Experimental investigation of reinforced concrete beam behavior under pure torsion and bending and microstructure characteristics

Atul Patane (pataneatul@gmail.com)
Sardar Vallabhbhai National Institute of Technology Surat

Gaurang Vesmawala
Sardar Vallabhbhai National Institute of Technology Surat

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Abstract

The present research paper presents the results of an experimental examination of the load behavior and microstructure property analysis of reinforced concrete beams. In addition, the mix design process involves a number of trials to determine the cement, fine aggregate, and coarse aggregate physical characteristics. Experimentally determined values are used in determining the mix design for M20 grade concrete. Eight different beams are produced from the same M20 concrete mixture. These beams range in length from 2100 mm to 2100 mm and have a width of 150 mm and a depth of 250 mm. The beam has 12 mm diameter longitudinal reinforcement at the bottom and 10 mm diameter reinforcement at the top. The employed stirrups have a diameter of 8 mm, a distance between each stirrup of 100 mm, and a distance between each support of 40 mm for a total length of 150 mm. All eight test beams are subjected to a wide range of loading conditions and BFRP wrapping combinations. The cracking load, ultimate load, twist angle and deflection are investigated for all the beams. It is observed that A6 beam combination is a good alternative over the beam with conventional reinforcement. It significantly enhanced the structural performance in all directions.

1. Introduction

RCC constructions are often designed to resist shear, flexure, or a combination of the two, with torsion being a secondary stress. It's not easy to predict how an RCC beam would react when exposed to a number of forces, including torsion. Therefore, several studies have been conducted to learn about the torsional behaviour of RCC beams (Ajeel, 2016; Alabdulhady et al., 2017; Cambronero-Barrientos et al., 2017). In the current context, a complex system of forces acting on the parts of the building may result from the rise in the construction industry, which may result in enormous RCC buildings with intricate design, etc. Torsion is one component of this complicated set of forces. As a result, it is important to learn how RCC components respond when exposed to torsional loads. Previous research shows that the tensile response of the material, especially its tensile cracking properties, largely determines the behaviour of concrete parts under torsion. Therefore, the RCC beam primarily has closed vertical stirrups to prevent torsion (Ameli & Ronagh, 2007; Atea, 2017).

Typically, only bending, shear, and axial forces are considered in structural analysis, whereas torsion effects are ignored. The study of torsion seems unnecessary. Many factors contribute to this. To begin, its effects need to be considered in certain buildings (such L-shaped beams) (Banibayat & Patnaik, 2014). Second, the reaction of the whole structure may be altered by even moderate torsional moments, which can cause significant strains. Third, torsional stress may be simply computed with increased computing power (3D analysis). Moreover, the combination of torsion with other loads is still not clear. In the cases of a spiral staircase, a beam curved in plan and an edge beam, sometimes called a spandrel beam, torsion may also be the primary effect and govern the design. The objective of the current research work is to investigate the behavior of reinforced concrete beam under the combined effect of bending, shear and torsion. To understand the combined effect of bending, shear and torsion, it is necessary to understand their individual actions. Since the combined effect will result from the modification of the
individual effects due to interactions. The knowledge of the behavior of the rectangular beams will also help in understanding the effect of T and L beams. The best solution in this regard if offered by FRP applications. In the past many research have been done to study the effect of FRP application on RCC elements mainly subjected to forces like shear and flexure. The number of researches on members subjected to torsion is limited. Industrial buildings, power plants, and bridges are all examples of modern civil engineering's essential role in maintaining society's smooth functioning. The current structural system will need maintenance and reinforcement to ensure its continued optimal functioning.

Deterioration or deterioration is an inevitable part of the lifespan of any engineered structure, whether it a house, factory, power plant, or bridge. Environmental impacts such as steel corrosion, strength loss with age, temperature change, freeze-thaw cycles, repetitive high intensity loading, contact with chemicals and salty water, and exposure to ultraviolet radiation are major contributors to these deteriorations. Earthquakes, in addition to these environmental consequences, are a key contributor to the decay of any building (Behera et al., 2016; Bhavani et al., 2015).

