CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete experiences volume changes throughout its service life. This total in-service volume change is the result of applied loads and shrinkage. When loaded, concrete experiences an instantaneous recoverable elastic deformation and a slow inelastic deformation called creep. Creep of structures is composed of two components, basic creep or deformation under constant load without moisture loss or gain, and drying creep. Drying creep is a time-dependent deformation of a drying specimen under constant load minus the sum of the drying shrinkage and basic creep. Deformation of concrete in the absence of applied loads is often called shrinkage. There are four main types of shrinkage in concrete i.e. plastic, autogenous, carbonation and drying shrinkage. This chapter includes the review of available literature on the influence of the type of the cement and fineness, mineral and chemical admixtures, ambient conditions, size of specimen, aggregate, various testing methods and remedial measures on plastic shrinkage cracking of concrete and the shrinkage mechanism is also addressed.

2.2 SHRINKAGE MECHANISM

There are four main types of shrinkage in concrete i.e. plastic, autogenous, carbonation and drying shrinkage.

Plastic shrinkage is due to a very rapid loss of moisture from the freshly laid concrete within a few hours of placement while the concrete is still plastic and before it gains any significant strength (Soroushian, P., et al, 1998; Powers T.C., 1968). This loss is generally caused by a combination of factors such as air and concrete temperature, relative humidity and wind velocity (Aitcin, P.C., et al, 1997). These factors can combine to cause high rates of surface water evaporation from concrete in the plastic state. When the moisture from the surface of freshly placed concrete evaporates faster than that which is replaced by bleed water, the surface concrete shrinks. Due to the restraints provided by
the interior concrete, tensile stress develops in the stiffening plastic concrete on the face zone which is weak and results in shallow cracks of varying depths which may form a random polygonal crack pattern. Often, these cracks will be parallel to each other. They will be generally wide at the surface and tend to become narrow towards the depth (Wittman F.H., 1976; Cohen, M.D., et al, 1990). Plastic cracks are frequently observed above reinforcing steel or at locations where there is a sudden change in cross-sectional thickness due to differential settlement (Weyers, R.E., et al, 1982).

Autogenous shrinkage, also known as self desiccation or chemical shrinkage, is associated with the loss of water from the capillary pores due to the hydration of the cement and develops isotropically within the concrete mass (Aitcin, P.C., et al, 1997; Person, B., 1997). Jensen, O.M., et al, (1996) define self desiccation as the lowering of internal relative humidity in a closed isothermal cement paste system resulting from the internal volume reduction associated with the hydration of Portland cement. This type of shrinkage tends to increase at higher temperatures and at higher cement contents. In general, it is relatively small and is not distinguished from plastic shrinkage of concrete. The autogenous shrinkage will be in the order of about 100 * 10⁻⁶ (Shetty, M.S., and Neville, A.M. 1998).

Carbonation shrinkage is caused by the chemical reaction of various cement hydration products with the carbon dioxide present in the air. The American Concrete Institute defines carbonation as the reaction between carbon dioxide and calcium compounds, especially in cement paste, mortar, or concrete to produce calcium carbonate (ACI Committee 116, 1990). This type of shrinkage is usually limited to the surface of the concrete.

Drying shrinkage is defined as the volumetric change due to drying environment. Drying shrinkage occurs in the hardened concrete as free water evaporates from the capillary pores. Capillary tension theory explains that drying shrinkage is caused by the capillary tension occurring in the moisture existing in the pores in the cement gel. The rate of progression of drying shrinkage depends on the ratio of volume to exposed surface area of the concrete specimen. Drying shrinkage decreases as this ratio increases (Aitcin, P.C., et al, 1997).
2.3 INFLUENCE OF CEMENT TYPE AND FINENESS

Coutinho, A.S., (1959) conducted an experimental test programme to identify the influence of the type of cement on the cracking tendency and he concluded that (a) Natural cement as well as the concrete prepared with it have an extremely low cracking tendency due to the high creep (or high relaxation) of this cement. (b) High early strength Portland cement has high cracking tendency due to its slight creep (or relaxation). Concrete prepared with it has a higher cracking tendency than concrete of normal Portland cement. (c) Aluminous cement has the highest cracking tendency of all the cements studied because of its extremely small creep and the very large increase in its initial shrinkage.

