Experimental investigation on strength properties of poly-propylene fibre reinforced concrete

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Abstract: The scope of the current investigation is to examine the mechanical properties of concrete with the addition of DURASTRAN Poly-propylene macro-fibres. The incorporation of highly engineered poly-propylene macro-fibre in concrete will result in improving many physical and mechanical properties of the concrete. Poly-propylene macro-fibre reinforced concrete has various applications such as tunneling & mining, commercial &industrial flooring and precast concrete structures. High strength (M40 grade) concrete with 0.36 water-cement ratio was used in this study. Poly-propylene macro-fibre was added only as an additional material, not as a replacement to aggregates. Various strength properties like compressive strength, tensile strength and flexural strength were studied and reported.

1. INTRODUCTION

Concrete has higher resistance towards compression but lower resistance for tension and flexure. As a result, some cracks can be seen, but majority of the cracks cannot be seen as these are developed inside the concrete mass which is well below the surface. Due to excessive tensile stresses cracks are developed. These cracks are mainly because of the difference in outer and inner temperature of hydration or due to the load which is above the design load. When stress in concrete changes swiftly, it begins to develop cracks and will continue to propagate when the time progresses and with the addition of stresses. There is an effect in the cracking mechanism, when there is a change in the condition of the weather. When concrete cracks, those cracks are held by the reinforcement. Later the load is transferred by bond action and the anchorage of bars. Poly-Propylene macro-fibre reinforcement also works in a similar manner; there is reduction in crack width and leads to gain in tensile strength. Macro-fibre plays a major role in arresting these cracks. Polypropylene monofilament macro-fibre uniformly holds the concrete and does not allow cracks to develop. Therefore, macro-fibre ensures concrete protection on both outside and inside.

2. MATERIALS AND MIXING:

2.1. Cement

The cement used is Ordinary Portland Cement - 53 Grade of Dalmia brand procured locally. The tests were done according to the codal provision of IS 4031 (part 1, 4, 5, 1996) and IS 4031 (part 11, 1988). The results of the tests performed on cement used (OPC) are listed in Table 1.
Table 1. Test results on Cement

| Cement                      | OPC (Grade 53) |
|-----------------------------|----------------|
| Specific gravity            | 3.06           |
| Fineness (%)                | 3.5            |
| Normal Consistency (%)      | 33.4           |
| Setting Time (Initial)      | 36             |
| Setting Time (Final)        | 490            |

2.2. Fine Aggregate
In this study river sand is used as fine aggregate. Tests were done according to the codal provision IS 2386 (part 3, 1963)[10] and tabulated in Table 2.

Table 2. Properties of Fine Aggregate

| Zone      | 2  |
|-----------|----|
| % Absorption of Water | 2  |
| Specific gravity     | 2.65|

2.3. Coarse Aggregate
The nominal size of the coarse aggregate used is 12.5mm and 20mm and it was blended in the ratio 1:1.5. Coarse aggregate properties were tested using the codal provision IS 2386 (part 3, 1963)[10] and are tabulated in Table 3.

Table 3. Properties of Coarse Aggregate

| Coarse Aggregate (Nominal Size) | 12.5mm | 20mm |
|---------------------------------|--------|------|
| % Absorption of Water           | 0.7     | 0.4  |
| Specific Gravity                | 2.71    | 2.74 |

2.4. Poly-propylene Macro-fibre
Polypropylene macro-fibres do not absorb water as they are hydrophobic in nature. The maximum nominal size of the aggregate plays a major role in determining the macro-fibre’s length used in the mix[1][2]. Many researches recommend that the macro-fibre’s length should be greater than two times the aggregate’s diameter. This finding was established based on past researches in this field[7][8]. Monofilament macro-fibres are single strand macro-fibre similar in shape to a standard finishing nail or smooth rebar[9]. It features a unique continuous embossed surface, enabling the macro-fibre to achieve maximum bond with the cement matrix for optimum performance[3][5]. An international brand of Poly - Propylene Macro Fibre DURASTRAN (Manufactured in India by Nuovafil and InfoteckP.Ltd, Coimbatore) was used in this study. The properties of the Poly - propylene macro-fibre used in this study is listed below in Table 4.