To solve this issue, researchers will need to perfect structural retrofitting techniques. Therefore, monitoring the ongoing efficiency of civil engineering facilities is crucial. Repair/retrofit or demolition/reconstruction are the two solutions to the structural retrofit challenge. Completely replacing an old building via demolition and reconstruction might be too expensive, especially if there is a feasible upgrade option available (Campione et al., 2015). For this reason, it is more common to choose for repair and rehabilitation of civil engineering structures rather than rebuilding after they have been damaged by factors such as deterioration, age, lack of maintenance, major earthquakes, and shifts in current design requirements. Columns, beams, and other reinforced concrete structural elements used to have their weak concrete or steel reinforcements removed and replaced with newer, stronger materials during retrofitting. Fibre reinforced polymer (FRP) composites are one kind of sophisticated composite material that has made it possible for concrete elements to be strengthened with little effort by means of external bonding. Because of its many advantages over the conventional methods, such as its low cost, high strength, low weight, corrosion resistance, high fatigue resistance, easy and rapid installation, and minimal change to the structural geometry, the retrofitting of concrete structures with wrapping FRP sheets is a viable option in many cases. Furthermore, FRP production enables the creation of shapes and forms that would be challenging or impossible to achieve with traditional steel materials. FRP systems may be installed for less money than conventional strengthening methods because of the reduced cost of manpower and specialized tools (Ameli & Ronagh, 2007). Where conventional methods would be unfeasible, such as in remote locations, FRP systems may be put to good use. Many researchers have focused on carbon Fibre reinforced polymer (CFRP) and glass Fibre reinforced polymer (GFRP) composites for retrofitting concrete beams and columns in order to improve their strength, ductility, durability, effect of confinement, design guidelines, and experimentation (Chalioris, 2008). There are still several caveats to the generally promising findings gained from many experiments addressing the improvement of fundamental metrics like strength/stiffness, ductility, and durability of structural elements retrofitted with externally bonded FRP composites. More research is required before FRP composites may be considered a reliable structural additive. Strength and service life may be easily improved with FRP repair. This technology is
perfect for fixing a degraded concrete structure because of its high strength to weight ratio and resistance to corrosion (Ajeel, 2016; Alabdulhady et al., 2017; Atea, 2017).

Civil engineering has struggled with the issue of structural member upkeep, repair, and improvement since ancient times. In addition, the outdated design requirements resulted in less secure buildings as compared to modern building standards. Regular steel reinforced concrete facilities are subjected to severe weather and other environmental stresses. Environmental assaults on these constructions ultimately lead to issues including reinforcement corrosion and concrete strength loss. Fibre reinforced polymer composites have various applications and may be used to increase the strength and stiffness of a damaged structure. The use of FRP materials in building has been the subject of study for a while now. Many kinds of concrete buildings may benefit from the use of fibre reinforced polymers to strengthen weak spots in the material. Due to the significant replacement cost and productivity losses associated with constructing new buildings, it is always preferable to repair and retrofit the existing structure instead of constructing new ones. Retrofitting and reinforcing damaged and degraded portions of in-service structures using FRPs is an effective way to increase the durability and strength of these structures.

Extensive studies have been conducted on the behavior and features of FRP wraps externally bonded to concrete components. Recent earthquakes throughout the globe have shown the fragility of preexisting reinforced concrete. In the past, steel plates were bonded to the concrete from the outside in order to strengthen flexural concrete parts. However, it does a good job of boosting the rigidity and strength of reinforced concrete structures. The fact that it is prone to corrosion and might be difficult to set up are other drawbacks. Recently, advances in high-strength epoxy have opened up exciting possibilities for enhancing the quality of existing buildings. The method consists essentially of adhering steel or fibre-reinforced polymer plates to the surface of the concrete (Deák & Czigány, 2009; Deifalla & Ghobarah, 2010b, 2010a). These plates then work in conjunction with the concrete to support weight. Many new advancements have been made in the realm of composite materials, making them an appealing option to traditional retrofitting methods due to their inherent features such as high specific tensile strength, excellent fatigue, corrosion resistance, and simplicity of use (Jariwala et al., 2013). FRP has many advantages over steel, including a higher ultimate strength and lower density, easier installation (since they can be bent into complex shapes on-site and the adhesive doesn't need to be supported temporarily until it gains strength), and easier cutting and lengthening (Escrig et al., 2017).