Bennet, E.W., et al, (1970) studied the unrestrained and restrained shrinkage and cracking of concrete by a ring test made with Portland cement of three different grades of fineness. The results revealed that the shrinkage may be increased with finer cement at an early age apparently on account of the faster hydration. Also, the use of finer Portland cement resulted in somewhat earlier cracking, but not comparable with very early cracking of concrete associated with calcium chloride or with high alumina cement.

Saito, M., (1991) examined the differences between expansive and ordinary cements and the role of aggregates with respect to shrinkage. It was determined that expansive cement in a mortar shows a large amount of shrinkage reduction. Expansive cement used in concrete had a more negligible effect on shrinkage. The aggregate plays a role in allowing the cement paste to change. Strain was measured within the aggregate particle. It was found that at the beginning of shrinkage, some cracks had already existed around the coarse aggregate particles embedded in the unreinforced and reinforced expansive cement concretes. The formation of cracks was found to lead to a partial loss of restraint of coarse aggregate particles against drying shrinkage.

Tazawa, E., et al, (1997) found that the cement composition has a greater influence on autogeneous shrinkage than drying shrinkage. Compared to normal Portland cement, larger autogenous shrinkage was observed for high early strength cement at an early age and blast furnace slag cement at later ages. Less autogenous shrinkage was observed for moderate heat cement paste and low heat Portland cement with high $C_2S$.
content. Autogenous shrinkage depends on the hydration of C₃A and C₄AF and it increases with increase in these compounds.

2.4 INFLUENCE OF AGGREGATE

**Almudaiheem, J.A., et al, (1987)** investigated the effect of specimen size on drying shrinkage. They found that shrinkage decreases with increasing aggregate content. All the mixes had water cement ratio of 0.40. The maximum aggregate size was 9.5 mm and the specimens were cured in lime-saturated water for 28 days. The mix consisted of either 50% or 60% aggregate content. The aggregate content had a more profound influence on shrinkage than the specimen size.

Smaller aggregates experience more uniform shrinkage. The type of aggregate, rather than the aggregate size, has an enhanced effect on the concrete shrinkage. Aggregate that shrinks considerably has a low rigidity compared to the compressive stresses developed by the shrinkage of the cement paste. These types of aggregate may also have a large water absorption value which will result in a concrete with higher shrinkage (**Troxell, 1996**).

**Saito, M., (1991)** studied the differences between expansive and ordinary cements and the role of aggregates with respect to shrinkage. River expanded shale was used as the fine aggregate with crushed stone and expanded shale being used as the coarse aggregate. Aggregates used in the mix were in the saturated surface dry state. All the mixes had a constant water cement ratio of 0.50. Shrinkage tests were conducted on 100 x 100 x 200 mm prism specimens. The specimens were placed in a controlled environment of 20 °C and 85% relative humidity for 24 hours. The specimens were then cured in water at the same temperature as above for 13 days. The specimens were then exposed to 20 °C and 60% relative humidity for 490 to 533 days. A strain gauge was placed inside an aggregate particle to examine the stress exerted on the aggregate by the cement paste. It was concluded that the elastic properties of the aggregate had a predominate effect on shrinkage. The lower the value of the Young’s modulus of the aggregate, the lower was the restraining effect of the aggregate on shrinkage. Light-weight aggregate in tests would be expected to show more shrinkage than a normal or heavy-weight aggregate. However, that was not the case, due to using the aggregate at a saturated surface dry condition. The
water in the pores of the aggregate had an influence on the drying shrinkage data. The light-weight aggregate used in this experiment showed that the shrinkage of light-weight concrete is more sensitive to change in aggregate content than that of concrete made with normal-weight aggregate.

