obtained as 3.08

Coarse Aggregate : Coarse aggregates that are used for this study consists of locally supplied granite type coarse aggregate of nominal size 20 mm. As per IS: 2386 (part III) – 1963, laboratory tests were conducted on coarse aggregate to determine the different physical properties.

Polypropylene Fibre : Polypropylene fibres of length 12mm is to be used for the study Fig. 3 shows the polypropylene fibres.

Fig. 3 Polypropylene fibres

Superplasticiser :In order to achieve the desired workability, poly carboxylate ether based new range water reducing admixture, Cera Hyperplast XR–W40 is to be used as the superplasticiser. Cera Hyperplast XR–W40 is available in liquid, which is dispensed into the concrete along with mixing water.

Fig. 4 Superplasticizer

Water :Drinking water directly drawn from the college water supply line is to be used for the entire casting work.

C. Mix design
The mix was designed as per IS 10262 -2009 for M 30 mix. Table 1 gives the mix proportion for the Shrinkage Compensating Concrete.

TABLE 1:MIX PROPORTIONS FOR M 30 CONCRETE MIX

Mix Designation	SHCC 0	SHCC 1	SHCC 2	SHCC 3	SHCC 4
Cement (kg/m^3)	413.33	413.33	413.33	413.33	413.33
Fine Aggregate (Kg/m^3)	392.32	392.32	392.32	392.32	392.32
Coarse Aggregate (Kg/m^3)	827.84	827.84	827.84	827.84	827.84
Polypropylene Fibre (Kg/m^3)	4.9	4.9	4.9	4.9	4.9
Metakaolin (Kg/m^3)	81.6	81.6	81.6	81.6	81.6
Plaster of Paris (Kg/m^3)	0	10.33	20.66	30.99	41.32
Water (kg/m^3)	186	186	186	186	186
Superplasticizer (kg/m^3)	0	13.68	27.52	41.50	55.63

D. Details of number of specimens

Table 2 gives the details of number of specimens cast.

TABLE 2 DETAILS OF NUMBER OF SPECIMENS

Sl No	Property	Specimen	Size (mm)	Numbers
1	Compressive Strength	Cube	150X150 X150	45
2	Splitting Tensile strength	Cylinder	150 dia,300 ht	15
3	Flexural Strength	Beam	400X100 X100	15
4	Shrinkage	Cube	100X100 X100	30
5	Durability	Cube	100X100 X100	135
Total 240 nos				

E. Casting of specimens

The moulds used for casting cubes, cylinders and beams were cleaned thoroughly. In order to prevent adhesion of concrete with the inner surface of the moulds and to prevent leakage a thin layer of oil was applied to inner surface of the moulds. The joints between the section of the mould were applied with a thin coat of mould oil to ensure that no water escape during filling . Moulds of size 150 mm x 150 mm x 150 mm were used to cast cubes for compressive strength tests. Cylindrical moulds of size 300mm height and 150 mm diameter were used to cast cylinders for splitting tensile strength tests. Beam specimens of size 500 mm x 100 mm x 100 mm were cast for performing flexural tests on beams. The concrete was then placed in to the moulds (cubes, beams & cylinders), which were already oiled, and compacted by a tamping rod. Tests were performed for compressive strength at ages of 3,7 and 28 days. Splitting tensile strength and flexural strength were found out at 28 days.

F. Curing

After 24 hours the specimens were demoulded and kept submerged in a curing tank till testing.

G. Tests on specimens

1. Study on workability
    - Slump test
    - Compacting factor test
2. Study on strength
    - Compressive strength test
    - Splitting tensile test
    - Flexural strength test
3. Study on durability
    - Sea water attack
    - Sulphate attack
    - Acid attack
    - Alkali attack
4. Study on shrinkage

III. RESULTS AND DISCUSSION

A. General: Tests were conducted on fresh concrete as well as on hardened concrete. Slump test and workability test were done on fresh concrete. Tests on hardened concrete include compressive strength, splitting tensile strength and flexural strength tests. The durability of concrete as well as the change in length due to shrinkage was also studied.