**Advantages and Disadvantages of FRP**

Fiber-reinforced polymers (FRP) are one example of a new class of structural materials that have emerged because of recent developments in the science and technology of structural restoration. Adding FRP sheets as outside reinforcement is one method of fortification in this category. The designer has access to a novel set of qualities not found in conventional materials and efficient rehabilitation methods thanks to the development of advanced materials. When designing for increased seismic and service load demands, FRP allows the designer to choose improve the ductility, flexure, and shear capacity of
structural parts. Columns strengthened and made more flexible by FRP wrapping (Jiang et al., 2014; Shen et al., 2018).

Compared to steel, FRP has a far higher strength to weight ratio, making it a viable alternative for exterior confinement. FRP plates are up to 20% lighter than steel plates but are at least twice as strong, if not stronger, in order to achieve the same degree of confinement. Thus, contemporary composites may be manufactured in smaller pieces, and composite plates can be formed on-site. Because of its reduced density, confinement applications may be placed more conveniently. The dead weight load of the main structure should be adjusted conservatively during the design phase of external confinement. When rebuilding the structure, it is important to consider any changes in the stiffness of the parts. FRP-wrapped members’ enhanced behaviour minimizes pressures on the steel reinforcement on the inside, putting off yielding for longer. When compared to internal 5 steel confinement along the longitudinal and lateral axes, the pressure exerted by external confinement on the concrete and the internal steel is almost the same (Khalifa & Nanni, 2000). In addition, the durability of FRP is enhanced by the fact that it is resistant to corrosion, even when exposed to harsh conditions. Long-term maintenance expenses may be reduced because of such sturdiness. There has been a lot of effort put into studying the torsional behaviour of reinforced concrete beams in recent years. Many scientists have studied the behaviour of RC beams under pure torsion since 1929. They have performed pure torsional load testing on the beam specimen and made recommendations on how to reinforce it. FRP wrapping greatly increases the strength of RC beams, and the beams deformed significantly before failing (Kumari et al., 2018).

Also, studying the combined torsional and compression strength analysis of beam using FRP has not received much attention. The reason for the lack of research area includes the specialized nature of the problem and the difficulties in conducting realistic tests and representative analysis. Hence, the objectives of the present research study are as follows: 1) Pure bending and torsion study of beams; 2) Morphological structural analysis of the beams; and 3) load vs angle of twist and deflection study of the beams.

2. Experimental Work

In this study, physical test of all ingredients of concrete was carried out and mix design for M 20 grade of concrete was prepared. Twenty Four beams of size 150 mm width 250 mm depth and 2100 mm length were casted using M 20 grade concrete and Fe 500 steel. The strain gauges for bottom reinforcement, top reinforcement and for stirrups was installed at middle of shear zone and at the center of the beam.
Table 1
The overall experimental program for the beam preparation.

<table>
<thead>
<tr>
<th>T/M Ratio</th>
<th>Control Specimen (Without Wrapping)</th>
<th>Full Wrap</th>
<th>Strip Wrap 150–150</th>
<th>Strip Wrap (300 – 150)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFRP</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Pure Bending</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Pure Torsion</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>
| Total No of Beam Specimen: 8

2.1 Materials properties and geometry

In the present study, cement, water, fine aggregates, coarse aggregates, reinforcing steel, strain gauge assembly has been used.

2.1.1 Cement

Cement is a substance that, when mixed with water to make a paste, may harden into a solid mass after being shaped or poured into a mould. Cement is a general word for any substance used in building, while there are several organic compounds used as adhesives that are also termed cements. Portland cement is the most used kind of building cement. Clinker, a product of intense heating a close combination of calcareous and argillaceous minerals, is finely ground to produce this greenish-gray powder. Cement rock, or high-calcium limestone, is combined with clay or shale to form the primary raw material. Some cements may also utilise blast-furnace slag, in which case the cement is referred to as Portland Slag Cement (PSC). Iron oxide plays a major role in giving the cement its colour. Whiteness indicates purity; yet, neither colour nor specific gravity is indicative of quality (Larrinaga et al., 2014).

