Experimental Study on Strengthening of Concrete Cylinders Using GFRP Sheets with Boron Carbide-Epoxy Composite

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Abstract. Usage of composite materials as a concrete strengthening agent had increased evidently in recent years. One of those materials is the Glass Fibre Reinforced Polymer (GFRP) which is used in various fields for strengthening and retrofitting of concrete structures. Various studies have shown that, the wrapping of concrete specimens with Glass Fibre Reinforced Polymer (GFRP) resulted in increase in the Compressive Strength as well as the ductility of the concrete members. The main Objective of this project is to enhance the axial compressive strength of concrete block wrapped by Glass Fibre Reinforced Polymer sheets tested with various compositions of Boron Carbide (B4C) mixed with epoxy resin to find out the increase in the compressive strength. Cylindrical Concrete specimen of standard size 150mm diameter and 300mm height were casted of M30 Grade Concrete. Totally 6 batches were casted which consists of 18 specimens composing of different compositions of Boron Carbide varying 1.5%, 3.0%, 4.5% and 6.0% of boron carbide (B4C) were added and mixed with epoxy resin. Finally, Glass fibre Reinforced Polymer is wrapped around the Concrete specimen with a single wrap and the results obtained from Compressive strength of the specimens were studied.

Keywords— Boron carbide, GFRP, Epoxy resin, Wrapping, Strength.

1. Introduction
Natural disasters and accidental events can damage or destroy the structures in a matter of seconds. On the other hand, other agents like saltwater, deicing chemicals, and freeze-thaw cycles can also cause structural deterioration. The majority of the existing buildings and bridges were constructed during the olden days. These structures are vulnerable during extreme events and need to be to made them serviceable by doing retrofitting [1]. Traditional retrofitting techniques like concrete and steel jacketing are time consuming and labor intensive also they increase the cross-sectional dimension of the column member. FRP (Fibre Reinforced Polymer) composite materials are playing a major role in the repairing of existing structures, in order to upgrade their service or to increase their life time. In repairing the concrete structures, application of FRP is a well-established practice. [2] These applications include mitigating brittle failure mechanisms such as shear failure of unconfined beam-column joints, shear
failure of beams and/or columns, and lap splice failure [3]. Also, they have been used to confine columns to resist buckling of longitudinal steel bars.

2. Material Description
Concrete is a highly adaptable and most commonly used construction material, well suited for many repairing and strengthening applications. It is a mixture of cement, water, aggregates, and in some cases, admixtures also added to enhance its properties. Strength, durability, and many other parameters depend on the relative amounts and properties of the individual components added in the concrete [4].

2.1. Glass fiber reinforced polymer
Glass fiber reinforced polymer is used as a wrapping material for confining the concrete. Glass Fibers are isotropic in nature and most widely used in retrofitting applications. The common types of glass fibers are E-Glass, S-Glass and C-Glass. The characteristic properties of glass fibers are high strength, low cost with good water resistance and resistance to chemicals [5].

| Table 1. Properties of GFRP and CFRP |
|--------------------------------------|
| **Type of Materials** | **GFRP** | **CFRP** |
| Nominal size (mm) | 13 | 100x1.2 |
| Cross section area (mm²) | 201 | 120 |
| Tensile strength (MPa) | 81 | 3100 |
| Elastic modulus (GPa) | 43.6 | 165 |
| Ultimate elongation (%) | 202 | 1.70 |

2.2. Epoxy Resin
Araldite LY556 is Bisphenol-A based epoxy resin which is mixed with hardener HY951 in a mix proportion of 100:10. Epoxy resin, which is one of the best thermosetting polymer resins in which the cost-to-performance ratio of epoxy resin is also outstanding [6]. Epoxy resins exhibits characteristics such as low creep, high strength, good adhesion to most of the substrate materials and less shrinkage during the curing. Epoxy resins are significantly used as matrix material in many applications such as aerospace, ship building, structural applications and in automobile industries. The tensile modulus and the tensile strength of Epoxy composite increases in fiber loading and the addition of Nano clay particles to the Epoxy composite increases the tensile strength [7].

