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Study on shrinkage properties of concrete with and without mineral admixtures

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ABSTRACT

Structures that complied with code requirements still fail due to excessive cracking. Shrinkage is primarily responsible for such failures. Concrete shrinkage is of increasing concern when focusing on maintaining durable structures. Shrinkage in concrete can be broadly classified into two different stages, namely early age and later age. At early ages, the concrete is still moist and there are difficulties in measuring the fluid material. These difficulties have hindered comprehensive physical testing of shrinkage in plastic concrete. This project aims in evaluating the plastic shrinkage of different concrete mixes. Over time, the shrinkage induces cracking which can severely decrease concrete life expectancy. Such cracks can be mitigated by inclusion of materials such as synthetic fibres, shrinkage reducing admixtures, expansive agents and superabsorbent polymers. And the corresponding variation of compressive strength of these mixes is also studied.

Keywords— *Concrete shrinkage, Superabsorbent polymers, Fly ash, Plastic shrinkage time*

1. INTRODUCTION

1.1 Cement concrete

Concrete is a composite material composed of cement, fine aggregates (sand) and coarse aggregates mixed with water which hardens with time. It can be said as a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete. High compressive strength and low tensile strength are properties of great importance regarding concrete.

1.2 Blended types of cement

Blended cement is obtained by mixing Ordinary Portland Cement (OPC) with mineral admixtures or additives like fly ash, slag or silica fumes. Usage of blended concrete mix provides advantages in two important ways: technical and environmental.

1.3 Durability

Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration of life span of trouble-free performance.

1.4 Shrinkage

Shrinkage is one important factor that causes cracking in concrete. The volumetric change of concrete structures due to the loss of moisture by evaporation is known as concrete shrinkage. It is a time-dependent deformation which reduces the volume of concrete without the impact of external forces. The various types of shrinkage are:

- Plastic Shrinkage.
- Autogenous Shrinkage.
- Drying Shrinkage.

- Carbonation Shrinkage.
- Thermal Shrinkage.

1.4.1 Plastic shrinkage: Shrinkage is one important factor that causes cracking in concrete. The volumetric change of concrete structures due to the loss of moisture by evaporation is known as concrete shrinkage. It is a time-dependent deformation which reduces the volume of concrete without the impact of external forces. Plastic shrinkage occurs during the first few hours after fresh concrete is placed. During this period, moisture may evaporate faster from the concrete surface than it is replaced by bleed water from lower layers of the concrete mass. Paste-rich mixes, such as high performance concretes, will be more susceptible to plastic shrinkage than normal strength concretes. Plastic shrinkage cracking usually occurs in concrete elements with large exposed surfaces.

1.4.2 Autogenous shrinkage: This type of shrinkage is a result of the withdrawal of water from the capillary pores that are present within the concrete. The hydration process is responsible for this water withdrawal. The water is necessary for the hydration of hydrated cement. This process of water withdrawal from the capillary pores to carry out the hydration of hydrated cement is called as self-desiccation. The shrinkage dealt with such conservative system can be named as autogenous shrinkage or autogenous volume change. This shrinkage is happening within the interior of the concrete member.

1.4.3 Drying shrinkage: Drying shrinkage is caused by the loss of surface -absorbed water from the calcium silicate hydrate (C-S-H) gel and also due to the loss of hydrostatic tension in the small pores. This shrinkage is mainly due to the deformation of the paste, though the aggregate stiffness also influences it. It takes place once the concrete has set is called as the drying shrinkage. Most of the kinds of drying shrinkage take place in the first few months of the concrete structure life. The withdrawal of the water from the concrete, that is stored within the unsaturated air voids causes drying shrinkage.

1.4.4 Carbonation shrinkage: The concrete cast has higher chances to react with the atmospheric gasses like carbon dioxide. This reaction is carried out in the presence of moisture. This will result in the formation of carbonates. The calcium hydroxide in the concrete, which is a by-product of hydration reaction will be found enormous in the concrete. This calcium hydroxide will react with the atmospheric carbon dioxide to give calcium carbonates. This will lead to the conversion of the concrete surface to get carbonated or acidic in nature. This process is called carbonation. This creates shrinkage that is observed on the surface.

1.4.5 Thermal shrinkage: Temperature difference within a concrete structure may be caused by portions of the structure losing the heat of hydration at different rates or by the weather conditions cooling or heating one portion of the structure to a different degree or at a different rate than another portion of the structure. These temperature differences result in a differential volume change, leading to cracks. This is normally associated with mass concrete including large and thicker sections of column, piers, beams, footings and slabs.

