CHAPTER 8

PROPERTIES OF SCC AT HARDENED STATE

8.1 GENERAL

After completion of the curing period, the hardened specimens must be tested to verify their performance. If the test results are less than the expected values, the SCC mix need to be redesigned. This chapter describes the various tests to be conducted on the hardened SCC specimens.

8.2 CURING THE TEST SPECIMENS

SCC tends to dry faster than conventional concrete because there is little or no bleed water at the surface. Initial curing should therefore be commenced as soon as practicable after placing in order to minimise the risk of shrinkage cracking. After casting, the specimens were stored in room temperature approximately 26°C for 24 hours. After hardening, the specimens were demoulded, placed in potable water for curing. After necessary curing, specimens were taken out from the curing tank, allowed to dry and tested.

8.3 TESTS ON HARDENED CONCRETE

After the necessary curing period, the concrete specimens were tested as per Table 8.1.
Table 8.1 Test details on hardened concrete

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Specimen details</th>
<th>No. of Specimen casted</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength ( 1st, 3rd, 7th, 14th, 28th, 56th and 90th days )</td>
<td>Cube – 150 x 150 mm</td>
<td>1232 Nos</td>
<td>Tests carried out as per BS 1881: Part 116, IS:516-1959 (Reaffirmed 2004)</td>
</tr>
<tr>
<td>Split tensile strength ( 1st, 3rd, 7th, 14th, 28th, 56th and 90th days )</td>
<td>Cylinder – 150 mm diameter and 300 mm long</td>
<td>1232 Nos</td>
<td>Tests carried out as per ASTM C496-96, IS:5816-1999 (Reaffirmed 2004)</td>
</tr>
<tr>
<td>Flexural strength (1st, 3rd, 7th, 14th, 28th, 56th and 90th days )</td>
<td>Prism – 100x 100 x 500 mm</td>
<td>1232 Nos</td>
<td>Tests carried out as per ASTM C78-94, IS:516-1959 (Reaffirmed 2004)</td>
</tr>
<tr>
<td>Modulus of elasticity – on 28th day</td>
<td>Cylinder – 150 mm diameter and 300 mm long</td>
<td>176 Nos</td>
<td>Tests carried out as per ASTM C469-14, IS:516-1959 (Reaffirmed 2004)</td>
</tr>
</tbody>
</table>

8.4 COMPRESSIVE STRENGTH

Self-compacting concrete with a similar water cement or cement binder ratio will usually have a slightly higher strength compared with traditional vibrated concrete, due to the lack of vibration giving an improved
interface between the aggregate and hardened paste. The strength development will be similar so maturity testing will be an effective way to control the strength development whether accelerated heating is used or not.

A number of concrete properties may be related to the concrete compressive strength, the only concrete engineering property that is routinely specified and tested. The steps involved in the determination of compressive strength are as follows.

- Prepare the test cube specimen in the standard manner as given before.
- Place this specimen in the compression testing machine with the cast faces in contact with the plates of the testing machine.
- Apply load at a uniform rate until the sample fails.
- Note down the Load at failure.

Figure 8.1 Testing of compressive strength of cubes
The compressive strength can be determined using the following relation.

Compressive strength = Crushing load / resisting area of cross section

\[ \text{Compressive strength} = \frac{W}{A} \]  
(8.1)

where

- \( W \) = Crushing load
- \( A \) = resisting area of cross section

The test results of compressive strength for SCC mixes M1 to M8 (without steel fibres and with steel fibres) are listed in Table A1.9 to Table A1.16 in the appendix. Testing of concrete cubes to determine compressive strength is shown in Figure 8.1

8.5 FLEXURAL STRENGTH

When concrete is subjected to bending, tensile and bending compressive stresses and shear stresses are developed. The most common plain concrete structure subjected to flexure is a highway pavement. Flexure test is intended to give the flexural strength of concrete in tension. The flexure test is also more easily carried out and may even be more convenient than the crushing test. The procedure involved in the determination of flexural strength is as follows:

- With 20 mm maximum size aggregates, cast three prism of size 100 x 100 x 500 mm.

