The Effects of Impact Loading on the Flexural Strength of Fibre Reinforced Concrete

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The research work presented in this paper focused on the experimental investigation of loss in flexural strength of fibre reinforced concrete (FRC) exposed to various levels of impact loading. For this purpose, a total of 210 (100 x 100 x 500 mm) specimens were cast using hooked end steel fibres with varying aspect ratios of 50, 65, and 80 at different volume fractions of 0.5, 1.0 and 1.5%. As per the guidelines of ACI Committee 544, Drop-weight test was performed on a 28 days cured specimen in order to identify the loss in flexural strength due to the effect of impact loading. The specimens were exposed to different levels of impact loads such as 15, 25, 35, 45, and 55% of their impact failure energy. In addition, a multiple linear regression model was developed using the experimental test results to predict the percentage loss in flexural strength due to the effect of various levels of impact load. The results displayed that as the volume fraction and aspect ratio of fiber was increased, the impact resistance of concrete was also increased while the losses in flexural strength were decreased.

Keywords: Impact Load, Flexural Strength, Steel Fibre, Concrete

Introduction

It is a well known fact that the impact resistance of high strength concrete is recognized as one of the important properties used in today’s civilian and military applications1. The usage of various types of steel fibers is hugely promising in improving the impact strength of concrete structures2-4. The plain and FRC’s resistance against the impact load is quite deficient, resulting in randomly occurring cracks and concrete losses its mechanical properties and hence material cannot deliver the expected performance. The available studies are majorly limited to evaluate the impact strength of FRC5-7, but losses in mechanical properties of FRC subsequently exposing to impact load is inexhaustible. This study primarily focused on the loss in flexural strength of FRC under impact loads corresponding to various levels of impact failure energies. Furthermore, for predicting the loss in flexural strength of FRC under different levels of impact loads, a multiple linear regression model was developed.

Experimental program

Materials

Cement

Ordinary portland cement (OPC) Grade 53 conforming to IS 12269:19878 and manufactured by bharathi cement corporation private limited with initial and final setting time of 160 and 260 minutes respectively was used in this investigation. The cement content was kept constant at 345 kg/m3 for all the mixes.

Fine and coarse aggregate

The fine aggregate used in this study was natural siliceous river sand conforming to IS 383:19709 having a specific gravity of 2.63. The coarse aggregates used were crushed granite gravel of size 12.5 mm and 20 mm and a specific gravity of 2.71.

Water and superplasticizer

Potable water with pH value of 6 was used in all the mixes. In order to improve the workability of all concrete mixes a commercial high-performance superplasticizer (Sp) master glenium SKY 8233 (polycarboxylic ether) was added on mass basis varying from 0.35 to 1.1% of the cement content and

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the slump value was maintained as 65 mm for all the mixes. Water binder ratio of 0.43 was adopted for M35 grade concrete for all the mixes.

**Fibres**

Hooked end steel fibres with aspect ratios of 50, 65 and 80 were used in this study. The fiber with the aspect ratio 50, was 50 mm in length, 1.0 mm in diameter, and had tensile strength of 1050 MPa. The fiber with the aspect ratio 65, was 60 mm in length, 0.9 mm in diameter, and had tensile strength of 1000 MPa. The fiber with the aspect ratio 80, was 60 mm in length, 0.75 mm in diameter, and had tensile strength of 1000 MPa. The dosage of steel fibers used was 0.5%, 1.0% and 1.5% in volume of the concrete. The details of the mixture proportions for a cubic meter of concrete are given in (Table 1).

**Specimen moulding**

A total of 210 specimens were fabricated in this study. Out of these, 30 specimens were used for determining the flexural strength prior to impact loading and another 30 specimens were used for determining the impact failure energy of plain and FRC. Remaining 150 specimens were used to determine the flexural strength of concrete exposed to impact loads of 15, 25, 35, 45 and 55% of the impact failure energy and the average results of three specimens were reported.

**Flexural strength**

The flexural testing was conducted on 100 mm x 100 mm x 500 mm size specimens and it was subjected to two point loading in order to determine the flexural strength of concrete in accordance with the procedure recommended by IS: 516-1959\(^\text{10}\).