1.2 Objectives

- To find the optimum dosage of mineral admixtures.
- To study the effect of mineral admixtures on the shrinkage of concrete.
- To study the effect of shrinkage reducing admixtures on concrete.

1.3 Scope

- The study is limited to Ordinary Portland Cement (OPC).
- Chemical admixtures limited to one type of shrinkage reducing admixture.
- Mineral admixtures limited to fly ash.

1.4 Methodology

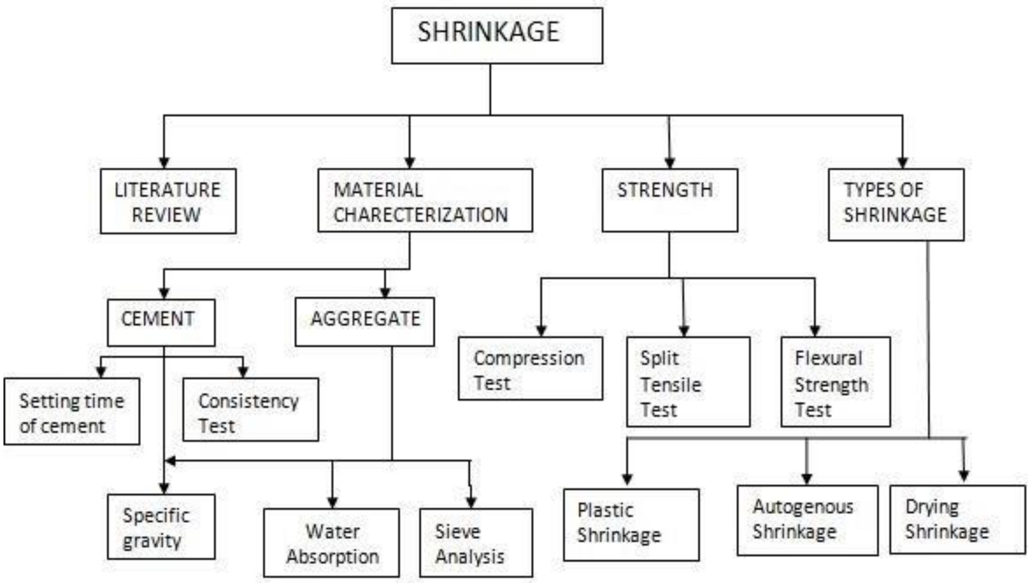

Fig. 1: Research methodology

2. LITERATURE REVIEW

Pengfei Zhao et al. (2017) found that fresh concrete exposed to a drying environment is susceptible to plastic shrinkage cracking, which can result in negative impacts on concrete durability. In the current ASTM standard, plastic shrinkage cracking is evaluated by the average crack width measured at 24 hrs after concrete placement, considering that the traditional crack measurement tools cannot be used on fresh concrete. In this work, a non- contact strain measurement technique based on Digital Image Correlation (DIC) was applied to study the behaviour of plastic shrinkage cracking. The crack areas were also determined by image analysis using MATLAB functions. It was found that DIC can provide a series of strain contour maps that helps to understand the process of plastic shrinkage cracking. The effects of air temperature, w/c, and substrate roughness were well explained by both DIC analysis results and crack areas computed in MATLAB

G. Appa Rao (2001) conducted an experimental investigation on the effect of silica fume and size of aggregate on the long-term drying shrinkage of mortar. Silica fume was used as a partial replacement by weight of cement from 0% to 30%. The maximum size of fine aggregate was 1.18 and 2.36 mm, respectively, in series I and II mortar mixes. The water ± cementitious material ratio and the cementitious material ± sand ratio was 0.50 and 1:3. The ultimate drying shrinkage was measured up to the age of 1095 days. From the experimental test results, it was observed that the addition of silica fume has a significant influence on the drying shrinkage at early ages of mortar. It increases with increase in silica fume content. This increase in early day drying shrinkage is mainly due to the very high pozzolanic reaction and pore size refinement mechanism of silica fume. The drying shrinkage in mortars with higher contents of silica fume was observed to be as high as 7 ± 10 times greater than that observed in mortars without silica fume at early days. No significant influence of silica fume was found on the long-term drying shrinkage of mortar. Furthermore, it has been dramatically observed that the long-term drying shrinkage of mortar decreases with the increase in the size of fine aggregate

