Shrinkage Characterization of Cement Concrete with Various Supplementary Cementitious Materials and Fibers-A Review

Ancia Cherian[1], Jerison Scariah James[2], Dr. Elson John[3]

[1] *Ancia Cherian, M.Tech Student, Department of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam*
[2] *Jerison Scariah James, Research Scholar, Department of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam*
[3] *Dr. Elson John, Professor, Department of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam*

Abstract–*Volumetric shrinkage occurs frequently in cement-based materials, which may cause tensile strains and cracking. The volume changes brought on by water evaporation are known as shrinkage. Volume variations in concrete can happen early in the material's life or later on. Plastic shrinkage occurs at the plastic stage of concrete. The change in volume after the setting has occurred is known as drying shrinkage. Autogenous shrinkage is the shrinking that occurs in a conservative system, or one in which moisture cannot migrate into or out of the paste. This study tries to examine the impact of various SCMs such as fly ash, GGBFS, silica fume, etc. and fibers such as steel fiber, polypropylene fiber, glass fiber, etc. in the shrinkage characteristics of concrete.*

Key Words: Shrinkage, Materials, Mechanical Properties, Plastic Shrinkage, Drying Shrinkage.

1.INTRODUCTION

Concrete is the second most widely used material globally, only after water. Concrete is the most extensively used construction materials. The flowability of the plastic mix and compressive strength of the resulting material allows it to be shaped to specification, making it a prime choice for building material. Several types of concrete are used in large quantities yearly all over the world. Owing to the extensive use of concrete, numerous researchers are studying its engineering properties and durability performance. Industrialization and development of construction have made a high challenge for innovative kinds of sustainable materials, which are necessary to possess enhanced properties such as strength, deformation, and durability.

Cement based materials normally undergo various types of volumetric shrinkage, which could induce tensile stresses and may in turn lead to cracking. In concrete, the development of cracks causes significant problems related to the strength and durability performance. The formation of cracks may reduce the lifespan of concrete structures by allowing the entry of harmful particles through it. Therefore, it is important to prevent crack formation and improve the durability of concrete structures. Shrinkage cracks impair the durability and serviceability of concrete structures[2].

2.SHRINKAGE IN CONCRETE

Shrinkage is the change in volume due to expulsion of water. In concrete, volume changes occur in two stages- in early ages or in long term. There are different types of shrinkage, namely, plastic shrinkage, drying shrinkage, autogenous shrinkage, thermal shrinkage and carbonation shrinkage. Plastic shrinkage occurs at the plastic stage of concrete, due to the effects of the gravity in the bleeding state and the pore water evaporation in the drying state, from casting to the final set. Since structural concrete is always restrained, e.g., by reinforcement, incompatibility of deformations occurs, which leads to the buildup of restraint stresses. During the above-mentioned period, concrete is plastic and has only insignificant strength, which makes it highly susceptible to cracking when the stresses increase beyond the limit. Accordingly, it is said that plastic shrinkage is the source of about 80% of the early-age cracking of RC structures. The cracks that appear on the surface may grow to widths larger than 1 mm and lengths of 50 to 1000 mm, and may be spaced in an irregular pattern. In shallow elements, e.g. concrete slabs, they can even grow throughout the whole depth. The cracks furthermore accelerate the ingress of harmful substances and leads to the reduction of serviceability. Therefore, they need to be eliminated or at least their width needs to be reduced with effective methods[1].

The shrinkage of hardened concrete consists of drying shrinkage, autogenous shrinkage, and carbonation shrinkage. The contribution of the autogenous shrinkage to long-term behavior should be negligible in normal strength concretes. The carbonation shrinkage can be considered a special case of drying shrinkage as the chemical process of carbonation occurs with concomitant loss of water. Drying shrinkage is the change in volume after the setting takes place[9]. Autogenous shrinkage is the shrinkage in a conservative system, i.e., where there is no moisture movement to and from the paste permitted. Three mechanisms, namely, capillary tension, disjoining pressure and surface free energy, are proposed in the literatures for the drying shrinkage of the cement based composites[2].

Strategies developed to mitigate shrinkage include incorporation of supplementary cementitious materials, shrinkage reducing admixtures, expansive agents, fibers, super absorbent polymers, etc. [1].

2.1 Supplementary Cementitious Materials

With the increasing emphasis on sustainability, supplementary cementing materials (SCMs) have been widely used as replacements of OPC to prepare blended cements. The influence of SCMs on the shrinkage and mechanical strength of cement composites depends upon the replacement levels and pozzolanic activity of the SCMs used. The utilization of pozzolanic materials as SCM to decrease the heat of hydration is well recognized[1]. The most common representatives of SCM are industrial by-products, such as fly ash, silica fume, or blast furnace slag[12]. The incorporation of fly ash and slag decreased the strengths at early age. The more the volume of slag and fly ash, the lower the strengths were gained. However at 28 days, the strengths were increased than that of corresponding PC mortars. Hydration of magnesia produced expansion and thus partly or fully compensated for the autogenous shrinkage of concrete paste. Samples prepared with 8% magnesia, 40% slag and 20 or 40% fly ash exhibited the least volume changes[13]. The addition of fly ash improves the cracking resistance and relaxation behavior of Self Compacting Concrete compared to control mix. The optimum proportion of fly ash was in the range of 35% for the potential to mitigate shrinkage cracking[3].