2.1.2 Fine Aggregates

Coarse aggregate consists of crushed, washed, and sieved gravel with particles ranging in size from 5 to 50 millimetres in diameter, whereas fine aggregate is just sand that has been processed to eliminate everything bigger than 5 millimetres. Separate deliveries are made for the fine and coarse material. A produced blend of fine and coarse aggregate costs more than natural all-in aggregate because it must be sieved. Mortar, concrete, polishing, and sandblasting are just a few of the many uses for sand. Foundries often employ sands with a little amount of clay in them to create mould. Water purification by use of clear sands. While sand is often supplied by weight, it may be purchased by the cubic yard (0.76 m³) or the ton (0.91 metric ton). Depending on the kind and size of grain, the density might range from 1,538 to 1,842 kg/m³. The specific gravity of the fine aggregate was 2.69, and it passed a sieve size of 4.75 millimetres (Gonzalez-Libreros et al., 2017).
2.1.3 Coarse Aggregates

Crushed stone is the coarse aggregate in concrete. The quarried, crushed, and graded commercial stone is ready for use. Crushed stone often consists of granite, limestone, or trap rock. Larger sizes may be utilised for large concrete aggregate, but typically range from 0.25 to 2.5 in (0.64 to 6.35 cm). Angular pieces of fractured granite that have been machine-chorded are utilised as coarse aggregate (Patil & Sangle, 2016).

2.1.4 Reinforcing Steel

High Yield Strength Deformed (HYSD) bars with a 10 mm top diameter and a 12 mm bottom diameter were utilised to strengthen the length of the structure. The stirrup bars were 8 mm in diameter and constructed of mild steel. A HYSD bar has a yield strength of 500 N/mm$^2$, but mild steel only has a yield strength of 250 N/mm$^2$.

2.1.5 Water

Water that may be used for drinking purposes is also acceptable for use in concrete production. Acids, oils, alkalis, vegetables, and other organic contaminants should not be present in drinking water. To add insult to injury, concrete made with soft water is less durable. There are two primary uses for water in concrete. First, it functions as a lubricant in the combination of fine aggregate and cement, keeping the inert aggregate suspended in the cement paste until the paste has hardened; second, it induces a chemical reaction with the cement to generate cement paste.

2.1.6 Formwork

Because it is pliable while wet, fresh concrete needs precise formwork to be molded into the desired shape and size. Therefore, the formwork must be sturdy enough to support the weight of wet concrete without sagging. For the formwork, we utilized three plywood plates, one on each side and one at the bottom. Cement slurry leakage was prevented by sealing the bottom and side joints. Then, Mobil oil was slathered over the formworks inside surfaces. Carefully covering the reinforcing cage with 25 mm of concrete on both sides and the bottom, the form work was lowered into place (Salom et al., 2004).

2.1.7 Strain Gauge Installation

To measure the strain in the reinforcement bars, 350 Ohm strain gauges of size 3mm X 5mm were used. Six strain gauges were installed for each beam specimen. Three at middle of shear zone and three at middle of the beam specimen.

2.1.8 Surface Preparation

For the installation of strain gauges, clean and proper finished plain surface is required. By using hand grinder, steel reinforcement surface was made plain to ensure proper contact between steel surface and
strain gauges. Thinner was used for the cleaning of the surface to avoid entry of dust particles. This activity should be carried out with proper care to avoid false readings (Santhakumar et al., 2007).

### 2.1.9 Mounting of Strain Gauges

After preparation of clean and well finished surface, adhesive was applied at the position where strain gauge is to be mounted. Then strain gauge was placed in the position using cello tape and tape was removed after hardening of adhesive. To avoid damage of the strain gauge while placing the concrete, silicon sealant was applied on the strain gauge after mounting. This will ensure that there will not be any contact of water present in the concrete with the strain gauge and also it protects the strain gauge from impact while placing the concrete during casting of the specimen (Shen et al., 2018; Zhou et al., 2017).

### 2.2 Mix design of the FRP beam

Cement of the OPC 43 grade, sand crushed into fine aggregates, and aggregates of 10 and 20 millimetres in size make up the mix design. Mix design is developed by testing cement, crushed sand (FA), and coarse aggregates (CA). In Table 2 the FRP beam's mix design composition is given.

