Interrelationship of Properties of PPFRC

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Abstract: The study is aimed at determining the interrelationship between various mechanical properties of Polypropylene Fibre Reinforced Concrete (PFRC). The existing Indian standard recommendations for characteristics relationships for normal-strength concrete were evaluated to determine their validity for PFRC. M 30 PFRC mix was analyzed in terms of compressive strength, modulus of rupture, splitting tensile strength, and modulus of elasticity. The Indian standard IS: 456 [13] relationships for the prediction of the modulus of rupture and the splitting tensile resulted in non-conservative results for PFRC; an alternative relationship is proposed for the PFRC while the results for Modulus of Elasticity were close to the relationship given by IS.

Keywords: Polypropylene Fibre, Compressive, Modulus of rupture, Tensile strength, Modulus of elasticity

1. INTRODUCTION

In recent years Fibre reinforced concrete (FRC) has been developed to overcome some shortcomings of conventional concrete such as low tensile and flexural strength, poor toughness, and high brittleness. The ability of the fibers to bridge cracks at high levels of strain determines the ductility of fiber reinforced concrete. The unit weight of concrete and its weight is increased on the addition of Polypropylene fibres [1]. Good concrete must have high strength and low permeability. Inclusion of polypropylene fibers reduces the water permeability, increases the flexural strength due to its high modulus of elasticity [2]. The Polypropylene fibers are protected against wetting with cement owing to their hydrophobic property. The water cement ratio for concrete is unaffected by the addition of Polypropylene concrete owing to its hydrophobic nature. Studies are needed to establish the relationships between its various physical properties. In the case of normal-strength concrete the relationships are well established. Utilizing formulas to determine the Elastic modulus of Concrete from compressive strength saves labor and time. For normal concrete various building codes have provided the formulas to predict the strength of concrete. Since PFRC have different physical characteristics from normal strength concrete, these existing prediction formulas may not be applicable for PFRC. This study is an attempt to establish such relationships for PFRC.

2. EXPERIMENTAL PROGRAM

Materials

The OPC 53 HAVING 3.15 Specific gravity was used. The cement Conforming to various specifications IS: 4031[8] part 5 and of IS: 12269[10] was used. Crushed angular aggregate of size 20 mm having specific gravity 2.7 and fineness modulus of 4.05 conforming to IS: 383[11] is used. River sand with specific gravity 2.6 and fineness modulus 2.62 conforming to IS: 383[11] is used. The Polypropylene staple fibre was obtained from Zenith fibers, Vadodara, India which acted as the bonding agent in concrete fabrication. The physical properties of polypropylene fibre conform to ASTM D-3822-07 and are enlisted in Table 1. The fibre was used by weight of cement i.e. 0.5%, 1%, 1.5% and 2% as Mix, Mix¹, Mix¹.5 and Mix² respectively.

<table>
<thead>
<tr>
<th>Table-1 Physical property of fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
</tr>
<tr>
<td>Polypropylene</td>
</tr>
</tbody>
</table>

The compressive strength of the original concrete was 36.69 N/mm².

Mixing of Concrete

All mix designs used in this investigation were developed using IS: 456 and IS: 10262[13][9].

Table II gives the mix proportion for the PFRC.
### TABLE 2 Laboratory Mix Proportions for the PFRC

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Cement (kg/m³)</th>
<th>Sand (kg/m³)</th>
<th>Aggr. (kg/m³)</th>
<th>Water (kg/m³)</th>
<th>%age fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>360</td>
<td>678</td>
<td>951</td>
<td>199</td>
<td>0.5%</td>
</tr>
<tr>
<td>II</td>
<td>360</td>
<td>678</td>
<td>951</td>
<td>199</td>
<td>1%</td>
</tr>
<tr>
<td>III</td>
<td>360</td>
<td>678</td>
<td>951</td>
<td>199</td>
<td>1.5%</td>
</tr>
<tr>
<td>IV</td>
<td>360</td>
<td>678</td>
<td>951</td>
<td>199</td>
<td>2%</td>
</tr>
</tbody>
</table>

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### Casting of Test Specimens

For beam specimens, standard 100x100x500 mm steel molds were used, while for the cylinder specimens, 150 x 300-mm steel molds were used. Upon completion of casting, all molds were immediately covered with wet burlap and plasticsheeting for 24 hours to prevent loss of moisture.