**Impact test**

The drop weight impact test was conducted based on modification of the recommendations by ACI Committee 544\(^\text{11}\). In this modified impact test, the 44.5 N steel ball of 60 mm diameter was released repeatedly from a height of 457 mm on to the center of the top surface of specimen which was supported on a 400 mm span as shown in (Figure 1). The number of blows required to cause 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:

$$U = \frac{mV^2}{2} \cdot n \quad \ldots \ (1)$$

where \(V\) is the velocity of hammer at impact, \(m\) is mass of hammer and \(n\) is the number of blows. The impact failure energy per blow, \(U\), of the hammer can be obtained by substituting the values in Eq. (1)\(^\text{12}\).

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**Table 1 — Mix proportion of concrete**

<table>
<thead>
<tr>
<th>Mix id</th>
<th>W/B</th>
<th>Water (Kg/m(^3))</th>
<th>Cement (Kg/m(^3))</th>
<th>Fine Agg. (Kg/m(^3))</th>
<th>Coarse Agg. (Kg/m(^3))</th>
<th>Volume fraction (V_f)</th>
<th>Aspect ratio (l/d)</th>
<th>Weight (Kg/m(^3))</th>
<th>Sp (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>0.43</td>
<td>148</td>
<td>345</td>
<td>888</td>
<td>679</td>
<td>452</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td>FC1</td>
<td>0.43</td>
<td>148</td>
<td>345</td>
<td>879</td>
<td>672</td>
<td>448</td>
<td>0.5</td>
<td>50</td>
<td>39</td>
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<tr>
<td>FC2</td>
<td>0.43</td>
<td>148</td>
<td>345</td>
<td>866</td>
<td>661</td>
<td>441</td>
<td>1.0</td>
<td>50</td>
<td>78</td>
</tr>
<tr>
<td>FC3</td>
<td>0.43</td>
<td>148</td>
<td>345</td>
<td>859</td>
<td>666</td>
<td>437</td>
<td>1.5</td>
<td>50</td>
<td>117</td>
</tr>
<tr>
<td>FC4</td>
<td>0.43</td>
<td>148</td>
<td>345</td>
<td>879</td>
<td>672</td>
<td>448</td>
<td>0.5</td>
<td>65</td>
<td>39</td>
</tr>
<tr>
<td>FC5</td>
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<td>148</td>
<td>345</td>
<td>866</td>
<td>661</td>
<td>441</td>
<td>1.0</td>
<td>65</td>
<td>78</td>
</tr>
<tr>
<td>FC6</td>
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<td>148</td>
<td>345</td>
<td>859</td>
<td>666</td>
<td>437</td>
<td>1.5</td>
<td>65</td>
<td>117</td>
</tr>
<tr>
<td>FC7</td>
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<td>148</td>
<td>345</td>
<td>879</td>
<td>672</td>
<td>448</td>
<td>0.5</td>
<td>80</td>
<td>39</td>
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<td>148</td>
<td>345</td>
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<td>441</td>
<td>1.0</td>
<td>80</td>
<td>78</td>
</tr>
<tr>
<td>FC9</td>
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<td>148</td>
<td>345</td>
<td>859</td>
<td>666</td>
<td>437</td>
<td>1.5</td>
<td>80</td>
<td>117</td>
</tr>
</tbody>
</table>

**Fig. 1 — Schematic diagram of drop-weight ball test device:**

1-Positioning magnetic switch, 2-Drop hammer, 3-Guidance, 4-Steel ball, 5-Specimen, 6-Positioning lug, 7-Base plate, 8-Support for specimen, 9-Impact frame
\[ U = \frac{44.5x294.01^2}{2x9810} = 20.345 \text{ kN mm}. \]