Tazawa, E., et al (1997) investigated the influence of cementitious materials on autogenous shrinkage. The cement paste specimens were 20 x 20 x 160 mm, 40 x 40 x 160 mm prisms. Mortar specimens were fabricated with dimensions of 40 x 40 x 160 mm. Concrete specimens were 100 x 100 x 1200 mm prisms. Specimens were either sealed with aluminum tape, subjected to drying, or submerged in water. Length change was measured at 20 °C. The decrease in aggregate volume fraction was found to increase the sealed specimen shrinkage. The effect of the aggregate can be explained by both the reduction in cement paste content and the elastic deformations of the aggregate particles.

2.5 INFLUENCE OF MINERAL ADMIXTURES

The use of mineral admixtures has become popular in industry, especially for high strength and low permeable concretes. The most common types of mineral admixtures are silica fume and fly ash. In general, some of these admixtures increase the water requirements for a concrete mix. In theory, the increased water demand should increase the shrinkage of the concrete, however, some studies have shown that the use of mineral admixtures with an increased water demand do not always increase the amount of shrinkage.

2.5.1 Silica Fume

Bloom, R., et al, (1995) tested concrete based on a graded aggregate with a maximum nominal aggregate size of 7 mm. This was due to the small cross section resulting in a need for smaller aggregate size to gain a representative sample. Shrinkage tests were conducted on 40 x 40 x 1000 mm prism specimens. The specimens were exposed to either 40 °C, 45% relative humidity, or they were sealed. Silica fume considerably increased the free shrinkage of the concrete compared to the reference Portland cement concrete with the same water to binder ratio. Concrete with a low water
to binder ratio of 0.33 cracked due to plastic shrinkage regardless of silica fume in the mix. Concrete with a higher water to binder ratio of 0.50 did not have cracking, but the mixes with a water to binder ratio of 0.40 cracked with silica fume and no cracking was observed in the non-silica fume mixes. The shrinkage of the sealed specimens was found to be negligible.

**Mehta, P.K., (1986)** has explained that silica fume is an industrial by-product with a particle size about 100 times finer than Portland cement. This material, which is highly pozzolanic also creates a greater water demand or the use of a high range of water reducer.

**Weigrink, et al, (1996)** investigated the concrete shrinkage and they found that higher silica fume contents produced concrete with higher early drying shrinkage.

**Tazawa, E., et al, (1991)** examined the shrinkage and creep of mortar and concrete. Drying shrinkage of concrete was tested using 100 x 100 x 400 mm prism specimens. The specimens were in a controlled environment of 20 °C and 50% relative humidity. The drying shrinkage of the concrete mixes with silica fume was lower than that of the same type mixes without the silica fume.

**Haque, M.N., (1996)** measured the drying shrinkage on 85 x 85 x 285 mm prism specimens. The addition of both 5 and 10% silica fume (by weight) in concrete mixes resulted in substantial reduction of drying shrinkage. Further addition of 20% fly ash or slag increased the shrinkage of these concretes.

**Tazawa, E., et al, (1997)** found that autogenous shrinkage of concrete during the first 24 hours after placement increases with decreasing water to binder ratio. When the water to binder ratio was reduced to 0.17 with superplasticizers and silica fume, the greater part of the shrinkage in the dried condition was attributed to autogenous shrinkage.

**Whiting, et al, (2000)** found that the tendency of concrete with silica fume to crack is influenced by the curing of the concrete and not the addition of silica fume. When the concrete is cured for 7 days in a continually moist condition, there was no
statistically significant effect on the tendency of the concrete to crack. However, it was found that at early ages, the silica fume concrete mixes did show somewhat higher shrinkage than those mixes not containing silica fume. It was recommended from this study that specifications for silica fume concrete mixes used in bridge deck construction include a provision for a 7-day continuous moist curing of exposed surfaces.

**Person, B., (1997)** examined self-desiccation of high performance concrete with water cement ratio varying between 0.25 and 0.38. The specimens were measured for autogenous shrinkage from one day to two years of age. It was found that decreasing the water cement ratio and increasing the silica fume content had the greatest effect on autogenous shrinkage.

