Chapter 4
Experimental Methodology

4.1 GENERAL

This chapter presents the testing details of fresh and hardened concrete. The hardened concrete was tested with two types of load namely static and dynamic which are described in the following section.

4.2 TESTING OF FRESH CONCRETE - SLUMP TEST

Slump test was performed as per IS: 1199–1959 to check the consistency of freshly made concrete. The slump cone mould of 100 mm diameter at top and 200 mm diameter at bottom with 300 mm height was used. The tamping rod of 600 mm length, 16 mm diameter was used for conducting the slump test.

4.3 TESTING OF HARDENED CONCRETE - STATIC TEST

The mechanical properties (as per Fig 1.1) such as compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of plain and FRC are described below.

4.3.1 COMPRESSION STRENGTH

As per IS:516-1959 and ASTM C39 the average of three values were taken to determine the compressive strength of hardened concrete of 100 mm size cubes and 150 mm dia cylinder at the age of 7, 28, 56 and 90 days ($f_{ck}$). The measured compressive strength of concrete specimen shall be calculated by dividing the maximum load applied to the concrete specimen during the test by its cross-sectional area and shall be expressed as N/mm$^2$.

4.3.2 SPLITTING TENSILE STRENGTH

Splitting tensile strength was measured by testing cylinders under diametral compression which was recommended by the IS: 5816-1999 and ASTM C496. The test was conducted on two different cylindrical specimens of size 100 mm $\Phi$ with 200 mm height and 150 mm $\Phi$ with 64 mm height.
4.3.3 FLEXURAL STRENGTH

The flexural testing was conducted on 500 mm x 100 mm x 100 mm size specimens and it was subjected to two point or four point loading (including the reactions) to determine the flexural strength of concrete in accordance with the procedure suggested by IS: 516-1959.

4.3.4 MODULUS OF ELASTICITY

The modulus of elasticity is a material property, that describes its stiffness and is therefore one of the most important properties of concrete. The test was conducted on concrete cylinders of size 150 mm Φ and 300 mm height in accordance with the procedure recommended by IS: 516-1959.

4.4 IMPACT TESTING

The impact resistance of the specimens was determined in accordance with the procedure in the ACI committee 544.2R-89. The discussions are given in the following section.

4.4.1 DROP WEIGHT IMPACT TEST ON 150 MM DIAMETER CYLINDER AND PRISM SPECIMENS

The impact test was carried out in two ways; one using drop weight hammer for cylindrical disc and another using drop weight ball for prisms. The testing arrangement of which is shown in Figure 4.1. In drop weight hammer test, the cylindrical discs of 150 mm diameter were placed on the base plate of impact testing machine and then struck with repeated blows. The impact load was applied with a 44.5 N hammer dropped repeatedly from a height of 457 mm onto the discs. Whereas in drop weight ball test, the prisms were supported on a 400 mm span and the impact load was applied with 44.5 N steel ball of 60.2 mm diameter, dropped repeatedly from a height of 457 mm on the center of top surface of the prism. In both these tests, the number of blows required to cause complete failure of the specimen was recorded as the impact failure strength and this method was used by several researchers (Song et al., 2005 a, Atef et al., 2006, Mahmoud and Afroughsabet 2010 a, Chen et al., 2011).
The impact energy delivered by the hammer per blow was calculated as follows:

\[
\text{Impact energy } U = \left( \frac{mV^2}{2} \right) \cdot n = mgH \cdot n \quad (4.1)
\]

\[
H = \left( \frac{gt^2}{2} \right) \quad (4.2)
\]

\[
V = g \cdot t \quad (4.3)
\]

\[
m = \frac{W}{g} \quad (4.4)
\]

Where \( V \) is the velocity of the hammer at impact, \( g \) is acceleration due to gravity, and \( t \) is the time required for the hammer to fall from a height of 457 mm. \( H \) is the height of the fall, \( m \) is mass of the hammer, \( n \) is the number of blows and \( W \) is the weight of the hammer.

Substituting the relevant values in equation 4.2 yields:

\[
457 = \frac{9810t^2}{2}
\]
\[ t = 0.3052 \text{ s and } V = 9810 \times 0.3052 = 2994.01 \text{ mm/s}. \]

The impact failure energy per blow, \( U \), of the hammer can be obtained by substituting the values in equation (4.1).

\[
U = \frac{44.5 \times 2994.01^2}{2 \times 9810} = 20.345 \text{ kNmm}
\]

A total of 126 prisms and 189 cylindrical discs were used in this study as shown in Table 4.1. Out of these, 21 prisms were used for determining the flexural strength prior to impact loading and another 42 prisms were used for determining the impact failure energy of plain and FRC. Remaining 63 prisms were used to determine the flexural strength of concrete exposed to impact load of 25%, 40% and 55% of impact failure energy. Similarly 42 cylindrical discs were used for determining the compression and splitting tensile strength prior to impact loading and another 21 cylindrical discs were used for determining the impact failure energy of plain and FRC. Remaining 126 cylindrical discs were used to determine the compression and splitting tensile strength of concrete exposed to impact load of 25%, 40% and 55% of impact failure energy. These tests were conducted in accordance with the ASTM C39 and ASTM C496 standards.
Table 4.1: Number of specimens employed in this investigation in section 4.4.1