| Table 2. Properties of Epoxy Resin |
|----------------------------------|
| **Property** | **Test method** | **Araldite (LY556) Resin** | **Araldite (HY951) Hardener** |
| Color | Visual | Clear, Pale yellow liquid | Clear liquid |
| Specific gravity at 25°C | ASTM D-792 | 1.15 | 0.98 |
| Viscosity at 25°C | ASTM D-2393 | 10000-12000 MPa s | 175 – 350 MPa s |
| Density at 25 °C | ISO 1675 | 1.15 - 1.20 g/cm³ | 1.20 - 1.25 g/cm³ |
2.3. **Boron Carbide (B<sub>4</sub>C)**
Boron carbide (B<sub>4</sub>C) composites and ceramics are high-tech materials, mainly due to their low density and high level of hardness. After diamond and cubic boron nitride, boron carbide is the third hardest material [8]. One of the major properties of Boron carbide is its abrasive property. Also, it was found that different erodent’s such as alumina, silica and silicon carbide cause different erosion mechanisms. B<sub>4</sub>C also possess a high melting point.

**Table 3. Properties of Boron Carbide**

| Properties                        | Magnitude           |
|-----------------------------------|---------------------|
| Density                           | 2.52 g.cm<sup>-3</sup> |
| Melting point                     | 2445 °C             |
| Hardness                          | 200-3580 kg mm<sup>2</sup> |
| Fracture toughness                | 2.9-3.7 MPa.m<sup>1/2</sup> |
| Youngs modulus                    | 450-470 GPa         |
| Electrical conductivity           | 140 S               |
| Thermal conductivity              | 30-42 W/m. K        |
| Thermal expansion Co-eff x 10<sup>-6</sup> | 5 °C               |
| Thermal neutron captures cross section | 600 barns          |

3. **Mix Design**
The suitable mix proportion is worked out as per Indian Standard Recommended Method of Concrete Mix Design IS10262 [9]. The calculated mix proportions are tabulated below.

3.1. **Design Specifications**
Grade of concrete M30
Maximum size of aggregate 20mm
Exposure condition severe
Type of Cement OPC 53 grade
Maximum w/c ratio 0.5
Maximum cement content 450 kg/m<sup>3</sup>

**Table 4. Mix ratio**

| Cement | Fine Aggregate | Coarse Aggregate |
|--------|----------------|------------------|
| 1.00   | 1.36           | 2.2              |

3.2. **Mix Proportion**

**Table 5. Mix proportion per m<sup>3</sup> of mix**

| Materials                                      | Quantity |
|------------------------------------------------|----------|
| Cement (kg/m<sup>3</sup>)                     | 492.5    |
| Fine aggregate (kg/m<sup>3</sup>)              | 668.73   |
| Coarse aggregate (kg/m<sup>3</sup>)            | 1095.11  |
| Water-cement ratio                             | 0.40     |
Quantity Required for Single Specimen:

Volume of one specimen = \( \pi r^2 h = 3.14 \times 75 \times 75 \times 300 = 0.00529 \text{ m}^3 \)

Wt. of Cement required = 0.0052 \times 450 = 2.35 kg

Wt. of Fine aggregate required = 0.0052 \times 800.4 = 4.16 kg

Wt. of Coarse aggregate required = 0.0052 \times 1087.75 = 5.65 kg.