**Li, H., et al, (2002)** studied the early age creep and shrinkage with and without silica fume (SF), ground granulated blast-furnace slag (GGBS) and their combinations. Prism specimens of size 100 x 100 x 400 mm were used to study the drying and autogenous shrinkage of six concrete mixtures. The prepared specimens were tested after 3 days under a controlled environment of 30 ± 2 °C and 65 ± 5% relative humidity as maintained by dehumidifiers. It was concluded that the blended cement concrete incorporating SF, GGBS or both had lower drying shrinkage especially at a later age after 60 days but greater autogenous shrinkage than that containing ordinary Portland cement alone.

### 2.5.2 Fly Ash

The particle size distribution, morphology, and surface characteristics of fly ash used as a mineral admixture has a considerable influence on the water requirement, workability, and rate of strength development of concrete (**Mehta, P.K., 1996**). Particle sizes range from less than 1 micron to 100 microns in diameter with more than 50% under 20 microns. The class C high calcium fly ash is more chemically active than the Class F low calcium fly ash.

**Tangtermsirikul, S., et al, (1995)**, conducted tests on 15 x 40 x 160 mm prism specimens to measure length change. The drying shrinkage tests were conducted in a controlled environment of 25 °C and 60% relative humidity. Three types of class C fly
ash and one type of class F fly ash were used in the experimental study. The class C fly ash had a smaller drying shrinkage than the ordinary cement paste mixes. The application of the fly ash reduced the water requirement of the mixes thus reducing the shrinkage. The class C fly ash also reduced the autogenous shrinkage due to chemical expansion of the concrete.

**Gebler, S.H., et al, (1950)** tested prism specimens of 75 x 75 x 285 mm according to ASTM C157. The specimens were cured in a controlled environment of both 23 °C and 4.4 °C and 100% relative humidity. Concrete containing fly ash and cured at 23 °C did not exhibit significant difference in shrinkage from the mixes not containing fly ash.

**Kayli, O., et al, (1999)** studied the drying shrinkage of fibre reinforced lightweight aggregate concrete containing fly ash. It has been reported that the concrete containing fly ash of 23% of the total cementitious content resulted in long-term shrinkage that is nearly twice as large as the normal weight concrete of somewhat similar strength.

### 2.6 INFLUENCE OF CHEMICAL ADMIXTURES

Chemical admixtures such as shrinkage reducing admixtures (SRA) are presently being used on a limited basis. The use of high range water reducers (HRWR) are common in use today. SRA lowers the surface tension of the pore water solution in the cement paste, thus decreasing the shrinkage stresses and reducing the cracking due to shrinkage. Concrete with a low water cement ratio and HRWR admixtures produce a more workable concrete mix. In general, HRWR admixtures do not affect the shrinkage deformation of concrete.

#### 2.6.1 Shrinkage Reducing Admixtures (SRA)

**Folliard, K.J., et al, (1997)** conducted tests on concrete mixes cured from 1 to 14 days. The specimens were stored at 23 °C and 50% relative humidity. The specimens containing 2% by weight of cement of SRA showed a minimal shrinkage at early ages after controlled drying. Drying shrinkage increased as the water cement ratio increases with all the mixes having the same cement content. The drying shrinkage was greatly
reduced with the introduction of the SRA. Drying shrinkage was significantly reduced with increased curing time. Longer curing periods reduced the sensitivity to changes in the water cement ratio with respect to shrinkage reduction.

**Folliard, K.J., et al, (1997)** used silica fume slurry and superplasticizer along with an SRA to produce a high strength concrete. The concrete was kept at a slump of 150 to 200 mm. Concrete prisms of 75 x 75 x 285 mm were cast to measure free drying shrinkage. The use of a SRA reduced the drying shrinkage of the high strength concretes both with and without silica fume.

**Shah, S.P., et al, (1992)** used the ring test to determine restrained shrinkage. The steel ring had an inner diameter of 305 mm and an outer diameter of 375 mm. The specimens were placed in a controlled environment of 20 °C and 40% relative humidity. Three different SRAs were used. The SRAs may decrease the compressive strength of concrete. The addition of the SRA did reduce the amount of shrinkage. As the amount of SRA added increases, the shrinkage further decreases. The addition of SRA reduced the restrained shrinkage crack width. Tests were also conducted on 100 x 100 x 285 mm prism specimens to study the free shrinkage. The test results showed improvement in the reduction of free shrinkage for the specimens with SRA. An equal amount of water was removed when the SRA was added. The addition of the SRA caused a delay in the restrained shrinkage cracking. Typical specimens cracked at 48 days or more.