Ilhami Demir et al. (2018) studied the effect of shrinkage reducing admixtures used in self-compacting concrete. Self-Compacting Concrete (SCC) is subjected to a higher number of shrinkage problems when compared to traditional concrete. Due to shrinkage, the stress developed exceeds the tensile strength of concrete and forms cracks resulting in the reduction of the strength of the material. Shrinkage Reducing Admixtures (SRA) has low viscosity and reduces the surface tension, finally reducing the shrinkage and crack formation. Different SRA dosage was produced to define the optimum SRA utilization rate in SCC mixtures. Dosage should be optimum within the rate .8 to 1.2%. It observed that SRA reduces the drying shrinkage of the concrete mixture at the early state. Also, the reduction in drying shrinkage is at a gradual rate. SRA addition delays early age restrained shrinkage of concrete cracks.

Antonio A. Melo Neto et al. (2008) studied on drying and autogenous shrinkage of pastes and mortars with Activated Slag Cement (ASC). The article investigates the relationship between ASC hydration, unrestrained drying and autogenous shrinkage of mortar specimens. The amount of activator is the primary influence on drying and autogenous shrinkage and early hydration makes a considerable contribution to the total result, which increases with the amount of silica that is present in the activation compound. Drying shrinkage occurred in two stages, the first caused by extensive water loss when the samples were exposed to the environment and the second was associated with the hydration process and less water loss.

Ravindra Gettu et al. (2008) studied the influence of shrinkage-reducing admixtures on the reduction of plastic shrinkage cracking in concrete. Plastic shrinkage cracking increases with an increase in evaporation rates and surface areas/volume ratios. The study shows that the reduction of surface tension of mixing water is an effective way of decreasing such cracking. This is achieved by using Super plasticizers and Shrinkage Reducing Admixtures (SRAs) in concrete. The various stages of plastic shrinkage cracking were identified. It indicated that there was no shrinkage until the surface water has evaporated after which the shrinkage strain increases until the capillary stress peaks and the crack initiates.

Riaan Combrinch et al. (2018) studied the interaction between settlement and shrinkage cracking in plastic concrete. Five different cracking behaviours of plastic concrete have been identified in the study. The mould used for plastic shrinkage study was ASTM C1579 based mould, but the coupled effect of plastic shrinkage crack and plastic settlement crack was identified. From the studies, pure plastic shrinkage cracking shows sudden single cracking throughout the entire depth of mould and not from top to bottom as expected.

Philippe Turcry et al. (2006) in the paper describe an experimental investigation of plastic shrinkage cracking of Self-Consolidating Concrete (SCC). Five SCC mixtures with compressive strengths were compared to five Ordinary Concrete (OC) mixtures. Free and restrained plastic shrinkage tests were performed in dry conditions. For restrained plastic tests, the authors used a mould very similar to ASTM C 1579 mould with a central restraint and smaller restraints at the two ends of the mould. Restrained shrinkage tests reveal that SCC tends to have less wide cracks than OC. SCC could be more vulnerable to shrinkage cracking, especially during setting. Thus, proper curing is recommended to protect SCC against evaporation at the fresh state.

2.1 Need for study

It was found that the durability of concrete is one of the main concerns in the present Civil Engineering field. The design life of any concrete structure member is always greater than 30 years. But, due to the use of improper or inferior materials, mix designs, insufficient curing, etc. a great many concrete structures across the globe are failing to live up to lifespan desires.

Shrinkage in concrete structures is one of the main factors that affect its durability. The problem of concrete shrinkage has been known in concrete technology for years, mainly in the theoretical and experimental aspects. However, there are few works in which the effect of concrete shrinkage in structures is studied. Hence, it is essential to study and evaluate the various types of shrinkage occurring in concrete.

3. MATERIALS AND MIX DESIGN METHODOLOGY

3.1 Materials and properties

3.1.1 Cement: The cement used for this project work is Ordinary Portland Cement of 53 grade. The cement is to be tested for specific gravity, standard consistency, fineness, initial setting time and final setting time.

