# A Study on The Shrinkage Control of Concrete Using Synthetic Fibers

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***Abstract-*** *Loss of water by evaporation from the surface of the concrete or by the absorption by aggregates is believed to be the reason of shrinkage, which reduces durability and life of a concrete. One of the methods for reducing shrinkage is addition of fibers. From the available literature, it is seen that synthetic fibers have shown encouraging results in reducing shrinkage effects.*

*In the present work, an attempt is been made to study the effect of different fibers and different dosages on the shrinkage of concrete. In this experimental program, concrete containing various synthetic fibers viz, polypropylene, glass and steel fibers in varying dosages are going to investigated. In order to estimate the effectiveness in preventing the growth of the cracks, an easy methodology, based on image analysis (IA), has been studied.*

***Keywords***- Synthetic fibers, Environmental chamber, Image analysis.

## I. INTRODUCTION

Shrinkage of concrete is the time-dependent strain measured in an unloaded and unrestrained specimen at a constant temperature.

Concrete is subjected to changes in volume either autogenously or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete. Volume change in fresh concrete occurs primarily due to rapid loss of surface bleed water on evaporation. In addition, the cracks allow water and other chemical agents to penetrate into concrete and get in touch with steel reinforcements, leading to reinforcement corrosion, even to breakage.

All this leads to shrinking of cement paste. The resultant restraint offered by aggregates leads to cracking on the surface of the fresh concrete. Fresh concrete is susceptible to shrinkage cracking especially during hot, windy and dry weather conditions. When the evaporation rate is higher than bleeding rate, it can cause high tensile stresses that may be sufficient to exceed the tensile strength of concrete. If the surface cracks that develop as a result of shrinkage remain unnoticed, they become channels for external deteriorating agents and reduce long-term durability.

Recent studies have shown that the early loss of moisture from fresh concrete can produce large tensile stresses in the concrete at a very early age. Early-age cracking can occur when volumetric changes caused by temperature reduction, chemical reaction and moisture loss are prevented. The reduction of volume reduction results in the development of tensile stress in concrete. If these tensile stresses exceed the tensile strength of concrete, a visible crack can be expected to occur. In addition to free shrinkage and tensile strength, several other factors can also influence the potential for early-age cracking including the magnitude and rate of shrinkage, the degree of restraint, stress relaxation, time-dependent material property development, the geometry of the structure and fracture resistance of material. Early-age cracking is problematic because it is responsible for the increase in the water penetration, de-icing chemicals, sulphates, and other corrosive or aggressive agents into concrete, thereby accelerating the corrosion of reinforcing steel. The structures that are particularly sensitive to the above-described phenomenon include pavements, industrial floors, bridge decks, walls and tunnel linings. The above is due to the low volume/surface ratio and to the fact that such structures typically have a high rate of shrinkage and, moreover, they are frequently exposed to high concentrations of corrosive agents. Due to the high impact associated with the repair of a damaged structure, significant interest exists for the improvement of the durability of the structural elements given that concrete restoration is expensive. The durability improving has typically resulted in the use of higher strength and lower permeability that may be more susceptible to early-age cracking, especially if they are insufficiently cured. In order to better control cracking and its adverse effects on durability, specifications have been developed to limit early-age cracking. At present, there are no standard testing methods to characterize plastic shrinkage cracking in plain and fiber reinforced concretes. Various specimen geometries have been used in the past to simulate a realistic condition of plastic shrinkage cracking.

Consequently, curing is a unique traditional method to avoid such problems. However, in certain applications, due to severe environmental conditions, the curing does not fit the purpose in the prevention of cracks. For the above said, fibers have been incorporated in concrete to reduce or prevent the propagation of early age shrinkage cracking. The fibers dispersed in the concrete matrix implement a three-dimensional reinforcement and are able to absorb tensile stresses acting in any direction. Moreover, the fibers prevent their rapid spread and especially limit their opening. Therefore, fiber reinforced concrete shows also a higher capacity to dissipate energy associated with impulsive loads (e.g. shocks and impacts). Also, fibers reduce the overall shrinkage strain and lower the possibility of tensile stresses exceeding the tensile strength. If the cracks do occur, fibers bridge them effectively and prevent them from growing in both longitudinal and transverse directions.

To understand this aspect more closely, shrinkage can be classified in the following way:

(a) Plastic Shrinkage

Shrinkage of this type manifests itself soon after the concrete is placed in the forms while the concrete is still in the plastic state. Loss of water by evaporation from the surface of concrete or by the absorption by a sub-grade is believed to be the reasons of plastic shrinkage.