B. Properties of fresh concrete

Mix	Slump value (mm)	Compaction factor
SHCC 0	48	0.892
SHCC 1	37	0.857
SHCC 2	33	0.845
SHCC 3	28	0.768
SHCC 4	22	0.735

C. Properties of hardened concrete

Compressive strength test of concrete cube specimens:Out of the many tests applied to concrete, this is the most important test which gives an idea about all the characteristics of concrete. By this test it is possible to judge whether concreting has been done properly or not. For cube compressive tests specimens of size 150 mm x 150 mm x 150 mm are normally used. Preparation of specimens and testing was done as per IS: 516-1959. The specimens were cast with the required mix proportions and cured for obtaining the 3 days, 7 days and 28 days cube compressive strength. The cured cube specimens were tested in a 3000 kN capacity compression testing machine and loaded till failure.

Compressive Strength is one of the most important property of hardened concrete. According to the results it is observed that the compressive strength increases at 2.5% addition of Plaster of Paris and on further increase in the percentage of Plaster of Paris the compressive strength decreases. Figure 5 shows the variation in the compressive strength of cube specimens.

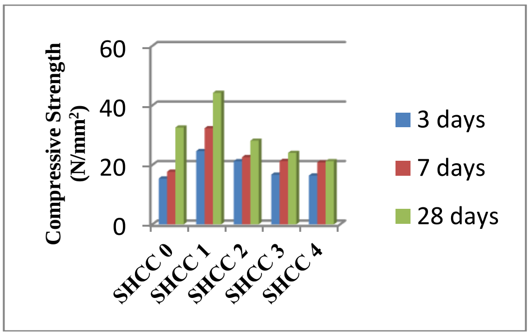

Fig 5: variation of compressive strength of cube specimens.

Splitting tensile strength test of concrete cylinder specimens: This test is an indirect test for determining the tensile strength of concrete. The splitting tensile strength test of concrete specimens was conducted on cylinders of size 150 mm diameter and 300 mm height at 28 days of water curing. The test was conducted as per IS: 5816-1999. Test Cylinders stored in water were tested immediately on removal from water and wiping off the surface water and grit from the specimen. The actual dimension and weight of the specimen was also noted. The specimens were placed with its axis horizontal between the plates of testing machine and load was applied. Load was applied uniformly till failure.

Splitting tensile strength test was carried out on cylindrical specimens placed horizontally on the compression testing machine. The load was applied until failure and the results of the splitting tensile strength are represented as a graph in Fig 6.The variation of the splitting tensile strength is similar to that of the compressive strength.

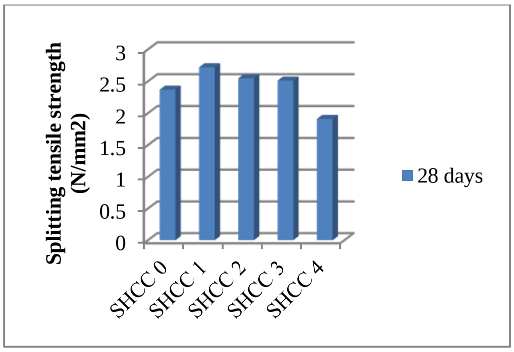

Fig 6:Variation of the splitting tensile strength

Flexural Strength of Concrete beam specimens: The flexural test of concrete was conducted on prisms of size 500 mm x 100 mm x 100 mm over an effective span of 400 mm, under symmetrical two point loading. Testing was done at 28 days of water curing and conforming to IS: 516-1959. Prisms stored in water were tested immediately on removal from water and wiping off the surface water and grit from the specimen. The actual dimension and weight of the specimen was noted. The specimen was kept on two roller supports of 38 mm diameter on the testing machine, the distance between the centers being 400 mm. The load was applied hydraulically through two similar rollers mounted at third points of the supporting span, till its failure.

The flexural strength was found out by testing specimens under two point loading. There was an increase in the flexural strength upto 5 % addition of Plaster of Paris and thereafter it decreased. Fig 7 shows the graphical representation of the variation in the flexural strength of the specimens.