**2.7 INFLUENCE OF AMBIENT CONDITIONS**

**Torrenti, J.M., et al, (1999)** examined a non-reinforced concrete beam of 0.3 x 1 x 3 m for ambient effects on shrinkage. The shrinkage of the beam was proportional to its self-weight. The thermal expansion coefficient of the concrete had a direct relation to the shrinkage values, but temperature had very little effect on the variations of the thermal expansion coefficient. The variations in the relative humidity had a greater influence on the thermal expansion coefficient.

**Almusallam, A.A., et al, (1999)** conducted tests with 450 x 450 x 20 mm specimens exposed to different temperature, relative humidity and wind velocity conditions. The increased relative humidity caused a decrease in water evaporation when
there was no wind. Relative humidity became insignificant to evaporation of water under windy conditions. The increase in wind increased the rate of water evaporation, crack length and area and early cracking as compared to non-windy conditions. The increase in temperature increased the rate of water evaporation and the crack length and area. It was concluded that water evaporation should be minimised to reduce the intensity of plastic shrinkage cracking.

2.8 INFLUENCE OF SPECIMEN SIZE

Almudaiheem, J.A., et al, (1987) investigated the effect of specimen size on drying shrinkage. The observations were made on the shrinkage of various specimen size over a period of one year. The shrinkage decreased with increasing specimen size. The ultimate shrinkage of paste, mortar, and concrete was found to be independent of specimen size and shape according to the dynamic shrinkage/weight loss curves. They concluded that the ultimate drying shrinkage may be estimated from shrinkage versus drying time curves for small laboratory specimens of 25 x 25 x 279 mm with the same mix proportions as the longer structural members.

2.9 TESTING METHODS


These different test methods produce a broad range of crack pattern and widths that can be subject to many different interpretations. Results from plastic shrinkage cracking tests are most commonly reported as the average crack width (Soroushian. P.,

ACI Committee 544, (1989) have reported that no standard test method is available to predict plastic shrinkage cracking resistance of concrete at an early age. This lack of a standard test has prompted the proposal of several methods. These involved measurement of the length and width of concrete cracks. Ring, rectangular, square and combinations of these shapes have been used to characterise the crack resistance characteristics of fibre reinforced concrete compared to non-fibre reinforced concrete. Also, it is stated that the relationship between these test results and field applications has not been determined.

Kraai, P.P., (1985) proposed a testing method to determine the cracking potential due to drying shrinkage of concrete and he concluded that this method provides a valid measure of the potential cracking caused by drying shrinkage. Also, this test can be adopted to study the effects of temperature.

Christos A. Shaeles, et al, (1988) carried out a research program based on the method developed by Kraai and concluded that the procedure given by Kraai can be useful for evaluating the effects of material and procedural factors on the plastic shrinkage cracking of mortars. The method may also be possible to extend the same concept to the evaluation of concrete mixes.

Banthia, N., et al, (1996) has developed a novel test technique to assess the plastic shrinkage cracking potential of cement based materials when used as a bonded overlay. In this technique, specimens were cast directly on to a substrate base and the entire assembly was subjected to a drying environment to induce cracking.

Toledo, F., et al, (1999) had used a forced ventilation method to study the shrinkage cracking behaviour of cement mortar. Specimens of 150 x 1200 x 15-mm size were enclosed in a chamber and the evaporation was accelerated by maintaining a constant airflow speed and temperature inside the chamber. An extensometer was attached to the specimen to measure the crack width.
Mora, J., et al. (2000) had used a large wind tunnel for supplying air at constant speed on a control panel of size 800 x 800 x 100 mm. Anchorage screws were provided at the four inner sides of the slab panel to induce restraints against shrinkage. A comparative assessment was made for the level of shrinkage by determining the visible crack area formed in a normal concrete and fibre reinforced concrete.