Mix Proportion is 1:3:3.43

#### 2.3 Casting of cube and cylinder specimen

To check the compressive strength of calculated mix proportion of M 20 grade concrete, casting of concrete cube specimen was done. Concrete cube specimens were casted of 150mm X 150mm X 150mm in size and their characteristic compressive strength were taken after 3 days and 7 days of water curing. Cylinder of size 150 mm diameter and 300 mm depth was casted for calculating split tensile strength of concrete and to find the modulus of elasticity of concrete. The curing of the specimen was properly done in the curing tank. Test on the cylinder specimen will be conducted after 28 days of curing (Tibhe & Rathi, 2016).

### 2.4. Analysis methods

#### 2.4.1 Compression test

The compressive strength results for the M 20 grade of concrete taken after 3 days, 7 days and 28 days of curing of samples.

**Casting of Beam Specimen**

To guarantee that all eight beam specimens would have the identical characteristics, they were cast all at once. M 20 grade concrete and Fe 500 steel were used to create the beam, which measures 150 mm in width, 250 mm in depth, and 2100 mm in length. Cement, fine aggregate (crushed sand), and coarse aggregate were mixed in the following ratio: 1:3:3.43. Wet gunny bags were used for the curing process. Waterproof plywood 16 mm in thickness was used to construct the necessary shuttering. Before the concrete was ever poured, it was well oiled (Zhou et al., 2017).
The concrete mix was prepared using weigh batching, and the concrete utilized was of the M 20 grade. Water-cement ratio was 0.5, and the weight ratio of cement to sand to coarse aggregate was 1:3:3.43. Using the necessary amounts of cement, sand, and coarse aggregate, the concrete was mixed in a ready mix concrete mixer. Consistent concrete was achieved by extensive mixing. The mold's inside was oiled, the reinforcement cage was set in the right spot, and 25-millimeter cover blocks were secured on both sides of the reinforcement before the concrete was poured. After the concrete was well mixed, it was carefully poured into the mould in three layers. Tamping rods and a 25 mm needle vibrator were used to compress the concrete while it was being poured into the mould. Expelling trapped air, filling spaces between concrete particles, and achieving a consistent volume all need compacting concrete (Jing et al., 2007; Zhou et al., 2017).

**Testing of Beams**

Experimental research on the enhancement of reinforced concrete beams' torsional resistance using Basalt Fibre Reinforced Polymer (BFRP) fabric is undertaken. Eight beams are cast from a single M20 concrete mixture. The A1 and A5 beam are the control beam samples without any wrapping. Beam samples of A2 and A6 are with full wrapping, whereas A3 and A7 are with strip wrap of 150 mm-150 mm. Also, A4 and A8 are the beam samples with strip wrap of 300 mm -150 mm. The beam samples of A1 to A4 are belongs to pure bending and A5-A6 are pure torsion. The beam has 12 mm diameter longitudinal reinforcement at the bottom and 10 mm diameter reinforcement at the top. The stirrups used are 8 millimetres in diameter, 100 millimetres apart, and 40 millimetres apart at the support, for a total of 150 millimetres (Escrig et al., 2017; Gonzalez-Libreros et al., 2017). Top and bottom stirrups and reinforcement are equipped with strain gauges. Three strain gauges are placed in the shear zone and three in the centre of the beam specimen for each beam. To apply torsional force to beam specimens, a bending and torsion test rig was developed, including a loading frame and unique end supports. There were two types of loads applied to the beams: bending alone, torsion only.

3. Results and Discussions

In the present study, the bending and torsion is reported using the casted beam samples.