3.3. Mix Proportions of B4C in Epoxy

Recent studies prove that we can improve the compressive strength of the concrete by increasing the strength of the adhesive material. In this study, different composition of epoxy resin and boron carbide is used to increase the compressive strength of the concrete \[10\]. The different proportion of B4C with epoxy is given in the following table.

| Sl. No | Name of batch | No. of samples | % of epoxy resin | % of boron carbide |
|-------|---------------|----------------|------------------|-------------------|
| 1     | CG            | 3              | 100              | 0                 |
| 2     | C1            | 3              | 98.5             | 1.5               |
| 3     | C2            | 3              | 97               | 3                 |
| 4     | C3            | 3              | 95.5             | 4.5               |
| 5     | C4            | 3              | 94               | 6                 |

- CG - GFRP used with only epoxy resin as adhesive.
- C1 - GFRP used with 98.5\% epoxy and 1.5\% of boron carbide as adhesive.
- C2 - GFRP used with 97\% epoxy and 3\% of boron carbide as adhesive.
- C3 - GFRP used with 95.5\% epoxy and 4.5\% of boron carbide as adhesive.
- C4 - GFRP used with 94\% epoxy and 6\% of boron carbide as adhesive.

4. Experimental Investigation

4.1. Testing of Materials

The materials used for specimens were tested as per Indian standard codes and the tests conducted were standard consistency and setting time tests for cement. For aggregates, sieve analysis, Water absorption and specific gravity of aggregates were conducted.

4.2. Casting Procedure and Curing Process

In this study, the concrete of grade M30 is considered. The mix proportion of 1: 1.36: 2.2 (Cement, sand & Coarse aggregate) was obtained from Design mix of M30 grade concrete. Using the above mix proportion, a total number of 18 specimens of dimension 150x300mm size cylinders were casted. During Batching, for a single mix, consisting of 3 cylindrical specimens an approximate amount of 8.75kg of cement, 11.25 & 18.25kg of fine and coarse aggregate were used. The concrete was mixed in a pan mixer and they were filled into the mould in 3 layers and each layer is compacted by Table vibrator.
The specimens were removed after 24 hours of casting and then cured in fresh water. The water which is used for curing is renewed every seven days. The specimens were dried after taking out from the curing tank.

4.3. Surface Preparation
Surface preparation plays a major role in deciding the efficiency of the bonding. The dust formed on the outer surface of the concrete cylinders has to be cleaned thoroughly for that the surface is roughened with a grinding machine and then cleaned off. The Glass Fibre Reinforced Polymer of dimension 1.5x0.3m is trimmed into a size of 480x300mm for single cylinder specimen. A single layer of primer was applied on the surface of the specimens and it is kept to dry for one day. Later Epoxy resin (LY556) and hardener (HY951) of mix ratio 1:10 respectively is stirred rapidly in a glass beaker with the help of a glass stirrer for 5 minutes and it was applied over the layer of primer coat. The trimmed GFRP was wrapped around the cylinder tightly immediately after the application of the Epoxy resin in case of a mix which is using plain GFRP and Epoxy. Similarly, different percentages (1.5%, 3%, 4.5%, 6%) of Boron carbide (B\textsubscript{4}C) is mixed with Epoxy and hardener for 5-6 minutes. Thus, the four different proportions of B\textsubscript{4}C Epoxy composite were applied on the remaining four mixes and the GFRP is wrapped around them.

4.4. Compressive Strength Testing
The specimens wrapped with GFRP were kept to dry for 24hrs and then subjected to compression load in a Compression Testing Machine (CTM). The ultimate load capacity values of each specimen obtained from the CTM is noted.
5. Results and Discussion

The maximum obtained compressive strength for cylinder specimen (150 x 300mm) of M30 grade concrete at 28 days is 569 kN. When glass fibre reinforced polymer which is bi-directional with 600gsm is wrapped around the concrete specimen, the obtained compressive strength on 28 days is 777 kN. When conventional concrete specimen is compared with the Glass fibre reinforced polymer specimen, there is an increase in strength. The compressive strength in the Glass fibre reinforced polymer is increased by 37.26% to 42.39% when compared with conventional concrete specimen.