Table 4. Properties of Poly-propylene Macro-fibre

| Specific gravity          | 0.91  |
| Fibre Configuration       | Modified, Crimped Monofilament |
| Macro-fibre Length (mm)   | 51    |
| Absorption                | Nil   |
| Alkali & Chemical resistance | Excellent |
| Melting point (° C)       | 160   |

2.5. Admixture
Poly carboxylate superplasticizer was used for the study. For every 25 litres reduction in water, 0.3% of superplasticizer by weight of cement was added[6].
2.6. Mix Design
M40 grade concrete was used in this study and the mix was designed based on the codal provision IS 10262 (2009)[11]. The amount of macro-fibre added to the concrete was 2kg per cubic meter. The amount of materials used per m$^3$ is listed in Table 5.

| Material               | Quantity (kg) |
|------------------------|---------------|
| Cement                 | 430           |
| Fine Aggregate         | 650.91        |
| Coarse Aggregate       | 1221.23       |
| Water                  | 155           |

### 3. EXPERIMENTAL INVESTIGATION

Details of the tests performed to examine the hardened properties of the concrete at different age levels are included in this section.

#### 3.1. Compressive Strength Test
A cube specimen of size 15X15X15 cm was used to determine the strength under compression. The methods and procedure were corresponding to IS 516(1959)[12]. After that the specimen sample was placed such that the load was applied perpendicular to the side of casting. At a constant rate of 140 kg/cm$^2$/min, the load was applied in the compression testing machine[4]. The specimen will be automatically unloaded and the failure load was noted. Figure 1 displays the image of the Compression Testing Machine. Compressive strength of the concrete was determined from the below formula.

$$\text{Compressive Strength}(f_{ck}) = \frac{\text{Load in N}}{\text{Area in mm}^2}$$

#### 3.2. Split Tensile Strength Test
The specimen in the shape of cylinder of diameter 15cm and height 30cm was used in the Split tensile test. The methods and procedure was according to IS 5816(1999)[13]. At a constant rate of 140 kg/cm$^2$/min, the load was applied in the compression testing machine. The specimen will be automatically unloaded and the failure load was noted. Tensile strength of the concrete was determined by the below formula.

$$\text{Tensile Strength}(f_{ct}) = \frac{2P}{\pi LD}$$

Where,

- $P = \text{maximum applied load indicated by the testing machine (N)}$
- $D, L = \text{diameter and length of the specimen respectively (mm)}$

![Figure 1. Compression Testing Machine](image)
3.3. Flexural Strength Test
The beam specimen of size 10X10X50cm was used for testing flexural strength of the concrete. Three point test was carried out using a Flexural testing machine in accordance with IS 516(1959). Flexural testing machine is shown in Figure 2.

\[ Flexural\ Strength = \frac{Pl}{bd^2} \]

Where,
- \( P \) = ultimate load applied (N)
- \( L, b, d \) = length, width, depth of the specimen respectively (cm)

![Flexural Testing Machine](image)

Figure 2. Flexural Testing Machine

4. RESULTS AND DISCUSSION

4.1. Compressive Strength of Concrete
This test was carried out on hardened concrete cubic specimens at different age levels (7, 14, 28 days) using a compression testing machine. The cubes were positioned at the centre and a small load was applied to keep the cube specimens in position. At a constant rate of 140 kg/cm²/min, the load was applied, until the concrete fails to take any further load. Table 6 shows the compressive strengths of both conventional concrete (without the addition of macro-fibres) mix and Polypropylene macro-fibre reinforced concrete (PFRC - 2kg/m³ dosage) mix at different age levels.

| Mix                      | Conventional Concrete | PFRC  |
|--------------------------|-----------------------|-------|
| Compressive strength on 7th day (N/mm²) | 38.50                 | 39.96 |
| Compressive strength on 14th day (N/mm²) | 43.92                 | 47.52 |
| Compressive strength on 28th day (N/mm²) | 52.29                 | 57.48 |
Figure 3 represents the comparison of compressive strength at different ages with that of control specimen. It is observed that there is a steady gain in the concrete’s compressive strength as the days of curing advances. When compared to conventional concrete there is a 3.79 % gain in the compressive strength of PFRC after 7th day of curing, there is 8.19 % gain in the compressive strength of PFRC after 14th day and 9.92 % gain in the compressive strength of PFRC after 28th day. Overall, when macro-fibre is added in the 2kg/m³ dosage there is a gain in the compressive strength.