3.1. Compressive strength results

The graph of Twisting Moment vs Angle of Twist was plotted for the pure torsion case.
Table 3
Compressive strength results for trial mix of cube samples

<table>
<thead>
<tr>
<th>Specimen Description</th>
<th>Age in Days</th>
<th>Load at Failure (kN)</th>
<th>Compressive Strength (N/mm²)</th>
<th>Average Compressive Strength (N/mm²)</th>
<th>Required Compressive Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>3</td>
<td>208</td>
<td>9.25</td>
<td>9.29</td>
<td>8</td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td>215</td>
<td>9.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td>204</td>
<td>9.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>7</td>
<td>317</td>
<td>14.00</td>
<td>14.03</td>
<td>13</td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td>322</td>
<td>14.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td>310</td>
<td>13.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>28</td>
<td>468</td>
<td>20.8</td>
<td>20.19</td>
<td>20</td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td>436</td>
<td>19.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td>459</td>
<td>20.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3-Days Compression Strength of Cubes: 9.29 N/mm

7-Days Compression Strength of Cubes: 14.03 N/mm

28-Days Compression Strength of Cubes: 20.19 N/mm

Based on the aforementioned data, the proportions are utilized to prepare the concrete mix were accurate. The concrete's characteristic strength was higher at each testing stage than was specified. It was discovered that U-wrapped beams performed better than the other strip wrapping methods.
Table 4
Effect of pure bending, and pure torsion of the beams.

<table>
<thead>
<tr>
<th>T/M ratio</th>
<th>Beam identification</th>
<th>Cracking load (kN)</th>
<th>Ultimate load (kN)</th>
<th>Maximum twist reached (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Bending</td>
<td>A1</td>
<td>13.01</td>
<td>15.31</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>17.96</td>
<td>24.12</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>15.84</td>
<td>22.56</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td>17.59</td>
<td>23.96</td>
<td>--</td>
</tr>
<tr>
<td>Pure Torsion</td>
<td>A5</td>
<td>14.28</td>
<td>18.38</td>
<td>15.69</td>
</tr>
<tr>
<td></td>
<td>A6</td>
<td>19.89</td>
<td>29.83</td>
<td>18.79</td>
</tr>
<tr>
<td></td>
<td>A7</td>
<td>16.85</td>
<td>26.42</td>
<td>16.42</td>
</tr>
<tr>
<td></td>
<td>A8</td>
<td>19.40</td>
<td>28.54</td>
<td>17.66</td>
</tr>
</tbody>
</table>

In the present study, the moment rotation behaviour of all the beams with full wrapped, strip 150–150 and strip 300 – 150 with different wrap width. The different cracking load, ultimate load and twist reached for the respective beams for full wrapping (pure bending and pure torsion) are shown in Fig. 5 and denoted by A1-A4 (pure bending) and A5-A8 (pure torsion). The full wrap beam samples show increasing strength and it is also observed that small cracks only detected at the bottom surface of the beams (see Fig. 7). It is also observed that the fully wrap of the RC beam is showing effective increase in tortional strength of the beam compared to different strips based reinforced concrete beams (Cambronero-Barrientos et al., 2017).

The behavior of beams (A5-A8) in terms of cracking strength, ultimate strength and angle of twist is strengthened by using the full wrap, strip of 150–150 mm width and strip of 300 – 150 mm width shown in Fig. 6. The strip 150–150 wrap is applied for the beams denoted in Table 4. The more effective results in terms of the strength of the A2 and A6 beams are detected because of the full wrapping of the beams. The strip wrap with width of 150–150 provide more suitable packing and strength against the cracking of the beams (see Fig. 6). The cracking strength for A1-A4 beams obtained around 13.01 kN, 17.96 kN and 15.84 kN, and 17.59 kN, respectively. Further, the maximum ultimate load is around 24.12 kN is detected for A1 to A4 beam subjected to pure bending. The maximum twist is obtained in full wrapped beams of 18.79°, further for strip wrap (150–150) and strip wrap of 300 – 150 mm shows angle of twist around 16.42° and 17.66°, respectively. Fully wrap beam samples shows outstanding increase in cracking load, ultimate load and maximum angle of twist. But, for the beam sample of A7 the cracking load, ultimate load, and angle of twist decreases, which is due to the beam composition and applied load (Bhavani et al., 2015; Escrig et al., 2017).