Table 1: Properties of cement

s no.	Properties	Values	IS code limits
1.	Specific Gravity	3.15	3.12-3.15
2.	Standard consistency	31%	26-33%
3.	Initial setting time	120 minutes	>30 minutes
4.	Final setting time	360 minutes	<600
5.	Fineness	8%	<10%

3.1.2 Fly ash: Fly ash is a byproduct from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases. As the fused material rises, it cools and solidifies into spherical glassy particles call fly ash. Fly ash is collected from the exhaust gases by electrostatic precipitators or bag filters. The fine powder does resemble Portland cement but it is chemically different.

3.1.3 Ground granulated blast furnace slag: Blast-furnace slag is the nonmetallic product consisting essentially of silicates and alumino silicates of calcium and other bases that develop in a molten condition simultaneously with iron in a blast furnace. Granulated slag is the glassy, granular material formed when molten slag is rapidly chilled. Slag cement or GGBFS is granulated blast- furnace slag that has been finely ground and that is hydraulic cement. When slag cement is mixed with water, however, the initial hydration is much slower than Portland cement mixed with water.

3.1.4 Fine aggregate: The fine aggregate to be used in the study is manufactured sand. Fine sand conforming to IS specification is to be used in the study. Tests were conducted according to IS specification and results are tabulated in table 2.

Table 2: Properties of fine aggregates

S no.	Properties	Values	IS code limits
1.	Specific gravity	2.61	2.6 - 2.8
2.	Fineness modulus	3.476	2.0 - 3.5
3.	Water Absorption	0.6%	<3%
4.	Effective Size D_{10}	0.155	
5.	Uniformity Coefficient D_{60}/D_{10}	5.677	
6.	Grading zone	II	

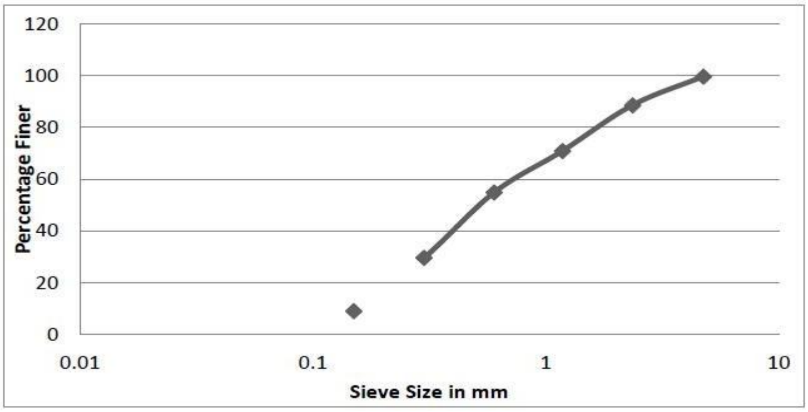

Fig. 2: Particle size distribution of fine aggregate

3.1.5 Coarse aggregate: Coarse aggregates of 20mm size were used. Tests were conducted according to IS specification and results are tabulated in table.

Table 3: Properties of coarse aggregate

S no.	Properties	Values	IS code limits
1.	Specific Gravity	2.69	2.5-2.9
2.	Fineness Modulus	6.2	6.0-6.9
3.	Uniformity coefficient D_{60}/D_{10}	1.26	
4.	Effective size, D_{10}	12.3	
5.	Water absorption	1.3%	<2%

Fig. 3: Particle size distribution of coarse aggregate

3.2 Mix design methodology

Firstly a conventional concrete mix is prepared which will be considered as the control mix.

3.2.1 Stipulations for Proportioning

Grade designation = M30
Type of cement = OPC 53 grade
Maximum nominal size of aggregate = 20 mm
Minimum cement content = 320kg/m^3
Maximum water-cement ratio = 0.45
Workability = 100 mm (slump)
Exposure condition = Severe

Test Data for Materials

Specific Gravity of Cement= 3.15
Specific Gravity of Coarse Aggregate = 2.69
Specific Gravity of Fine Aggregate= 2.61

3.2.2 Target strength for mix proportioning

$f'_{ck}= f_{ck}+ 1.65\ s = 25 + 1.65 \times 5 = 38.25$ N/mm

Where,
f'_{ck}= target mean compressive strength at 28 days in N/mm^2
f_{ck}= characteristic compressive strength at 28 days in N/mm^2
s = standard deviation in N/mm^2 = 5 N/mm^2 (From table 1, IS 10262:2009)

3.2.3 Selection of water cement ratio

Taking severe exposure condition for M30 (From table 5, IS 456: 2000) water-cement ratio = 0.45