(b) Drying Shrinkage

The drying shrinkage is an everlasting process when concrete is subjected to drying conditions, as the hydration of cement is an everlasting process.

(c) Autogenous Shrinkage

In a conservative system i.e. where no moisture movement to or from the paste is permitted, when the temperature is constant some shrinkage may occur. The shrinkage of such a conservative system is known as autogenous shrinkage.

(d) Carbonation Shrinkage

Carbon dioxide ($CO_2$) present in the atmosphere reacts in the presence of water with hydrated cement. Calcium hydroxide gets converted to calcium carbonate and also some other cement compounds are decomposed. Such a complete decomposition of calcium compound in hydrated cement is chemically possible even at the low pressure of carbon dioxide ($CO_2$) in the normal atmosphere.

## II. FACTORS AFFECTING SHRINKAGE

The shrinkage of concrete is affected by so many factors. The most important factor is the drying condition or the humidity in the atmosphere. Shrinkage will not occur if the concrete is placed in one hundred percent relative humidity.

The shrinkage rate will decrease rapidly with time. It has been documented that fourteen to thirty-four percent of the twenty-year shrinkage will occur within two weeks of it being poured. Shrinkage will be about sixty-six to eighty-five percent of the twenty-year shrinkage within one year of the concrete being poured.

The water to cement ratio will influence the amount of shrinkage that occurs. The concrete's richness also affects the shrinkage. The process of swelling and then drying affects the concrete's integrity and the shrinkage. You can also read about sulphate attack on concrete here.

## III. NEED FOR RESEARCH

- To reduce cracks in the concrete.
- To reduce permeability and thus reduce the bleeding of water.

## IV. METHODOLOGY

1) Materials used and mix proportion

Ordinary Portland cement was used for the concrete mixtures. Crushed sand with a specific gravity of 2.7 was used as the fine aggregate, while crushed granite of specific gravity 3.4 was used as coarse aggregate. The fibers used in the study were hooked steel, polypropylene and AR-glass, obtained from local manufacturers.

Two trial mixtures were prepared to obtain target strength of 60MPa and 40MPa at 28 days. Concrete was mixed using a rotary pan mixer of 100 kg capacity. The coarse aggregate, fine aggregate and cement were first mixed dry for a period of 2-3 min. and then mixed thoroughly by the addition of water in a specified mixing proportion.

2) Specimen dimension and casting

The specimen mould used was of dimension 325mm X 100mm X 40mm and was made of wooden laminated board.The casting was done in two layers. First layer was the substrate base layer and the second one was the overlay layer. Substrate bases are made from high strength concrete ($f_c \approx$ 60MPa). Therefore, for a substrate base, a trial mixture is prepared to obtain target strength of 60MPa at 28days. The substrate base is cast in the mould provided with protuberances. These bases are deliberately left somewhat smaller than the actual size of overlay.

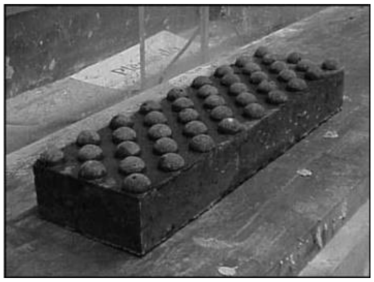

Fig. 1) Substrate base.

The overlay layer was prepared to obtain target strength of 40MPa at 28days. This overlay mixture is placed on a substrate base to avoid curling up at the ends. This way, the overlay is able to wrap over the base and is thus restraint from upward curling. The entire operation of placement of overlay layer, external vibration and finishing is completed in less than 10 minutes.

The entire assembly is then transferred to the environmental chamber. After 2±1 hr. the chamber is open and sides of the moulds are removed to expose the specimen to a uniform state of drying. The chamber is then closed and the environmental parameters like temperature, relative humidity and air velocity are maintained for a next 22hrs.

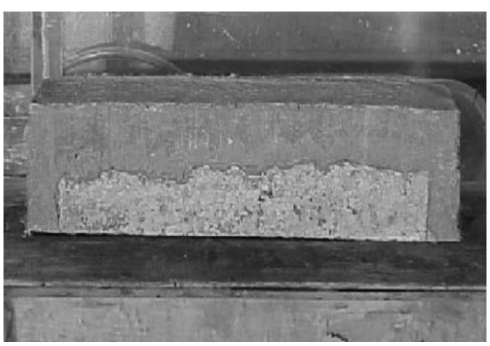

Fig. 2) Overlay layer of concrete on a substrate base.