### Curing of Concrete Specimens

Approximately 20 to 24 hours after initial curing, specimens were stripped and kept in the standard moist room where curing continued at about 27° ± 2°C and 90 percent relative humidity until the time of testing as per IS: 516-1959.

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### 3.0 RESULTS AND DISCUSSION

#### Relationship of the Compressive Strength and the Modulus of Rupture

The modulus of rupture was performed according to IS: 516-1959[12] with three-point loading. The modulus of rupture was calculated by the relation:

$$fr = \frac{PL}{bd^2} \quad (1)$$

Where:

- $fr =$ flexural strength or modulus of rupture
- $P =$ maximum applied load
- $L =$ span length
- $b =$ average width of specimen
- $d =$ average depth of specimen

The modulus of rupture calculated using Equation 1 is not a true representative of the tensile strength of concrete since it assumes the applicability of Hooke's law of stress-strain proportionality throughout the depth of the beam. Since concrete deformations do not follow Hooke's law, the formula results in fictitious tensile stress values that are higher than the actual stresses in the beam. In fact, concrete researchers [3-7] have indicated that the true tensile strength is about 65 to 70 percent of the modulus of rupture. Nevertheless, the compressive strength and the modulus of rupture are closely related. As the compressive strength increases, the modulus of rupture also increases.

One of the most commonly used equations for relating the compressive strength of normal-weight concrete and its modulus of rupture is the following IS: 456 [13] equation:

$$fr = 0.7 \sqrt{fckMpa} \quad (2)$$

Where:

- $fr =$ modulus of rupture
- $fck =$ compressive strength

The results of the modulus of rupture for the PFRC are given in Table 4 and shown in Figure 1 along with the IS: 456[13] equation. Regression analyses were performed to establishempirical relationships between the compressive strength and the modulus of rupture using the following regression model: $fr = Afck$(3)

The following predicted relationship was obtained with the coefficient of determination $R^2 = 0.828$, as shown in Figure 2.

$$fr = 1.326 fck^{0.852} \quad (4)$$

Table-4

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Test Age</th>
<th>Fck (MPa)</th>
<th>fr Exp. (MPa)</th>
<th>fr IS Eq (MPa)</th>
<th>fr Proposed (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>28 Days</td>
<td>41.19</td>
<td>5.2</td>
<td>4.49</td>
<td>5.2</td>
</tr>
<tr>
<td>II</td>
<td>28 Days</td>
<td>41.78</td>
<td>5.6</td>
<td>4.52</td>
<td>6.1</td>
</tr>
<tr>
<td>III</td>
<td>28 Days</td>
<td>42.97</td>
<td>6.28</td>
<td>4.59</td>
<td>6.32</td>
</tr>
<tr>
<td>IV</td>
<td>28 Days</td>
<td>42.67</td>
<td>6.57</td>
<td>4.57</td>
<td>6.5</td>
</tr>
</tbody>
</table>
The IS: 456[13] equation resulted in a significant underestimation of the modulus of rupture of the PFRC, thus generating conservative results. The proposed equation was accurate in predicting the results which were almost same as to the experimental result values.

The regression analysis was performed between the experimental modulus of rupture and the predicted modulus of rupture which resulted in the value of $R^2$ as 0.82 which suggests a strong relationship between the two. Hence the predicted equation was more close and accurate in predicting the results of experimental study.

**Relationship of Compressive Strength and Splitting Tensile Strength**

Splitting tensile strength tests were performed to compare with the modulus of rupture. These tests were performed in accordance with IS: 5816-1959[14] and IS: 516-1959[12]. The tensile strength was computed as follows:

$$f_t = \frac{2P}{\pi DL} \quad (5)$$

Where:
- $f_t =$ tensile strength
- $P =$ maximum applied load
- $L =$ length of cylinder
- $D =$ diameter of cylinder

The following equation is used by IS: 456[13] to estimate the splitting tensile strength of concrete:

$$f_r = 0.7 \sqrt{f_{ck}} \quad (6)$$

Where:
- $f_r =$ splitting tensile strength
- $f_{ck} =$ the compressive strength

The results of the splitting tensile strength for the PFRC are given in Table 5 and shown in Figure 3 along with the IS: 456[13] equation.