Results and Discussion

It can be observed from (Table 2) that there is an increase in flexural strength of concrete as dosage and aspect ratio of fibres is increased\(^{13}\). In general, the increase in the flexural strength varies from 14 to 41% in FRC. The maximum increase in flexural strength varied from 14 to 30%, 17 to 34% and 22 to 41% for mixes FC1-FC3, FC4-FC6 and FC7-FC9 respectively. The number of blows (N) required to cause the failure of PC specimens was 18 and it has been displayed in Table 2. There was a significant increase in the number blows to cause failure of FRC and it was 1.3 - 2.2 times for the FRC with \( l/d = 50 \) (FC1-FC3), 1.4 - 2.5 times for the FRC with \( l/d = 65 \) (FC4-FC6) and 1.8 - 2.7 times for the FRC with \( l/d = 80 \) (FC7-FC9) when compared to PC. Also from Table 2, the impact energy of PC was found to be 366.21 kN mm and the impact energy increased by 33 - 117% for the FRC with \( l/d = 50 \) (FC1-FC3), 44 - 150% for the FRC with \( l/d = 65 \) (FC4-FC6) and 78 - 167% for the FRC with \( l/d = 80 \) (FC7-FC9) with reference to PC. Results displayed that increasing volume fraction of steel fibre and aspect ratio in concrete led to conclusive increase in impact strength\(^{14}\). It can seen from (Figure 2) that the loss in flexural strength of concrete when exposed to 15% of impact failure energy was 44% for PC and it was between 41 and 34% for the FRC (FC1-FC3), between 39 and 26% for the FRC (FC4-FC6) and between 38 and 23% for the FRC (FC7-FC9). When the concrete specimens was exposed to the level of 25% of their impact failure energy, the loss occurred in flexural strength of PC was 55% and it was between 46 and 33% for the FRC (FC1-FC3), between 44 and 21% for the FRC (FC4-FC6) and between 39 and 26% for the FRC (FC7-FC9). The specimens exposed to the level of 35% of their impact failure energy experienced a loss in flexural strength of 58% in case of PC and it was between 49 and 38% for the FRC (FC1-FC3), between 47 and 26% for the FRC (FC4-FC6) and between 46 and 30% for the FRC (FC7-FC9). The loss occurred in flexural strength of PC was 65% and it was between 55 and 44% for the FRC (FC1-FC3), between 53 and 31% for the FRC (FC4-FC6) and between 50 and 33% for the FRC (FC7-FC9) when the specimens were exposed to the level of 45% of their impact failure energy. Similarly the losses in flexural strength of specimens, exposed to the level of 55% of their impact failure energy was 70% for PC and it was between 58 and 46% for the FRC (FC1-FC3), between 54 and 36% for the FRC (FC4-FC6) and between 51 and 36% for the FRC (FC7-FC9). From the results of five levels of impact effects, a least amount of loss in flexural strength was observed in FRC (FC7-FC9) when

![Fig. 2 — The loss of flexural strength and level of impact energy](image-url)

<table>
<thead>
<tr>
<th>Mix id</th>
<th>Loss of flexural strength and the level of impact load employed</th>
<th>Impact Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>15%</td>
</tr>
<tr>
<td>PC</td>
<td>4.28</td>
<td>2.39</td>
</tr>
<tr>
<td>FC1</td>
<td>4.86</td>
<td>2.88</td>
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<tr>
<td>FC2</td>
<td>5.28</td>
<td>3.35</td>
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<tr>
<td>FC3</td>
<td>5.58</td>
<td>3.68</td>
</tr>
<tr>
<td>FC4</td>
<td>4.99</td>
<td>3.05</td>
</tr>
<tr>
<td>FC5</td>
<td>5.39</td>
<td>3.38</td>
</tr>
<tr>
<td>FC6</td>
<td>5.74</td>
<td>4.25</td>
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<tr>
<td>FC7</td>
<td>5.22</td>
<td>3.25</td>
</tr>
<tr>
<td>FC8</td>
<td>5.67</td>
<td>3.96</td>
</tr>
<tr>
<td>FC9</td>
<td>6.03</td>
<td>4.62</td>
</tr>
</tbody>
</table>

N—Number of blows; U—Impact failure energy (kN mm)
compared to PC. When the volume fraction of fiber and aspect ratio of fibers were increased the losses in flexural strength of concrete decreased substantially at all the five impact levels\textsuperscript{15}. It can be concluded from the above investigation that when the concrete is exposed to an impact load of 15\% of its impact failure energy, the PC had 1.0-1.9 times loss in flexural strength compared to FRC. Similarly when the concrete is exposed to impact loads of 25, 35, 45 and 55\% of their impact failure energy, the loss in flexural strength of PC varies from 1.2-2.1, 1.2-1.9, 1.2-2.0 and 1.2-1.9 times respectively. The best performance was obtained from the concrete incorporating 1.5\% volume fraction of steel fibre with l/d = 80 (FC9)\textsuperscript{15}.