3.2.4 Selection of water content

Maximum water-cement ratio = 0.45 (IS 456:2000; Table 5)
Maximum water for 20mm aggregate = 186 (IS 10262:2009; Table 2)
Consider 3% water rise for every 25mm slump rise (IS 10262:2009; Clause 4.2) Therefore, for 100mm slump: Water content = 186 (1+ 0.03 × 1) = 197.16

3.2.5 Calculation of cement content

$$\frac{w}{c} = \frac{197.16}{c} = 0.45 \quad (1)$$

So c = 438.13 kg > 320 kg
Hence OK

3.2.6 The proportion of coarse aggregate and fine aggregate content

From table 3, IS 10262: 2009 volume of coarse aggregate per unit volume of 20 mm maximum size aggregate and fine aggregate (zone II) for water-cement ratio of 0.5 is 0.62.

Volume of Coarse Aggregate = 0.62 (IS 10262:2009; Table 3: Corresponding to 20mm size aggregate and Zone 2)
Volume of Fine Aggregate = 1 - 0.62 = 0.38

3.2.7 Mix calculations

The mix calculations per unit volume of concrete shall be as follows:
Volume of concrete = 1m^3

$$Volume\ of\ cement = \frac{\text{Mass of cement } \times 1}{\text{Specific gravity of cement } \ 1000} = \frac{438.13 \text{ x } 1}{3.15\ 1000} = 0.1391 \text{ m3}$$

$$\text{Volume of water} = \frac{197.16}{1000} = 0.19716 \text{ m3}$$

Volume of all in aggregate = a-(b + c) = 1-(0.1391+0.197) = 0.664m^3

Mass of coarse aggregate = d × Volume of coarse aggregate × Specific gravity of coarse aggregate

= 0.664 × 0.62 × 2.69 × 1000 = 1107.42 kg

Mass of fine aggregate = d × Volume of fine aggregate × Specific gravity of fine aggregate

= 0.664 × 0.38× 2.61 × 1000

= 658.56 kg

3.2.8 Field correction

$$Water\ content\ in\ coarse\ aggregate\ = \frac{0.6\ \times\ 1107.42}{100} = 6.64\ Kg$$

$$Water\ content\ in\ fine\ aggregate\ = \frac{1.3\ \times\ 658.56}{100} =\ 8.56\ \text{Kg}$$

Actual water content = 197.16 + 6.64 – 8.56= 195.24 Kg

Actual quantity of sand required = 658.56 +8.56 = 667.12 Kg

3.2.9 Mix design

Cement Content = 438.13 kg/m^3

Water content = 195.24 kg / m^3 Mass of coarse aggregate = 1107.42 kg/m^3 Mass of fine aggregate = 667.12 kg/m^3

4. EXPERIMENTAL PROGRAM

4.1 Mix combination

Different concrete mixes with varying amount of supplementary cementitious material will be prepared. Supplementary cementitious materials used are fly ash and GGBS.

- Control mix
- Control mix + Fly ash
- Control mix + GGBS

Mixes are prepared with different percentage of fly ash and GGBS. The optimum percentage of fly ash from the literature obtained is around 20 to 25% replacement for cement mass and that of GGBS is 40%. So the percentage variation of fly ash replacement in cement is to be taken as 15, 20, 25 and 30% and that of GGBS is taken as 30, 40 and 50%. All the mixes are tested for mechanical properties and shrinkage. The physical test conducted will include slump test, compressive test, split tensile strength test, flexural strength test and shrinkage tests.

4.2 Physical tests on concrete

To study the properties of normal concrete and the concrete modified by replacement following tests are conducted:

4.2.1 Slump test: This test is intended for measuring the workability of concrete. The apparatus for conducting the slump test essentially consists of a metallic mould in the form of a frustum of a cone having the internal dimensions as 200mm bottom diameter, 100mm top diameter and a height of 300mm. The mould is placed on a smooth, horizontal, rigid and non-absorbent surface. The mould is filled with concrete in four layers, each approximately ¼ of the height of the mould. Each layer is tamped 25 times by a tamping rod taking care to distribute the strokes evenly over the cross sections. Tamping rod is a steel rod of 16mm diameter and 0.6m long with bullet end. After the top layer has been compacted, the concrete is struck off level with a trowel or rod. Then the mould is removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside. This subsidence is referred to as SLUMP of concrete. The slump shall be measured immediately by determining the difference in level between the height of the mould and that of the highest point of subsided concrete.