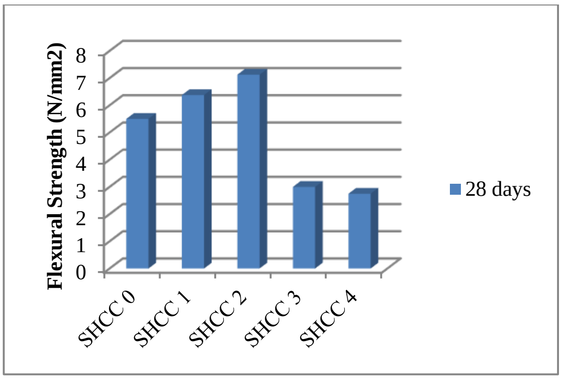

Fig 7 :variation in the flexural strength of the specimens.

D. Durability study

1. General

Designers of concrete structures have been mostly interested in the strength characteristics of the material for a variety of reasons, they must now become durability conscious. Whereas properly constituted, placed, and cured concrete can be durable under most natural and industrial environments, cases of premature deterioration of concrete structures do occur and they provide valuable lessons for control of factors responsible for the lack of durability. Water is generally involved in every form of deterioration and, with porous solids the ease of penetration of water into the solid usually determines its rate of deterioration. Specimens of size 100 mm x 100 mm x 100 mm were cast and immersed in water for 28 days. The cured specimens are then immersed in various solutions and the compressive strength and weight loss was calculated at 28 days, 56 days and 90 days.

2. Sea water attack

Concrete exposed to sea water is wetted by a solution of salts, principally sodium chloride and magnesium sulphate. Damage to concrete, if it occurs, usually results from failure to use good practices in concrete construction, and often is the result of freezing and thawing or wetting and drying as much as or more than the results of the effects of sea water as such. Magnesium sulphate may attack most, if not all, of the constituents of hardened Portland cement paste, especially the Aluminate constituent chlorides may promote corrosion of steel and alkalies may participate in alkali-aggregate reaction.

The test was conducted by curing the specimens of size 100 mm x 100 mm x 100 mm cubes in sea water for 90 days. The loss of weight of the specimen and the compressive strength are tested. Figure 8 shows the strength loss and figure 9 shows the weight loss of the specimens in sea water.

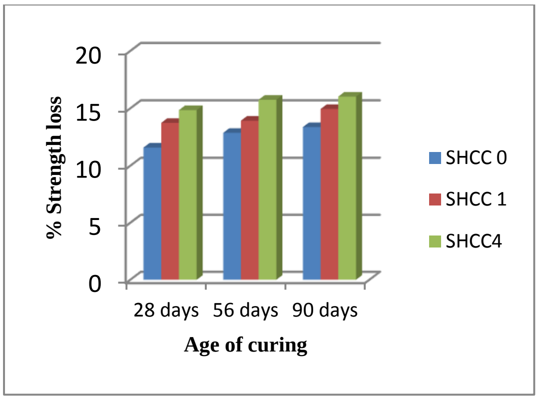

Fig 8: strength loss of the specimens in sea water.

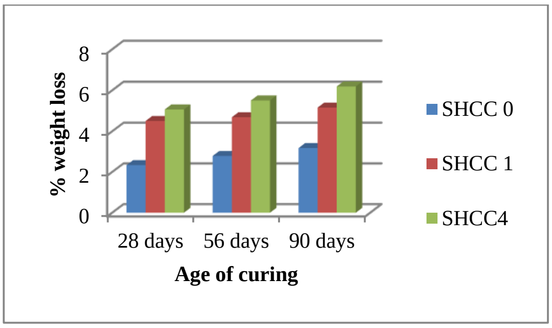

Fig 9: weight loss of the specimens in sea water

3. *Sulphate Attack*

Most soils contain some sulphate in the form of gypsum $CaSO_4 . 2H_2O$ (0.01 to 0.05 percent expressed as SO_4); this amount is considered harmless to concrete. The solubility of gypsum in water at normal temperatures is rather limited (approximately 1400 mg/l SO_4). Higher concentrations of sulphate in groundwater are generally due to the presence of magnesium, sodium, and potassium sulphates. Ammonium sulphate is frequently present in agricultural soil and water. Effluents from furnaces (that use high-sulphur fuels) and from chemical industry may contain sulphuric acid. Decay of organic matter in marshes, shallow lakes, mining pits, and sewer pipes often leads to the formation of H_2S gas which is transformed into sulphuric acid by bacterial action. The water used in concrete cooling towers may also contain a high concentration of sulphate due to evaporation. Thus, it is not uncommon to find potentially deleterious concentrations of sulphate in natural and industrial waters.