Shrinkage of GGBFS concrete was found to be higher than ordinary Portland cement concrete. The higher shrinkage was attributed to the greater volume of paste in GGBFS concrete. The finer GGBFS particles have larger surface area exposed for the pozzolanic reaction and hence a faster rate of reaction. It has been shown that fine GGBFS particles increase the early hydration process. The fine and rough textured GGBFS particles are also able to absorb more water. As there is less free water, self-desiccation in the cementitious matrix results in greater capillary pore pressure. This leads to autogenous shrinkage of the GGBFS concrete. In addition, the fine GGBFS also produces finer capillary pores in the cementitious matrix and the radius of the curvature of the meniscus in the capillary is less in the fine pores. Moreover, the shrinkage increase may also be due to the greater volume of paste in the GGBFS concrete as GGBFS replaces OPC on an equal weight basis. The primary cause of shrinkage is the loss of moisture from the cement paste of concrete. Thus, the shrinkage strain is higher for GGBFS concrete as compared to plain concrete, because of higher moisture absorption in GGBFS concrete.[4]

2.2 Shrinkage Reducing Admixtures

Shrinkage Reducing Admixtures (SRAs) are organic compounds that reduce both autogenous shrinkage and drying shrinkage in cement based composites. They help to reduce the risk of cracking in cement based composites.[11] SRA impacts the drying shrinkage by acting on the capillary forces, by acting on the specific range of relative humidity over which those forces occur, and potentially by acting on the surface stressed through pore wall adsorption. However, precautions are needed while using the SRA, since they may reduce the compressive strength and retard the development of mechanical properties at high dosages and they are in general expensive.. Therefore, the dosage of SRA needs to be optimized.[3]

2.3 Fibers

The inclusion of short fibers could be a substitute solution to decrease the shrinkage of concrete over time. The addition of fibers resulted in better performance under impact loads with higher energy absorption capacity. Fibers helps to reduce the size and the area of the plastic shrinkage cracks in many studies. Their mechanism of action is by: 1- Reduction of bleeding by enhancement of the concrete stiffness caused by the interlocking network of fibers, therefore beneficial against cracking in the bleeding state. 2- Increase of the cohesion, and therefore tensile strength, which can prevent or retard crack propagation in the evaporation state. Generally, increase in fiber volume slightly reduces drying shrinkage. This is due to the fibers acting as a skeleton for the concrete matrix along with the fine aggregate to provide increased dimensional stability.[4] Moreover, the reduction in all categories of shrinkage with increased fiber content can also be attributed to the higher elastic modulus of the fibers, as well as the higher strength-to-size ratio of the fibers. Incorporation of discrete fibers can significantly reduce the total- and autogenous- shrinkage, this is mainly due to the bond stress between the fibers and matrix resisting the self-desiccation of the matrix. An increase in fiber volume fraction leads to a reduction in both the total and autogenous shrinkage magnitudes.[7]

2.4 Super Absorbent Polymers (SAP)

Internal curing using superabsorbent polymer (SAP) is an effective method to control the shrinkage development. SAP has a better performance on restraining shrinkage of larger Ultra High Strength Concrete (UHSC) specimens than small ones along with incorporation of 20% fly ash and 25% silica fume. This was due to the more efficient performance of SAP at the inner layers, which was less influenced by the dry environment. However, the SAPs located at the vicinity of the drying surface lowered the migration of water to the surface to some extent[5].

3.MATERIALS

3.1 Ordinary Portland Cement

Cement is the individual unit of calcareous and argillaceous materials with the property of setting or hardening in combination with water. It helps to fill the voids and gives density to the concrete. Some of the important factors which play vital role in selection cement are compressive strength at various ages, fineness, heat of hydration, tricalcium aluminate(C_3A) content, tricalcium silicate (C_3S) content, dicalcium silicate(C_2S) content, etc. It is also necessary to ensure compatibility of the chemical and mineral admixtures with cement. Ordinary Portland Cement is the most common type of cement used for constructing structures like building foundations, bridges, tall buildings, and structures designed to withstand heavy pressure. Different laboratory tests are conducted on OPC to determine standard consistency initial setting time, final setting time, compressive strength as per IS 4031 and IS 269:1967.

3.2 Fine Aggregate

Fine aggregate used should be properly graded to give minimum void ratio and be free from deleterious materials like clay, silt content and chloride contamination etc. Indian Standard (IS) committee reports that sand with fineness modulus below 2.5 gives concrete sticky consistency making it difficult to compact and sand with fineness modulus of about 3 gives the best workability and compressive strength .Properties such as void ratio, gradation, specific gravity, fineness modulus, free moisture content, bulking and bulk density have to be assessed to design a concrete mix with optimum cement content and reduced mixing water.