4.2.2 Compressive strength test: The bearing surface of the testing machine shall be wiped clean and any loose sand or other material shall be removed from the surfaces of the specimen which are to be in contact with the compression platens. In case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. The load shall be applied without shock and increased continuously at a rate of approximately 14N/mm^2/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen shall then be recorded and the appearance of the concrete and any unusual features in the type of failure shall be noted. The measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen by cross-sectional area of the specimen.

$$Compressive\ Strength\ = \frac{P}{A}$$

4.3 Shrinkage measurement

Fig. 4: ASTM C 1579 mould fabricated

Concrete will be tested for its plastic shrinkage. Plastic Shrinkage appears on the surface of fresh concrete soon after it is placed and while it is still plastic. The primary cause of plastic shrinkage is the rapid evaporation of water from the surface of the concrete. The mould for plastic shrinkage measurement is designed and fabricated in accordance with ASTM C 1579. Plastic shrinkage is measured using a steel mould of 600 x 200 x 100mm^3 size with 3 stress risers, which is used to provide restraint and promote cracking. The mould is made out of cast iron and Plexiglas is provided on one side, this is to make the crack visible which is formed along with the depth of the mould.

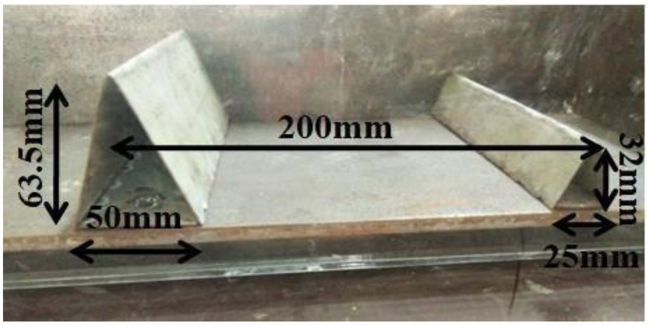

Fig. 5: Dimensions of the risers

Cracking is created above the central riser through the depth and across the width of the mould. During testing, the time at which the concrete surface starts cracking is recorded. Six hours after concrete placement, the maximum crack width will be measured with a handheld microscope.

4.3.1 Cracking of concrete

Fig. 6: Hair line cracks

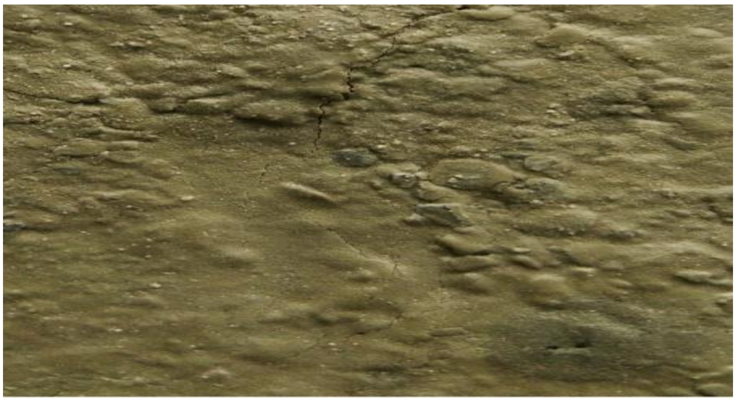

Fig. 7: Centre line crack

Fig. 8: line full-length crack

5. RESULTS AND DISCUSSIONS

5.1 Workability

The property of concrete which determines the amount of useful internal work necessary to produce full compaction is known as workability. The workability of fresh concrete depends mainly on the material, mix proportion and environmental conditions. The workability of concrete is measured using the slump test.