2.10 REMEDIAL MEASURES


Low volumes of randomly distributed fibre reinforcement have been used as a common practice to control plastic shrinkage cracking in concrete structures (Hannet, 1978; Balaguru, P., and Shah, 1992). However, limited testing and analysis have been performed to quantify the recommendations for preventing plastic shrinkage cracks.

Swamy, R.N., (1975) has established that apart from increasing the tensile strength of the composite, the most significant influence of the fibre reinforcements is in controlling the cracking of the matrix.

Swamy, R.N., (1979) carried out a ring test program to find the influence of fibre reinforcement on restrained shrinkage and cracking and concluded that the presence of glass and polypropylene fibres produced a reduction of about 10% in free shrinkage. With normal and lightweight aggregate concrete mixes, 1% volume of steel fibres reduced drying shrinkage by 15% to 20%. The fibre reinforced specimens control shrinkage cracking much better than the unreinforced mixes. While the unreinforced rings failed immediately on the formation of first crack, the fibre reinforced specimens delayed the formation of first crack. The latter also enabled the composite to accommodate more than one crack. Moreover, it reduced the crack widths substantially and continued to sustain the shrinkage stresses even after 8 to 12 months in the concrete mixes. It was also concluded that the fibre reinforced specimens were able to resist 50% to 100% more tensile stress.
Paillere, A.M., et al, (1989) conducted an experimental study on the effect of fibre addition on the autogeneos shrinkage of silica fume concrete. In their study, two types of hooked fibres with ratios of length to diameter (length in mm to diameter in hundredths of mm) of 30/60 and 50/50 were used at a constant volume of 0.8%. It was concluded that the shrinkage led to rapid cracking of specimens held at constant length, even in the absence of any evaporation. This phenomenon is a pathological condition that seems to be peculiar to these very high strength concretes. It was also observed that steel fibres can lengthen the time elapsed before cracking and can provide a confinement after the cracking of silica fume concretes.

Grzybowski, M., et al, (1990) studied the shrinkage cracking of fibre reinforced concrete with ring type specimens for two different fibres of steel and polypropylene with differing amounts. The length of drying was taken as 2 hours to 4 days with the drying environment of 20 °C and 40% relative humidity. It was concluded that 0.25% by fibre volume can substantially reduce crack widths resulting from restrained drying shrinkage. Steel fibres were more effective than polypropylene fibres. No influence of the addition of polypropylene fibres in the amount equal to 0.1% by volume was observed.

Banthia, N., et al, (1996) had studied the plastic shrinkage cracking potential of cement based materials when used as a bonded overlay. With steel fibres of 0.5% to 1% volume fractions, restrained shrinkage cracking were tested with the novel technique and it was concluded that the steel fibres not only reduced the maximum crack width but also caused multiple cracking in the composite upto a fibre volume fraction of 0.5%. At 1% fibres by volume, only minimal cracking was seen to have occurred even under a particular severe environment.

Banthia, N., et al, (2000) studied the effectiveness of polyolefin fibres in controlling restrained shrinkage and thermal cracking in concrete at a temperature of 38 °C with a relative humidity of 5%. Four types of polyolefin fibres were used in their study. A new technique developed by the authors was employed for this study. In this technique, fibre reinforced concrete to be tested was laid on top of a fully hardened base concrete that provided the bottom restraint and this resulted in cracking in the freshly placed overlay. It was found that crack widths exceeded 1 mm in plain concrete.
specimens and were reduced to less than 0.4 mm with 0.7% of by the volume of the 50/63 fibres. Cracks were completely eliminated at the same volume fraction of type 19/15 fibre. It was concluded that the fibres were very effective in reducing the extent of shrinkage cracking and in reducing crack widths.

Zhang, J., et al, (2001) had stated that besides adopting a good concreting, finishing, and curing practice, the use of fibre reinforcement has been as one of the most effective methods to reduce shrinkage cracking of cement based materials.