### 4.2. Tensile Strength of Concrete

Split tensile strength test was carried out on hardened concrete cylinder specimens at different age levels (7, 14, 28 days) using a compression testing machine. At a constant rate of 1.2 N/mm²/min, the load was applied, until the concrete fails to take any further load. Table 7 shows the tensile strength of both conventional concrete (without the addition of macro-fibres) mix and Polypropylene macro-fibre reinforced concrete (PFRC - 2kg/m³ dosage) mix at different age levels.

| Mix                          | Conventional Concrete | PFRC |
|------------------------------|-----------------------|------|
| Tensile strength on 7th day (N/mm²) | 3.18                  | 3.21 |
| Tensile strength at 14th day (N/mm²) | 3.50                  | 3.57 |
| Tensile strength at 28th day (N/mm²) | 4.13                  | 4.17 |
Figure 4 represents the comparison of average tensile strength at different ages with that of control specimen. From the above figure it is observed that there is a slight gain in the split tensile strength of the concrete as age of concrete increases. There is a 0.94% gain in the tensile strength of PFRC when compared to conventional concrete after 7th day, there is 2% gain in the tensile strength of PFRC after 14th day and 0.96% gain in the tensile strength of PFRC after 28th day.

4.3 Flexural Strength of Concrete
The tests were conducted on concrete beams. Gradual load was applied until the specimen fails to take any further load. Table 8 gives the flexural strengths of both conventional concrete (without the addition of macro-fibres) mix and Polypropylene macro-fibre reinforced concrete (PFRC - 2kg/m3 dosage) mix at different age levels.

| Mix                           | Conventional Concrete | PFRC |
|-------------------------------|-----------------------|------|
| Flexural strength on 7th day (N/mm²) | 6.40                  | 6.70 |
| Flexural strength on 14th day (N/mm²) | 6.50                  | 7.10 |
| Flexural strength at 28th day (N/mm²) | 7.60                  | 8.80 |

Figure 5. Average Flexural Strength Comparison
Figure 5 represents the comparison of average flexural strength at different ages with that of control specimen. It is found that there is a gain in the flexural strength of the concrete as the age of concrete progresses. There is a 4.68 % gain in the flexural strength of PFRC when compared to conventional concrete after 7th day, there is 9.23 % gain in the flexural strength of PFRC after 14th day and 15.78 % gain in the flexural strength of PFRC after 28th day. Overall there is a linear gain in the flexural strength when the macro-fibre is added in the 2kg/m³ dosage.

5. CONCLUSION

According to the study the following conclusions were observed in DURASTRAN Poly - propylene macro-fibre incorporated concrete.

- There is an effect in the hardened properties of the concrete when the macro-fibre is added.
- The flow properties of the concrete were affected when Poly - propylene macro-fibre was added.
- When Poly - propylene macro-fibre was incorporated in the above dosage, there was a linear gain in the concrete’s compressive strength.
- When Poly - propylene macro-fibre was incorporated in the above dosage, there was a slight increase in the concrete’s tensile strength.
- When Poly - propylene macro-fibre was incorporated in the above dosage, there was a gain in the concrete’s flexural strength.
- When conventional concrete cubes were tested the mode of failure occurred is by spalling the outer surface of concrete. But, when PFRC cubes were tested the mode of failure occurred is by bulging in the transverse direction where the load is applied.
- The pattern of failure in concrete changed from brittle to ductile when the Poly - propylene macro-fibres were incorporated.

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