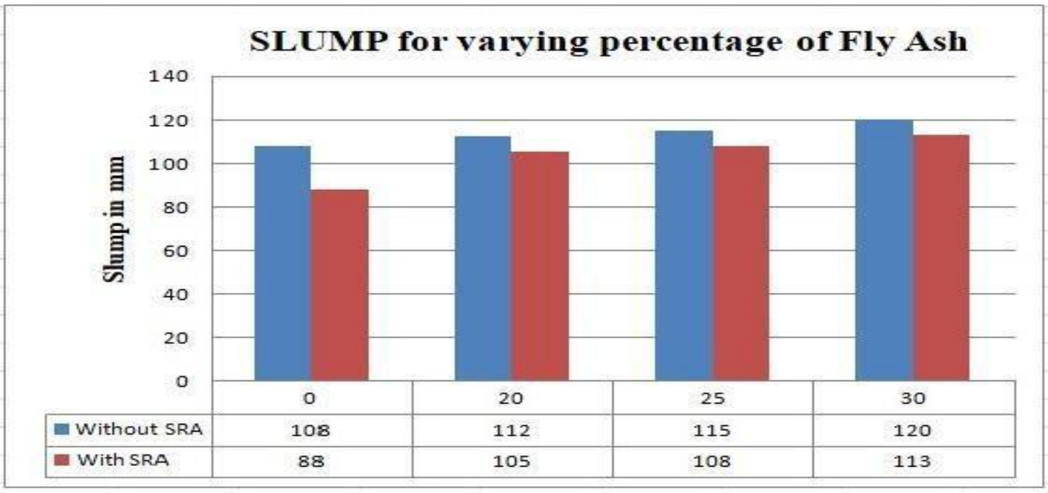

Fig. 9: Comparison of slump values for varying percentage of fly ash with and without shrinkage reducing admixture

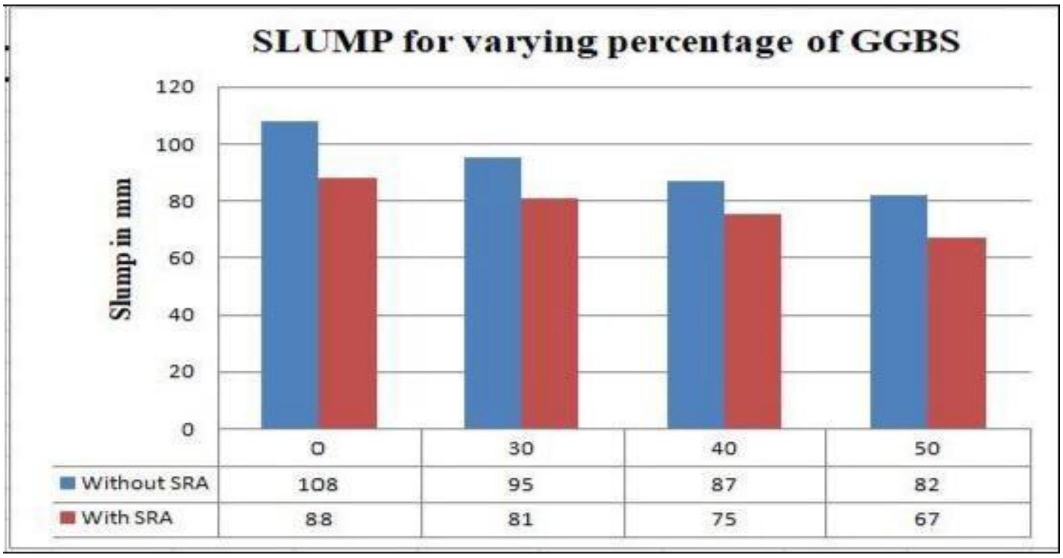

Fig. 10: Comparison of slump values for varying percentage of GGBS with and without shrinkage reducing admixture

The results show that compared to the normal concrete, the mix with GGBS showed less workability when used with or without shrinkage reducing admixture, but an increase in the value of slump was observed for mixes with cement replaced by flash.

5.2 Compressive strength

The compressive strength tests were conducted on concrete cube specimens of size 150mm. The cubes are to be tested after curing periods of 7 days. The results obtained for cube compressive strengths for different mixes at 7 days are shown below.

Table 4: 7th day compressive strength of concrete

Mix Designations	Fly Ash %	GGBS %	Cube compressive strength (MPa)
CM	0	0	25.4
CM0.5	0	0	24
CM1	0	0	22.8
CM2	0	0	21.4
CM4	0	0	17.6
M20F	20	0	19
M25F	25	0	17.8
M30F	30	0	16.8
M30G	0	30	14.4
M40G	0	40	13.9
M50G	0	50	12.4

As the percentage of SCM increased, the 7-day strength reduced for the concrete mixes. The 7-day strength of mixes with fly ash is found to be more than mixes with GGBS.