Lim, Y.M., et al, (1998) had stated that, in general, an increase in the fibre density/fractions provides a uniform distribution of fibres throughout the concrete matrix, which results in an increase in the tensile strain capacity of the concrete in the plastic state. Fibres do not change the density of mortar but do reduce micro-crack formation, enabling the concrete to progress from the plastic to hardened state with greater integrity.

Sourashian, P., et al, (1995) found that polypropylene fibres, at relatively low fibre volume fractions, substantially reduced the total crack area and the maximum width of crack of slab surfaces subject to restrained plastic shrinkage movements. Also, it was concluded that longer fibres of 19 mm length generally performed better than shorter fibres of length 13 mm. However, at certain volume fractions of fibre addition, the effect of fibre length did not show a satisfactory performance in controlling plastic shrinkage cracking.

Sourashian, P., et al, (1998) studied the performance of specialty cellulose fibres in the control of plastic shrinkage cracking. Specimens of size 560 x 365 mm with sheet metal stress risers were used for this study. The restrained plastic shrinkage characteristics of two types concrete mixes (one of conventional and the other of high performance concrete) with and without specialty cellulose fibres were tested under an ambient condition of 36.6°C, 20% relative humidity, and 9.5 m/sec wind speed. It was concluded that cellulose fibres have statistically significant effects, on the plastic shrinkage cracking of concrete. Further it was added that the introduction of cellulose fibres, on the average, reduces the plastic shrinkage crack area of conventional and high performance concrete by 78% and 47%, respectively. The average reduction in maximum
crack widths in conventional and high-performance concrete were 47% and 34% respectively.

Najm, H., et al, (2002) studied the contribution of three types of large diameter polymeric fibres to the reduction of crack width in cement composites caused by plastic and drying shrinkage. The matrix for the drying shrinkage ring type specimens consisted of concrete with and without silica fume. The matrix for the plastic shrinkage slab specimens of 600 x 900 x 19 mm size was a rich cement mortar mix. The test results showed that addition of these fibres provide substantial reduction in plastic and drying shrinkage cracking. All three fibre types were effective for both matrix types. A fibre content of approximately 9 kg/m³ resulted in a 60% reduction in crack width. Polymeric fibres provided the same crack reduction as steel fibres at half the fibre volume fraction. Also it was concluded that the long fibres were more effective than short fibres in reducing cracks. The drying shrinkage test results revealed that for the same fibre content and fibre aspect ratio, the mixes with silica fume achieved a greater crack reduction compared with mixes without silica fume.

Bayasi, Z., et al, (2002) reported the findings of the experimental research investigation on the application of fibrillated polypropylene fibres for restraint of plastic shrinkage cracking in silica fume concrete. The test procedure initially proposed by Kraii was followed. This experimental study was performed in an environmental condition with 18°C, 60% relative humidity and which produced 0.3 kg/m²/h free surface water evaporation rate. The use of 0.1% volume fraction of fibrillated polypropylene fibres was found to be effective in shrinkage crack reduction of concrete with a silica fume content of 0 or 5%. The use of 0.3% volume fraction of fibres was found to be successful in combatting plastic shrinkage cracking in concrete with a 10% silica fume content.

Kayli, O., et al, (1999) studied the effect of polypropylene and steel fibre addition on drying shrinkage of lightweight aggregate concrete containing fly ash. It has been concluded that polypropylene fibres did not reduce the drying shrinkage while steel fibres did. Also, it was concluded that fibre reinforcement significantly increases the tensile strength of lightweight concrete and fibres with higher tensile strength together with the low modulus of elasticity is believed to be more effective in reducing shrinkage cracking.
The literature review indicates that there is a lack of understanding of plastic shrinkage cracking of plain and fibre reinforced concrete. Also there is no generalised recommendation available on prediction of plastic shrinkage cracking in plain cement concrete and on the use of fibre reinforcement in controlling such cracking. Hence, there is an urgent need for arriving at some solid recommendations for the prediction and control of plastic shrinkage cracking. Therefore the main objective of this present work has been set to obtain generalised methodology to predict and prevent the plastic shrinkage cracking.