- Assume mix proportion 1:2:4, w/c ratio 0.6. Weight of cement = 6.5 kg, weight of CA = 26 kg, weight of FA = 13 kg, water = 3.9 lit.
Figure 8.2 Testing of flexural strength

- The moulds shall be filled in two layers.

- After casting, the moulds shall be covered with wet cloths or gunny bags. Demoulded after 24 hours and wet cured for 27 days.

- The specimen shall be tested immediately on removal of water, while they are still in wet condition.

- The dimension of each specimen shall be noted before testing.

- The bearing surfaces of the supporting rollers and loading rollers shall be wiped clean, any loose sand or other material removed from the surface of the specimens where they are to make contact with the rollers.

- The specimen shall be placed in the machine in such a manner
that the load shall be applied to the upper most surface as cast in the mould along two lines 133 mm apart if the span of the specimen is 400 mm.

- Load shall be applied without any shock and increasing continuously at a rate such that the extreme fibre stress increases approximately 0.7 N/mm².

- The load shall be increased until the specimen fails and the maximum load applied on the specimen during the test shall be recorded.

- The appearance of fractured faces of concrete and any unique features in the type of failure shall be noted.

The formula for determining the flexural strength is

\[
\sigma_r = \frac{Pa}{bd^2}
\]

(8.2)

Flexural strength testing is shown in Figure 8.2. The test results of flexural strength for SCC mixes M1 to M8 (without steel fibres and with steel fibres) are listed in Table A1.17 to Table A1.24 in the appendix.
8.6 SPLIT TENSILE STRENGTH

The tensile strength is one of the basic and important properties of the concrete. Concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure.

Figure 8.3 Testing of split tensile strength of cylinders

Apart from the flexure test, the other methods to determine the tensile strength of concrete can be broadly classified as a) direct methods, and b) indirect methods. The direct methods suffers from a number of difficulties related to holding the specimen properly in the testing machine without introducing stress concentration and to the application of uniaxial tensile load
which is free from eccentricity to the specimen. Since concrete is weak in
tension, even a small eccentricity of load will induce combined bending and
axial force condition and the concrete fails at the apparent tensile stress other
than the tensile strength.

Because of the difficulties associated with the direct tension test, a
number of indirect methods have been developed to determine the tensile
strength. In these tests in general a compressive force is applied to a concrete
specimen in such a way that the specimen fails due to tensile stresses
developed in the specimen. The tensile stress at which the failure occurs is
termed as the tensile strength of concrete.

The split tensile strength is determined as per the following
procedures:

- Prepare the test cylinder specimen in the standard manner as
given before.
- Place this specimen in the compression testing machine with
  the cast faces in contact with the plates of the testing machine.
- Apply load at a uniform rate until the sample fails.
- Note down the Load at failure.

The split tensile strength is calculated using the following relation:

\[
\text{Split tensile strength} = \frac{\text{Crushing load}}{\text{resisting area of cross section}}
= \frac{W}{\pi d L}
\]  

(8.3)

where

\[ W = \text{Crushing load} \]
Testing of cylindrical specimens is shown in Figure 8.3. The test results of split tensile strength for SCC mixes M1 to M8 (without steel fibres and with steel fibres) are listed in Table A1.25 to Table A1.32 in the appendix.

8.7 STATIC MODULUS OF ELASTICITY

The modulus of elasticity (E-value, the ratio between stress and strain), is used in the calculation of deflection. As the bulk of the volume of concrete is aggregate, the type and amount of aggregate as well as its E-value have the most influence. Selecting an aggregate with a high E-value will increase the modulus of elasticity of concrete. However, increasing the paste volume could decrease the E-value. Because SCC often has higher paste content than traditional vibrated concrete, some differences can be expected and the E-value may be somewhat lower but this should be adequately covered by the safe assumptions on which the formulae provided in EN1992-1-1 are based.