3) Environmental Chamber

Environmental chamber measuring 900mm X 600mm X 400mm is used. The chamber is made of acrylic transparent glass so that all three specimens can be observed. The environmental chamber is equipped with high speed fan to accelerate drying of concrete. Also it is equipped with a digital anemometer which is capable of recording and maintaining the environmental parameters such as air velocity, temperature and relative humidity.The chamber is accelerated with a high speed fan of air velocity 4.5m/s, relative humidity 45±1% and temperature 31±1ºC. To maintain the relative humidity, a bowl filled with fresh tap water is kept inside the environmental chamber. These environmental parameters are obtained and maintained for a period of 24hrs in the environmental chamber.

Fig. 3) Environmental Chamber

Fig. 4) Specimen placing in the environmental chamber just after the casting in moulds.

Fig. 5) Specimen demolding after 2-3 hrs. of casting

4) Image analysis

Images of the crack were captured using an optimal zoom camera based on crack visibility; some captured images of different concrete specimens are shown below. The captured images were processed and edited with image analysis software to get a clear crack profile using various mathematical operations such as binarization, thresholding, cleaning and filtering.

Recently, image analysis has become a powerful tool that can be used in order to study cementitious materials at different scales. Image analysis has been used in order to better understand the development of the cracks and the microstructure of the cement-based systems determines the orientation and dispersion of the reinforcing fibers and characterize the fracture process in concrete. Using the above cited technique, diverse sizes of cracks have been identified, from about 10 lm to several millimeters, depending on the field of interest. In the present study the detection of cracks and the evaluation of their size in terms of opening on the surface has been carried out 24 ± 2 h after casting. In the present paper using ImageJ, it is possible to analyze the acquired images and evaluate the size of the crack assigning measures, based on the pixels, showing different sizes. The length of crack was determined by using a curve-tracing tool in the image analysis software to trace the crack. At the end of such a process, the software is able to provide the following key parameters in order to characterize the crack from a dimensional point of view

- Area of the crack relating to the extent of the flat surface comprised within the perimeter of the crack;
- Length of the crack intended as the sum of the distances between end to end of each crack;
- Width of the crack defined as the distance from one side to the other of the crack, measured among all those cracks that form the pattern of the crack.

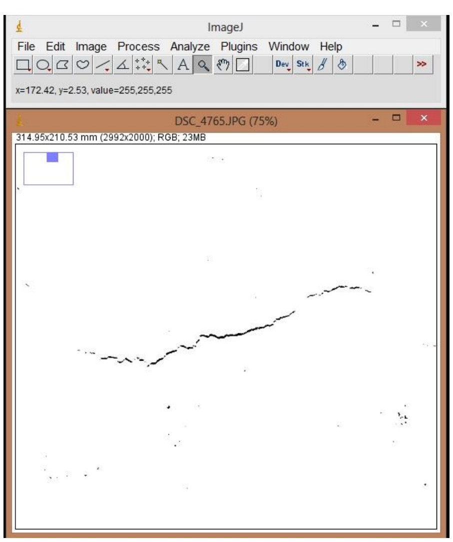


Fig. 6 Image-J software application frame.

## V. PROCEDURE FOR CASTING AND OBSERVATION

In this experiment, casting of 3-cubes of each sample was carried out. i.e. 3-cubes for plain cement concrete, 3-cubes for AR-Glass fibers, 3-cubes for Polypropylene fibers and 3-cubes for Steel fibre. Also we are adding fibers in the concrete in three different proportions as confirmed by Fiber Suppliers as mentioned below.

- Glass fibers: - 200kg, 250kg, 300kg per M3
- Steel fibers: - 500kg, 550kg, 600kg per M3
- Polypropylene fibers: - 800kg, 900kg, 1000kg per M3

The following steps are to be considered for casting and observation.

- Casting of sub grade base layer
- Casting of overlay layer
- Placing of specimen in environmental chamber & maintaining environmental parameters
- Observation of the cracks.

Concrete of compressive strength of 60MPA (at 28days) is casted as sub grade base layer in a mould with protuberances. These moulds are kept for 1day under curing condition. After 1day of casting and curing process, the specimens are then replacing in a wooden mould of size 300mm X 100mm X 40Mmm for the next casting procedure of overlay layer on it.

Concrete of compressive strength of 40MPA (at 28days) is then casted over a sub grade base layer. After the casting is done, the moulds are placed in the environmental chamber for the further observation purpose. The overlay layer of concrete specimen is casted with plain cement concrete and the mix proportion of fibre mix concrete in the proportion as mentioned above.