3.2. Load vs Angle of Twist Analysis
When a beam is subjected to an external load, it experiences two primary types of deformation: bending and twisting. Bending refers to the curvature or deflection of the beam along its length, while twisting refers to the rotational deformation of the beam about its longitudinal axis. The relationship between the applied load and the resulting angle of twist is governed by the beam's material properties, geometry, and boundary conditions. Load and angle of twist are directly proportional in a linear elastic range (Atea, 2017; Ajeel, 2016). This means that as the magnitude of the applied load increases, the angle of twist also increases linearly. However, it is important to note that this relationship holds true only within the elastic limit of the beam material. When the load on a beam exceeds its elastic limit, the material may undergo plastic deformation, causing permanent changes in the beam's shape and behavior. In this case, the relationship between load and angle of twist becomes more complex, and the beam may experience significant non-linear behavior (Behera et al., 2016). The load vs angle of twist analysis of the beam sample is showing in Fig. 6. For the A6 beam at maximum load of 29.83 kN the maximum angle of twist obtains around 18.79°, which is substantially higher than other beam samples. For the controlled beam A5 at 18.38 kN load 15.69° angle of twist is reach, whereas for A7 and A8 beam samples at 26.42 kN and 25.84 kN, angle of twist obtained around 16.42° and 17.66°, respectively.

3.3. Load vs Deflection Analysis

The correctness of the beam samples for the load bearing capacity is experimentally investigated using the load deflection analysis (Kumari et al., 2018; Shen et al., 2018). Figure 8 shows the experimental load and deflection curves for all the beam samples. The beam with A6 reinforcement carries a maximum load of 29.83 kN with deflection of 7.3 mm. In other hand, the beam with A1-A4 shows deflection around 12.9 mm, 8.6 mm, 9.8 mm, 9.1 mm, respectively. Further, A5, A7 and A8 shows the deflection around 11.2 mm, 7.3 mm, 9.2 mm, and 8.9 mm at 18.38 kN, 29.83 kN, 26.42 kN and 28.54 kN of ultimate load, respectively. The uniform and homogeneous reinforcement of A6 beam samples shows higher load carrying capacity as compared to other beam having conventional packing density. The area of reinforcement in A6 beam sample sustainably carry higher load. It is found that the A6 beam sample had a stiffer response than other beam samples considering its reinforcement structure and area covered by the reinforcement (Patil and Sangle, 2016).

3.1. Microstructure study of the beam composite

The microstructure study of the beam samples are performed to study the morphology of the beams. After preparation of beams using the all the composition mentioned in materials section the ultimate obtained morphology of the beams shows uniform and homogeneous composition and the curing of the beams. Also, the reinforcement used in the present study to provide the strength to beam samples significantly enhanced the microstructure packing of the beam samples. The packing density and uniform morphology of the prepared beams shows the uniform composition and superior degree of hydration in the beam samples (Jariwala et al., 2013; Patil & Sangle, 2016).

Conclusions
The present experimental work is consisting the technical and practical aspects of physical properties and preparing the mix design for M20 grade of concrete and casting of eight beam specimen of size 150 mm X 250 mm X 2100 mm. The beams homogeneous and structural (morphological) properties are investigated using FE-SEM analysis. The packing density and uniform morphology of the prepared beams shows the uniform composition and superior degree of hydration. Further, prepared beams are studied for pure bending and pure torsion characteristics. In pure bending A1 beam shows maximum deflection at 12.9 mm and in case of pure torsion A5 beam shows maximum deflection at 11.2 mm. For the A6 beam at maximum load of 29.83 kN the maximum angle of twist obtains around 18.79°, which is substantially higher than other beam samples. The correctness of the beam samples for the load bearing capacity is experimentally investigated using the load deflection analysis. The beam with A6 reinforcement carries a maximum load of 29.83 kN with deflection of 7.3 mm as compared to other beam samples. Based on the physical properties of the materials used in concrete obtained by required testing in the laboratory, mix design for M20 concrete is prepared as 1:3:3.43.

Declarations

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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References


29. Statements & Declarations

**Figures**
Figure 1

The design of the FRP beam.
Figure 2

Geometry of the FRP beam (Atul Patane et al., 2023)
Figure 3

Position of strain gauges in the beam specimen
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Concrete cube and cylinder specimen of trial mix
Figure 5

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The pure bending of the beam samples and propagation of the cracks after loading
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Load vs deflection analysis of the beam samples
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The effect of torsion on the propagation of the cracks after loading
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FE-SEM images of the beam samples