<table>
<thead>
<tr>
<th>Mixture id</th>
<th>Mechanical properties</th>
<th>level of the impact loads employed</th>
<th>Prism</th>
<th>Cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>100% of Impact failure energy</td>
<td>f_{cs}</td>
<td>f_{ts}</td>
</tr>
<tr>
<td>PC</td>
<td></td>
<td>100% of Impact failure energy</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>CF2</td>
<td></td>
<td>55% of impact failure energy</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>CF3</td>
<td></td>
<td>40% of impact failure energy</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>CF4</td>
<td></td>
<td>25% of impact failure energy</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>HF5</td>
<td></td>
<td>100% of Impact failure energy</td>
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<td>3</td>
</tr>
<tr>
<td>HF6</td>
<td></td>
<td>55% of impact failure energy</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>HF7</td>
<td></td>
<td>40% of impact failure energy</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

f_{cs} - Compressive strength of cylinder,

f_{ts} - Splitting tensile strength of cylinder and

f_{fs} - Flexural strength of prism
4.4.2 DROP WEIGHT IMPACT TEST ON 100 MM CYLINDRICAL SPECIMEN

The impact resistance of the specimens was determined in accordance with the procedure suggested by ACI committee 544.2R-89. For this purpose, from each mixture, three discs of size 100 mm x 64 mm were cut from 100 mm x 200 mm cylindrical specimens using a diamond cutter. They were placed on the base plate of impact testing machine and was then struck with repeated blows. The impact load was applied with a 44.5 N hammer dropped repeatedly from a 457 mm height onto a 63.5 mm steel ball, which was located at the center of the top surface of the disc. Figure 4.2 shows the drop weight testing machine with the hardened steel ball. In each test, the number of blows \(N_1\) required to produce the initiation of crack was recorded as the initial crack strength, and the number of blows \(N_2\) needed to cause complete failure of the specimen was recorded as the failure strength and this was method used by several researchers (Song et al., 2005 a, b, Atef et al., 2006, Mahmoud and Afroughsabet 2010 a,b, Chen et al., 2011). The first crack was noted by using portable microscope and failure was noted when the crack reached from top to bottom of the specimen before it was broken and the typical failure of the specimen is shown in Figure 6.13. The impact energy delivered by the hammer per blow can be calculated as discussed in section 4.3.1.

![a) Drop weight testing machine](image1.png)  ![b) Hardened steel ball](image2.png)

Figure 4.2: Drop weight testing machine with the hardened steel ball

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4.4.3 DROP WEIGHT IMPACT TEST ON 100 MM CUBICAL SPECIMEN

The impact resistance of the specimens was determined in accordance with the procedure recommended by ACI committee 544. For this purpose, from each mixture, three cubes (100 mm) were tested under the impact loads. The 13.5 kg hammer was used for applying the impact load which was dropped continuously from a height of 413 mm onto a specimen that was located at the base plate of the impact testing machine is shown in Figure 4.3. In each test, the number of blows required to produce complete failure of the specimen was recorded as the impact failure strength. The impact energy delivered by the hammer per blow can be calculated as follows.

Substituting the corresponding values in equation from 4.1 to 4.4:

\[ 413 = \frac{9810t^2}{2} \]

\[ t = 0.290 \text{ s and } V = 9810 \times 0.290 = 2846.58 \text{ mm/s} \]

The impact energy per blow, \( U \), of the hammer can be obtained by substituting the values in equation 4.1.

\[ U = \frac{135 \times 2846.58^2}{2 \times 9810} = 55.75 \text{ kNmm} \]

Figure 4.3: Drop weight testing machine with cubical specimen
4.4.3.1 ULTRASONIC PULSE VELOCITY TEST

By using ultrasonic concrete tester the pulse velocity of 28 days cured FRC samples was measured according to the procedure recommended by IS: 13311-1992. This measurement of pulse velocity was done on the side faces of the concrete cube and it was repeated for every three impact load until the failure of specimen.

4.5 SUMMARY

This chapter summarizes the testing methods of concrete specimen for evaluating their mechanical properties and impact strength. Also it describes the concrete specimen being subjected to two different types of impact load namely single point impact and surface area impact. For this purpose, the impact test was carried out in two ways; one using drop weight hammer and another using drop weight ball test which has been discussed in detail in this chapter. The mechanical properties of FRC have been discussed in detail in chapter 5. The losses in mechanical properties under different level of impact load, impact resistance, MLR model for evaluating impact strength of FRC and quality of concrete under impact load which was evaluated using UPV are discussed in the chapter 6.