3.3 Coarse Aggregate

Aggregate is an inert material which is mixed with cement and water to create concrete which is hard, strong, and long-lasting. The aggregate occupies the three-quarter of the volume of the concrete. It contributes significantly to the structural performance of concrete, especially strength, durability and volume stability.

3.4 Supplementary Cementitious Materials

The most common representatives of SCMs are industrial by-products, such as fly ash, silica fume, ground granulated blast furnace slag(GGBFS),etc.

Finely divided residue resulting from the combustion of pulverized coal is termed as fly ash. It is the most widely used pozzolanic material all over the world. There are mainly two types of fly ash, namely, class C and class F flyash. Now a days, fly ash has become a common ingredient in concrete, particularly for making high strength and high-performance concretes. Flyash when used in concrete contributes to the strength of concrete due to its pozzolanic reactivity.

The ground granulated blast furnace slag (GGBFS) is a by-product from iron manufacturing. It is obtained by heating of iron ore, limestone and coke at a high temperature about 1500°C, in a blast furnace. The main constituents of blast furnace slag are CaO, SiO2, Al2O3 and MgO. These are the minerals that are found in most of the cementitious substances. Ground granulated blast furnace slag has a colour nearly white in appearance. Hence the use of GGBFS in concrete manufacture would give a light and brighter colour to concrete unlike the dark grey colour of ordinary cement concrete structures.

4.TESTS ON CONCRETE

4.1 Slump test

The slump test is done as per IS : 1199 – 1959 to measure workability of concrete. The apparatus consists of a metallic mould in the form of frustum of a cone with internal dimensions of 200mm bottom diameter, 100 mm top diameter and 300mm height. Concrete is filled in the mould in four layers with 25 tamps in each layer. Then the mould is removed and the concrete is allowed to subside. This subsidence is measured and referred as the slump of concrete.

4.2 Compressive strength test

The Compressive strength test is done as per IS: 516-1959. 150x150x150 mm concrete cubes are the test specimens to determine the compressive strength of concrete cubes. Compression test is conducted on an Universal Testing Machine. The load was applied without shock and increased continuously at a uniform rate of $14N/mm^2/min$.

4.3 Split tensile strength test

The Split tensile strength test is done as per IS: 5816-1959. Concrete cylinders of 150 mm diameter and 300 mm length are the test specimens to determine the split tensile strength of concrete cylinders. Split tensile strength test is conducted on an Universal Testing Machine. The load is applied without shock and increased continuously at a uniform rate.

4.4 Flexural strength test

The Flexural strength test is done as per IS: 516-1959. Concrete beams of dimensions 100 x 100 x 500 mm are the test specimens Flexural strength test was conducted on an Flexural strength Testing Machine. The load is applied without shock and increased continuously at a uniform rate.

4.5 Plastic shrinkage measurement test

Plastic shrinkage is measured using a steel mould of 600×200×100 mm size with three stress risers in accordance with ASTM C1579. The central riser has a height of 63.5 mm which is used to provide maximum stress concentration on the central area and promote cracking. The other two risers of height 32 mm each are used to provide restrain in the concrete. The mould is made out of cast iron and transparent acrylic sheet is provided on one side; to make the crack visible, which is formed along the depth of the mould. For determination of plastic shrinkage, the mould is filled with fresh concrete and compacted. It is to be kept as such, where the environmental conditions are sufficient to maintain the minimum evaporation rate during the test. Start a stop watch and observe the occurrence of crack with naked eyes [10].

4.6 Drying shrinkage measurement test

Drying shrinkage is measured using a prismatic three compartment mould of size 285×75×75 mm in accordance with ASTM C1579. After 24 hours, the prisms are to be demoulded and a shallow depression is drilled at the centre of 75×75 mm side of the prism. After that 4mm diameter steel balls need to be fixed to the depression by cementing the balls with cement. Then using length comparator, the change in length is noted. This gives the magnitude of shrinkage[8].

5. CONCLUSION

In comparison to the control mix, the inclusion of fly ash enhances the cracking resistance and relaxing behavior. For the ability to reduce shrinkage cracking, a fly ash content in the range of 35 percent was ideal. It was found that GGBFS concrete shrinks more than ordinary Portland cement concrete did. Short fibers could be used as an alternative to reduce the shrinkage of concrete over time. Drying shrinkage is typically slightly decreased by increasing fiber volume. Together with the fine aggregate, the fibers serve as a skeleton for the concrete matrix to promote dimensional stability. Discrete fiber incorporation can greatly minimize total and autogenous shrinkage. This is mainly because the binding stress between the fibers and matrix prevents the matrix from drying up on its own. Both the total and autogenous shrinkage magnitudes decrease with an increase in the fiber volume fraction. Other methods to mitigate shrinkage include incorporation of shrinkage reducing admixtures, expansive agents, super absorbent polymers, etc.

6. REFERENCES

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