5.3 Plastic shrinkage time

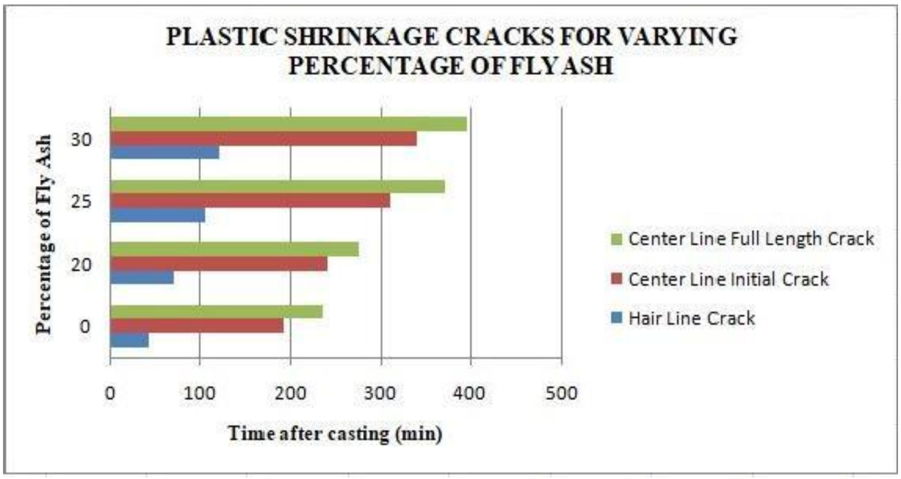

Fig. 11: Comparison of time of occurrence of crack for varying percentage of fly ash

The plastic shrinkage test was conducted using ASTM C 1579 mould. The time of occurrence of hairline cracks, initial centre line crack and centre line full-length crack was observed. The time of occurrence of hairline, centre line initial and full-length crack was delayed with the replacement of cement by supplementary cementitious materials. For the mixes with GGBS alone showed fast initial centre line crack but delayed crack propagation & mixes with fly ash alone showed delayed initial centre line crack but the crack propagation was fast.

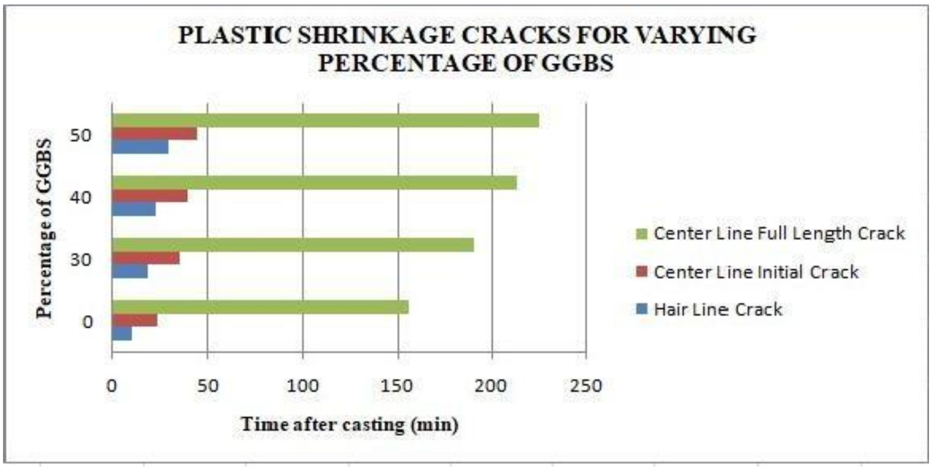

Fig. 12: Plastic shrinkage cracks for varying percentage of GGBS

6. CONCLUSIONS

6.1 General

Experimental investigations were carried out on M30 concrete and it is modified by replacing cement with fly ash and GGBS. The effect of shrinkage reducing admixtures on concrete with and without supplementary cementitious materials was examined. The main objective of the present investigation was to study the workability, strength and shrinkage characteristics of different mixes with varying replacement rates. Mechanical and shrinkage properties of concrete were examined in this study and the results were compared with that of normal concrete. The conclusion from the present investigation is based on the observations made during the study period.

6.2 Conclusions

The following results were obtained from the experimental study on the concrete with and without supplementary cementitious materials.

- Improved workability was shown for mixes with fly ash content & decreased workability for GGBS mixes.
- The time of occurrence of hairline, centre line initial and full-length crack was delayed with the replacement of cement by SCM. For the mixes with GGBS alone showed fast initial centre line crack but delayed crack propagation & mixes with fly ash alone showed delayed initial centre line crack but the crack propagation was fast.
- As the percentage of SCM increased, the 7-day strength reduced for the concrete mixes. The 7-day strength of mixes with fly ash is found to be more than mixes with GGBS.

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