The test was conducted on specimens of size 100 mm x100 mm x 100 mm cubes. The specimens are then immersed in 5 % Sodium Sulphate solution for 90 days. The loss of weight of the specimen and the compressive strength are tested. Figure 10 shows the loss in strength and figure 11 shows the weight loss of specimens immersed in Sodium Sulphate solution.

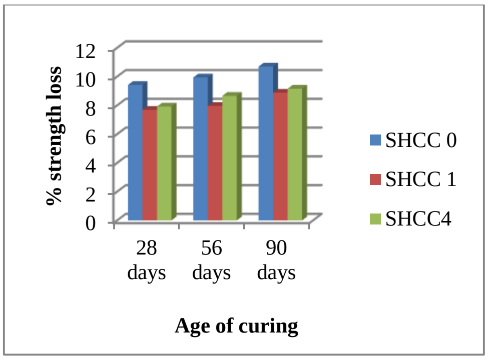

Fig 10: strength loss of specimens in Sulphate solution

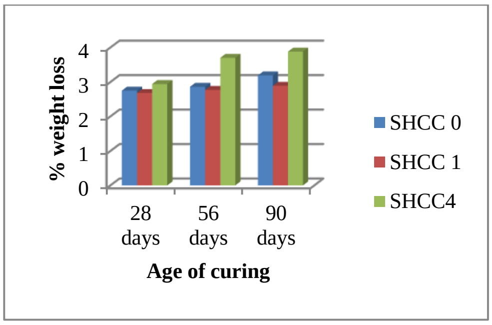

Fig 11: Weight loss of specimens in Sulphate solution

4 . *Acid Attack*

Acidic attack represents a topic of increasing significance, owing to the spread of damages of concrete structures in both urban and industrial areas. Cement type is an important factor affecting performance of cement based materials in an aggressive environment. The spectrum of aggressive acidic media is wide. Acidic attack usually originates from industrial processes, but it can even be due to urban activity. Even natural exposure conditions may cause acid attacks. Free acids in natural waters are rare. Exceptions are carbonic waters and sulphurous and sulphuric acids in peat waters. Several organic and inorganic acids may occur in shallow regions of sea-water as a consequence of bacteriological activity. Significant quantities of free acids in plants and factories may be found. In these cases, the concentration of acid, which comes in contact with concrete structures, may reach to high values.

The test was conducted on specimens of size 100 mm x100 mm x 100 mm cubes. The specimens are then immersed in 3 % Sulphuric acid solution for 28, 56, 90 days. After exposure to acids, the specimens were washed in order to remove the porous layer of the corrosion products such as soft and crystallized acidic materials or calcium salts. Loss in weight of the specimens was measured. Compressive strength of the specimens are also tested. Figure 12 shows the loss in strength and figure 13 shows the weight loss of specimens immersed in acid.

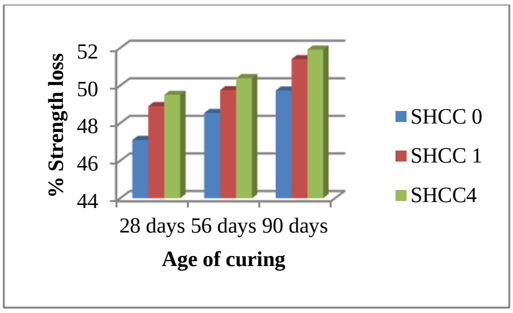

Fig 12: loss in strength of specimens immersed in acid

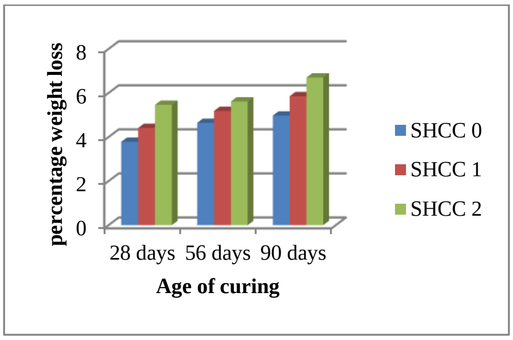

Fig 13: weight loss of specimens immersed in acid

5 . Alkali Attack

Alkali aggregate attack is a chemical reaction of alkali in concrete and certain alkaline reactive minerals in aggregate producing a hygroscopic gel which, when moisture present, absorbs water and expand. Gel expansion causes cracking in the concrete. The number of structures affected by alkali is relatively small comparing to the total number of concrete structure built, but the problem has been found in many countries around the world.