A total of four compositions of boron carbide with varying percentages of 1.5%, 3%, 4.5% and 6% were calculated and mixed with epoxy resin. Then the GFRP was wrapped around the concrete specimen with varying compositions of boron carbide. The 28 days compression test results showed the following results with increase in strength with 1.5% Boron carbide at the peak when compared with other compositions. The maximum strength obtained with the 1.5% Boron carbide is 822 kN. The strength of 44.22% to 50.64% is obtained with the composition of 1.5% of boron carbide specimen when compared with the conventional concrete specimen.

This study further showed that an increase in strength of about 7.73% in 1.5% of Boron carbide when compared with specimen wrapped with only GFRP was obtained.

| Table 7. Compressive strength Test Results |
|------------------------------------------|

| Grade of Concrete* | M30                                                                 |
|-------------------|---------------------------------------------------------------------|
| Dimensions of specimen in mm | Cylinder: Dia -150mm Length -300mm (for compression test) |
| Date of Casting | 04.02.2020 |
| Date of Testing | 09.03.2020 |
| **Trial Number** | **Specimen Details** | **Test Results** |
|-----------------|---------------------|-----------------|
| 1               | Conventional Concrete | Ultimate Load (kN) |
|                 |                      | Compression Strength (N/mm²) |
|                 | 551                  | 31.20            |
|                 | 517                  | 29.27            |
|                 | 569                  | 32.22            |
| 2               | GFRP WRAPPING        | 749              |
|                 |                      | 42.41            |
|                 | 763                  | 43.20            |
|                 | 777                  | 43.99            |
| 3               | 1.5% Boron Carbide   | 882              |
|                 |                      | 46.54            |
|                 | 787                  | 44.56            |
|                 | 819                  | 46.37            |
| 4               | 3.0% Boron Carbide   | 798              |
|                 |                      | 45.18            |
|                 | 789                  | 44.67            |
|                 | 803                  | 45.46            |
| 5               | 4.5% Boron Carbide   | 782              |
|                 |                      | 44.27            |
|                 | 769                  | 43.54            |
|                 | 764                  | 43.26            |
| 6               | 6.0% Boron Carbide   | 761              |
|                 |                      | 43.09            |
|                 | 754                  | 42.69            |
|                 | 775                  | 43.88            |
**Figure 5.** Comparison of ultimate loads in each trial

**Figure 6.** Comparison between Conventional Concrete and GFRP Wrapped Specimens
Among all the compositions, 1.5 %, Boron carbide shows more strength. From the compressive load of 822 kN (1.5 % Boron carbide), there was a linear drop in the compressive load of composition in 3.0 % of Boron carbide, the percentage of drop is noticed to be 2.31% when compared with 1.5% Boron carbide composition. Similar drop was obtained when 4.5 % Boron Carbide is used when compared with 1.5% and 3% of Boron carbide compositions. A minor drop is noticed with the 6 % Boron Carbide composition as compared with the last composition.

6. Conclusions
In this experimental study, the compression behaviour of the cylindrical specimen is studied when it is wrapped with GFRP using epoxy resin and boron carbide composition in different proportions. From the study the following conclusions were made,

The use of GFRP with epoxy resin and hardener as adhesive over the cylindrical specimen increase its compressive strength by 37.26% to 42.39%. When an addition of 1.5% boron carbide ceramic micro powder to the epoxy resin and hardener surge the compressive strength of the block by 44.22% to 50.64%. Further increase in the percentage of B4C in epoxy resin leads to decline in the compressive strength of the specimen when compared to the 1.5% of B₄C epoxy composite. In addition to this, the cost for the specimen using 3% of B₄C in epoxy is nearly 20% & 54% higher than the specimens with 1.5% of B₄C and specimens using only epoxy respectively. From the result, we can conclude that B₄C micro powder with epoxy resin can be used only to a certain percentage to increase the compressive strength of the cylindrical concrete specimen.
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