**Loss of flexural strength—analysis and modeling**

Percentage loss of flexural strength (dependent variable) of PC and FRC when exposed to impact loads of 15, 25, 35, 45 and 55\% of their impact failure energy were considered as a function of the following four input parameter (independent variable). (i) Level of the impact loads employed ($x_1$) (ii) Volume fraction of fiber ($x_2$) (iii) Aspect ratio ($x_3$) and (iv) Tensile strength of fiber ($x_4$). The loss of flexural strength of PC and FRC exposed to impact load greatly depends upon these four parameters and hence it has been used in regression analysis to establish a relationship between the dependent and independent variables. In multiple linear regression analysis, it is assumed that the variable $y$ is related to variables $x_1$, $x_2$, $x_3$, $x_4$, for which an individual value of $y$ is defined as:\textsuperscript{16}

$$y = A + Bx_1 + Cx_2 + Dx_3 + Ex_4$$

where $y$ is the estimated percentage loss of flexural strength exposed to impact loads of 15, 25, 35, 45 and 55\% of their impact failure energy or dependent variable, where A, B, C & D are the regression coefficients and $x_1$, $x_2$.....$x_4$ are the independent variables. The statistical models (equation for loss of flexural strength) was developed using SPSS software package as given in Eq. (3). The correlation coefficient for $y$ was found to be 0.853.

$$y = 3.4 + (-0.042 \times x_1) + (0.023 \times x_2) + (1.166 \times x_3) + (-0.001 \times x_4)$$

The predicted values of percentage loss of flexural strength exposed to impact loads of 15, 25, 35, 45, and 55\% of their impact failure energy obtained using Eq. (3) can be seen in (Figure 3). The proposed models were in good agreement with the experimental and predicted value. Moreover the maximum difference between the experimental and predicted value was 21\% for the loss of flexural strength and hence a higher is being achieved as shown in (Figure 3). In the view of convenience and generality, the statistical model is reasonable, accurate and preferable to evaluate the loss of flexural strength of PC and FRC exposed to impact load without carrying out the drop weight test and this model is applicable only up to M35 grade of concrete.

**Conclusions**

The following conclusion has been arrived from this experimental investigation conducted on plain and FRC mixtures. Addition of fibre to concrete increased the number of blows required to cause the failure by 1.3 - 2.2 times for the FRC with l/d =50 (FC1-FC3), 1.4 - 2.5 times for the FRC with l/d =65 (FC4-FC6) and 1.8 - 2.7 times for the FRC with l/d =80 (FC7-FC9) when compared to PC. Increasing the steel fiber volume and its aspect ratio in concrete leads to an increase in its impact resistance. The steel fibers increased the impact failure energy by 33 - 117\% for the FRC with l/d =50 (FC1-FC3), 44 - 150\% for the FRC with l/d =65 (FC4-FC6) and 78 - 167\% for the FRC with l/d =80 (FC7-FC9) when compared to PC. Increasing the steel fiber volume and its aspect ratio in concrete leads to an increase in its impact resistance. The steel fibers increased the impact failure energy by 33 - 117\% for the FRC with l/d =50 (FC1-FC3), 44 - 150\% for the FRC with l/d =65 (FC4-FC6) and 78 - 167\% for the FRC with l/d =80 (FC7-FC9) when compared with PC. The PC had 1.0 - 1.9, 1.2 - 2.1, 1.2 - 1.9, 1.2 - 2.0 and 1.2 - 1.9 times loss in flexural strength when exposed to impact load levels of 15, 25, 35, 45 and 55\% their impact failure energy with reference to FRC. The losses in flexural strength were decreased considerably as the volume fraction and aspect ratio of fibers were increased. The best performance of concrete under impact loading was obtained in the mixes FC9 (l/d =80), followed by FC6 (l/d =65) and FC3 (l/d =50). The multiple linear regression analysis showed that the
predicted values were in good agreement with the experimental data. The developed multiple regression model can be used to predict the loss of flexural strength exposed to various levels of impact load and this model would be suitable for preliminary design of marine and offshore structures exposed to ice and barge impact, the impact from in-service bullets to a military fortification, in case of defense structures and vehicle crash impact of concrete structures etc.

References