For alkaline attack test concrete cube of size 100 x100 x 100 mm are prepared. The specimen are cast and cured in mould for 24 hours, after 24 hours, all the specimen are demoulded and weighed. It was then immersed in 5% sodium hydroxide (NaOH) solution for 90-days. After 28, 56, 90 days of immersing in alkaline solution, the specimens are weighed and loss in weight and hence the percentage loss of weight was calculated. The compressive strength of the specimens was also tested. Figure 14 shows the loss in strength and figure 15 shows the weight loss of specimens immersed in alkali.

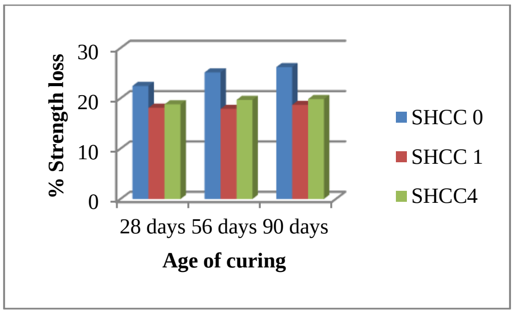

Fig 14: loss in strength of specimens immersed in alkali

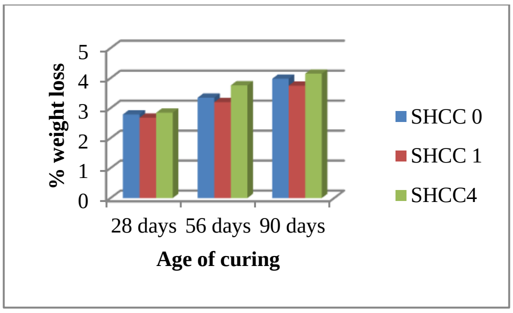

Fig 15: shows the weight loss of specimens immersed in alkali

E. Shrinkage Test On Concrete

Knowledge of the shrinkage characteristics of concrete is a necessary starting point in the design of structures for crack control. Such knowledge will enable the designer to estimate the probable shrinkage movement in reinforced or prestressed concrete and the appropriate steps can be taken in design to accommodate this movement.

When concrete is exposed to its service environment it tends to reach an equilibrium with that environment. If the environment is a dry atmosphere the exposed surface of the concrete loses water by evaporation. The rate of evaporation will depend on the relative humidity, temperature, water-cement ratio and the area of the exposed surface of the concrete. The first water to be lost is that held in the large capillary pores of the hardened concrete. The loss of this water does not cause significant volume change. However, as drying continues, loss of water from small capillary pores and later from gel pores takes place. With the reduction in the vapour pressure in the capillary pores, tensile stress in the residual water increases. Tensile stresses in the capillary water are balanced by compressive stresses in the surrounding concrete and as a result the concrete shrinks. Evaporation of gel water changes the surface energy of the solid phase and causes further shrinkage. Drying shrinkage makes up a portion of the total deformation that is observed in a concrete member.

1. Measurement of changes in length using a length comparator

Comparators are the instruments calibrated by means of end standards to measure unknown dimensions. The purpose of a comparator is to detect and display the small differences between the unknown linear dimensions and the length of the standard. The difference in lengths is detected as a displacement of a sensing probe.

The comparator for determining length changes of specimens consists of a dial micrometer graduated to read in 0.002-mm units .The terminals of the comparator shall be plane, polished and heat-treated. They shall be fitted with collars held in place with set screws. Prior to the moulding of specimens, the outside joints of the mould and the contact lines of the mould and base plate shall be sealed to prevent loss of mixing water from a freshly moulded specimen. A reference bar is also provided with the length comparator.