**TABLE 5 Results of the Splitting Tensile Strength for RAC and ACI Equation**

<table>
<thead>
<tr>
<th>Mix</th>
<th>Test Age</th>
<th>Fck (MPa)</th>
<th>$f_t$ Exp (MPa)</th>
<th>$f_t$ IS Eq (MPa)</th>
<th>$f_t$ Prop (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>28 Days</td>
<td>41.19</td>
<td>3.53</td>
<td>4.49</td>
<td>3.03</td>
</tr>
<tr>
<td>II</td>
<td>28 Days</td>
<td>41.78</td>
<td>3.67</td>
<td>4.52</td>
<td>3.78</td>
</tr>
<tr>
<td>III</td>
<td>28</td>
<td>42.97</td>
<td>3.87</td>
<td>4.59</td>
<td>3.88</td>
</tr>
</tbody>
</table>
As shown in the figure, the IS equation resulted in an excellent representation of the compressive and tensile strength relationships for PFRC. Regression analyses performed on the results gave the following relations for the PFRC with the coefficient of determination $R^2 = 0.67$, as shown in Figure 4.

$$fr = 2.687f_{ck}^{0.25} \quad (7)$$

Again, Equation 7 is almost identical to IS Equation 6. Therefore, the use of the IS equation for the prediction of the splitting tensile strength from the compressive strength of the PFRC should be adequate.

**Figure 3 Comparison of Experimental Splitting Tensile Strength for the RAC with Code Equation**

**Figure 4 Experimental Vs Predicted Splitting Tensile Strength**

**Relationship of the Modulus of Rupture and the Splitting Tensile Strength**

Although both the modulus of rupture and the splitting tensile strength are usually used to estimate the tensile strength of concrete, they do not yield equivalent results.

Regression analyses were performed on the results obtained in this study using the following linear regression model:

$$ft = Afr \quad (8)$$

As shown in Equation 8, the splitting tensile strength was approximately 50 percent of the modulus of rupture for the PFRC.

**Relationship of the Compressive Strength and the Modulus of Elasticity**

The modulus of elasticity (Young’s Modulus) test was performed in accordance with IS: 516-1959[12]. An extensometer was used to measure the deformation of the cylindrical specimen as it was loaded. According to the IS: 456[13] Code, the empirical relationship between the
compressive strength and the modulus of elasticity is given by:

\[ Ec = 5000 \sqrt{f_{ck}} \]

Ec = static modulus of concrete

fck = the compressive strength

**TABLE 6 Results of the Modulus of Elasticity for PFRC and IS Equation**

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Test Age</th>
<th>Fck (MPa)</th>
<th>EcExp (MPa)</th>
<th>Ec IS Eq. (MPa)</th>
<th>Ec IS Prop (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>28 Days</td>
<td>41.19</td>
<td>38.34</td>
<td>32.09</td>
<td>30.33</td>
</tr>
<tr>
<td>II</td>
<td>28 Days</td>
<td>41.78</td>
<td>39.45</td>
<td>32.32</td>
<td>30.87</td>
</tr>
<tr>
<td>III</td>
<td>28 Days</td>
<td>42.97</td>
<td>37.65</td>
<td>32.78</td>
<td>30.56</td>
</tr>
<tr>
<td>IV</td>
<td>28 Days</td>
<td>42.67</td>
<td>39.56</td>
<td>32.66</td>
<td>31.34</td>
</tr>
</tbody>
</table>

**Figure 5 Comparison of Experimental Modulus of Elasticity for the PFRC with Code Equation**

The results of the modulus of elasticity for the PFRC are given in Table 6 and shown in Figure 5 along with the IS equation. As shown in the figure, the IS equation resulted in an overestimation of the modulus of elasticity for PFRC. Regression analyses performed on the results gave the following relations for the PFRC with the coefficient of determination \( R^2 = 0.61 \), as shown in Figure 6.

### 4.0 CONCLUSIONS

Based on the results of the limited testing program reported herein, the following conclusions are appropriate.

- The IS: 456\[13\] relation for the prediction of rupture for normal-strength concrete results in very conservative estimates when used for the PFRC. Therefore, the following relation is proposed for the PFRC:

\[ f_r = 1.326 f_{ck}^{0.852} \]

- The ACI relation provides adequate estimates for the prediction of the modulus of rupture of the PFRC.

- The modulus of rupture was found to be about 50 percent of the splitting tensile strength of the PFRC.

A research study which compiles all available data on the physical properties of PFRC is needed to provide...
adequate evaluation of the relationships discussed herein. While the conclusions stated appear to be reasonable and consistent with most other published data, a more extensive study of the relationship between compressive strength and modulus of elasticity for PFRC is clearly needed.

REFERENCES