After doing all the casting process, the specimen are then shifted to environmental chamber where environmental parameters such as air velocity, temperature and relative humidity are maintain over a period of 7days. After the 2±1 hr casting and placing the specimen under the environmental chamber, the specimen are then removed from the moulds and they again undergo the environmental chamber for a period of 7 days for further observation process. The environmental parameters are maintained and measure by the instrument called Digital Anemometer in front of the chamber. The anemometer is able to measure the environmental parameters at once.

Fig. 7 Specimen placing in the environmental chamber just after the casting in moulds.

Fig. 8 Specimen demolding after 2 hrs. of casting

## VI. RESULTS AND DISCUSSION

### 1. Crack observation:

In the case of plain concrete, a fine hair-line crack running throughout the width of the specimen was observed above the central stress riser. This fine crack, which could have possibly been caused due to settlement, was found to widen upon further drying. In the case of fibre reinforced concrete specimens, the appearance of the crack took a relatively longer time. This could be attributed to the availability of bleed water on the top surface, which delays drying of the surface. A single crack over the central stress riser was found to run almost straight throughout the width of the specimen. However, for fibre concretes the crack was rather short, discontinuous and took a tortuous path around aggregate pieces or along fibers. In addition, some hairline cracks were noticed to branch out from the main cracks in the case of hybrid fibre concretes.

### 2. Plastic Shrinkage Cracking

All the specimen was placed in the environmental chamber for the period of 24hrs. measuring and maintaining the environmental parameter such as temperature, relative humidity and wind velocity in the range of 31±1ºC, 45±1% and 4.0 – 4.8 m/s respectively. The surfaces of typical plastic shrinkage cracking specimen with the different fibers are shown in figures below. It can be observed that the cracks formed generally parallel to the width of the specimen.

Fig.8 Plastic shrinkage crack in Plain concrete specimen

### 3. Crack Measurement

The crack measurements comprise of the crack length, crack width and total crack area. Images of the crack were captured using an optimal zoom camera based on crack visibility; some captured images of different concrete specimens are shown below. The captured images were processed and edited with image analysis software to get a clear crack profile. The length of crack was determined by using a curve-tracing tool in the image analysis software to trace the crack. The length was then calculated in terms of pixels, which were converted to length units (mm) using the calibration scale. The total crack area was then calculated on the binarized image using the software.

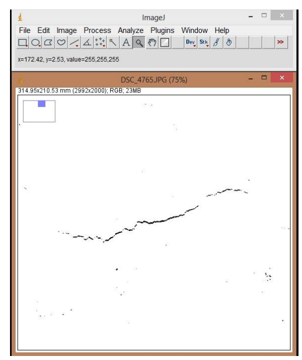

Fig. 9 Example of processed image of concrete specimen

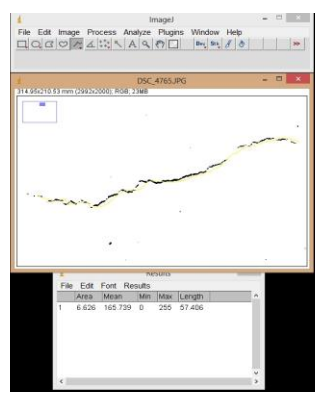

Fig. 10 Analysis and measurement of crack.

Experimental results indicate that the maximum crack width was observed in the case of plain concrete; with fibre addition, no cracks were found. The total crack area reduced with increased addition of non-metallic fibers. Typical test results for the proposed test method are described in the context of two reinforcing fibers: AR- Glass Fiber and Polypropylene.

## VII. CONCLUSION

The present study has led to following conclusions:

1. The use of fibers confirmed to be very effective in the width reduction of the cracks and, even if not so significantly, in the length reduction.
2. Basing on the tests, it seems that the magnitude of shrinkage is primarily influenced by relative ambient humidity of the environment where the concrete sample is kept. This phenomenon is related to the amount of water and rate of drying of concrete, the higher the humidity the longer the expansion lasts.
3. The most important parameter confirmed is the aspect ratio, assuming that the number of fibers is about of the same order of magnitude.
4. The software Image-J has proven effective not only in measuring the width of the cracks, but also the length by following the path, tight curves and right angles included.
5. Results illustrate that the method can characterize such cracking with reasonable accuracy, and it is particularly suitable for repair and overlay materials.
6. Results also indicate that fiber reinforcement is considerably effective in reducing shrinkage induced cracking in cementitious materials.
7. The addition of fibers results in a certain delay in cracking formation.
8. The addition of fiber at the time of mixing of concrete, cubes becomes porous that means the w/c ratio has been decreased due to this type of mixing.

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