Place the reference bar in the instrument in the same position each time a comparator reading is taken. Rotate specimens slowly in the measuring instrument while the comparator reading is being taken. Record the minimum reading of the dial if the rotation causes a change in the dial reading. Place the specimens in the instrument with the same end up each time a comparator reading is taken.

The length change at any age was calculated. Fig 16 shows a length comparator

Fig 16 Length comparator

Specimens of size 100 mm x 100 mm x 100 mm were cast for the shrinkage test.The change in length of the specimen due to shrinkage was measured by means of the length comparator.

The 7 days shrinkage in concrete was found to decrease by 77% for SHCC 4 .As the percentage of Plaster of paris is increased the shrinkage was found to decrease.Moist cured specimens showed better resistance to shrinkage than water cured specimens at all percentages of Plaster of Paris.Figure 17 and 18 shows the percentage change in length of water cured and moist cured specimens.

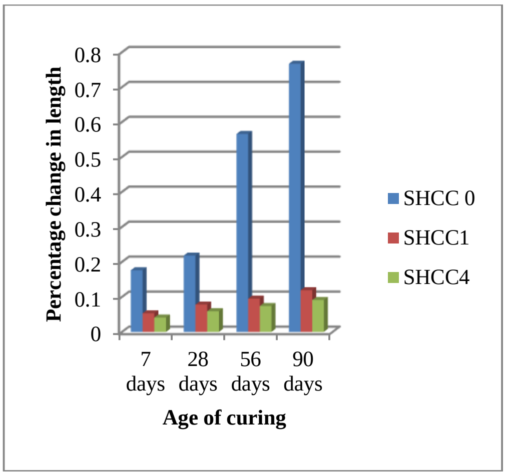

Fig 17 Percentage change in length of water cured specimens

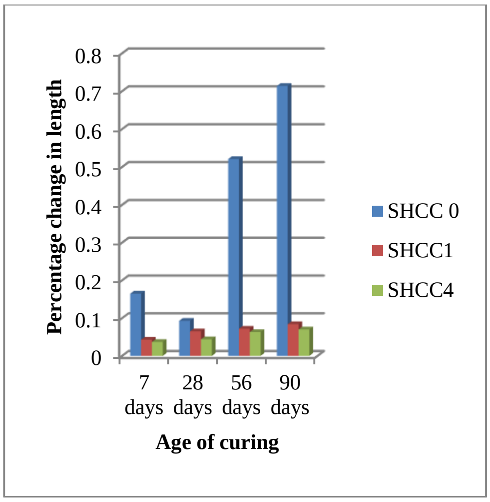

Fig 18 Percentage change in length of moist cured specimens

IV.CONCLUSION

In my thesis work five different mixes were made. First is the control mix which is M 30 mix called as SHCC 0. The other mixes namely SHCC1, SHCC 2, SHCC 3 and SHCC 4 were made by varying the percentages of Plaster of Paris from 2.5% to 10%. The main conclusions drawn from the work are as follows.

(i) The workability of concrete was found to decrease as the percentage of Plaster of Paris was increased. This may be due to the reason that this additive is a good water absorbent. This reduces the water content in the mix thereby reducing the workability.

(ii) The compressive strength of concrete cubes was found to increase by 36% for the mix SHCC1.This may be due to the addition of Polypropylene fibres. On further increasing the percentage of Plaster of Paris the compressive strength of concrete cubes was found to decrease. The Compressive strength of gypsum products directly depends on the unreacted water in mix and may change the crystal morphology of gypsum crystals formed during setting and lead to early failure of the material when stressed. This may be considered as the decrease in compressive strength on increasing the percentage of Plaster of Paris.

(iii) The splitting tensile strength was found to increase by 15 % for the mix SHCC1.

(iv) The flexural strength was found to increase by 30% for the mix SHCC2. Polypropylene fibres along with the expansive agent, Plaster of Paris improved the flexural resistance of the mix.

(v) The durability of the mix was found to improve in sulphate and in alkali.

(vi) Results show that addition of Plaster of Paris decreased the drying shrinkage in concrete. The drying shrinkage is even more reduced when the specimens are moist cured that water cured.

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