The modulus of elasticity is designated in various ways and they have been illustrated on the stress strain curve. The term Young's Modulus of Elasticity can strictly be applied only to the straight part of stress-strain curve. In the case of concrete, since no part of the graph is straight, the modulus of elasticity is found out with reference to the tangent drawn to the curve at the origin. The modulus found from this tangent is referred as initial tangent modulus. This gives satisfactory results only at low stress value. For higher stress value it gives a misleading picture.
Figure 8.4 Determination of static modulus of elasticity

Tangent can be drawn at any other point on the stress-strain curve. The modulus of elasticity calculated with reference to this tangent is then called tangent modulus. The tangent modulus also does not give a realistic value of modulus of elasticity for the stress level much above or much below the point at which the tangent is drawn. The value of modulus of elasticity will be satisfactory only for stress level in the vicinity of the point considered. A line can be drawn connecting a specified point on the stress-strain curve to the origin of the curve. If the modulus of elasticity is calculated with reference to the slope of this line, the modulus of elasticity is referred as secant modulus. If the modulus of elasticity is found out with reference to the chord drawn between two specified points on the stress-strain curve then such value of the modulus of elasticity is known as chord modulus.
The test specimen shall be kept as per Figure 8.4. The static modulus of elasticity most commonly used in practice is secant modulus. There is no standard method of determining the secant modulus. Some time it is measured at stresses ranging from 30 to 140 kg/cm² and sometime the secant is drawn to point representing a stress level of 15, 25, 33 or 50 percent of ultimate strength. Since the value of secant modulus decreases with increase in stress, the stress at which the secant modulus has been found out should always be stated. The variation of static modulus of elasticity with copper slag proportions for SCC mixes M1 to M8 (without steel fibres and with steel fibres) are listed in Table A1.33 in the appendix.

8.8 DENSITY

The density of hardened concrete has been determined on the 28th day after the necessary curing. The weights of the hardened concrete cubes are noted in surface dry condition. Density is determined dividing the weight by volume of the concrete cubes. The variation of density with copper slag proportions for SCC mixes M1 to M8 (without steel fibres and with steel fibres) are listed in Table A1.34 in the appendix.

8.9 DURABILITY

Concrete is not fully resistant to acids. Most acid solutions will slowly or rapidly disintegrate portland cement concrete depending upon the type and concentration of acid. Certain acids such as oxalic acid and phosphoric acids are harmless. The most vulnerable part of the cement hydrate is Ca(OH)₂, but C-S-H gel can also be attacked. Silicious aggregates are more resistant than calcareous aggregates.

Concrete can be attacked by liquids with pH value less than 6.5. But the attack is severe only at a pH value below 5.5. At a pH value below 4.5,
the attack is very severe. As the attack proceeds, all the cement compounds are eventually broken down and leached away, together with any carbonate aggregate material. With the sulphuric acid attack, calcium sulphate formed can proceed to react with calcium aluminate phase in cement to form calcium sulphoaluminate, which on crystallisation can cause expansion and disruption of concrete. If acids or salt solutions are able to reach the reinforcing steel through cracks or porosity of concrete, corrosion can occur which will cause cracking.

8.9.1 Resistance to Sulphuric Acid

After 28 days of curing in water, 3 Nos of SCC cubes for each concrete grade M1 to M8 were immersed in 5% concentrated H$_2$SO$_4$. The pH value of the solution was maintained the same throughout the test duration. The cubes were tested on the 28$^{th}$ day of immersion to determine the reduction in compressive strength. The variation of compressive strength with copper slag proportions for SCC mixes M1 to M8 (without steel fibres and with steel fibres) are listed in Table A1.35 in the appendix.

8.9.2 Resistance to Hydrochloric Acid

After 28 days of curing in water, 3 Nos of SCC cubes for each concrete grade M1 to M8 were immersed in 5% concentrated HCl. The pH value of the solution was maintained the same throughout the test duration. The cubes were tested on the 28$^{th}$ day of immersion to determine the reduction in compressive strength. The variation of compressive strength with copper slag proportions for SCC mixes M1 to M8 (without steel fibres and with steel fibres) are listed in Table A1.36 in the appendix.
8.10 CONCLUSIONS

After completion of the curing period, the SCC specimens were tested and the test results are given in Table A1.9 to A1.36 in the appendix. The results will be discussed in the next chapter.