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Experimental Performance of Concrete with Carbon and Glass FRP Wrapping System

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Abstract — Carbon Fibre Reinforced Polymer (CFRP) and Glass Fibre Reinforced Polymer (GFRP) belong to a relatively recent category of composite materials. These materials are produced using a blend of fibres and resins. These composite materials have demonstrated their effectiveness and cost-efficiency in the construction of new structures and the restoration of failing structures in civil engineering. One of the primary justifications for utilising CFRP and GFRP composite materials is their exceptional mechanical qualities. The mechanical qualities of this material encompass impact resistance, strength, stiffness, flexibility, and its heightened capacity to bear loads. The construction industry is developing new and innovative technologies and materials to meet the demands of sophisticated infrastructure requirements. Furthermore, any novel technology or substance possesses inherent constraints. However, in order to fulfil emerging demands, it becomes imperative to develop and implement fresh technologies and materials. Due to the ageing of structures and the progressive corrosion of reinforcement bars, it is necessary to retrofit ancient buildings with supplementary materials in order to enhance their longevity and resilience. FRP confinement has multiple applications in reinforcing and retrofitting concrete buildings. Fibre-reinforced polymer (FRP) is a highly successful method for retrofitting and reinforcing structures. This study involves the application of carbon and glass fibre-reinforced polymers to concrete specimens in order to investigate the impact of confinement on the strength of the specimens.

Indexed Terms— Square cubes, Carbon fiber-reinforced polymer (CFRP), Glass fiber-reinforced polymer (GFRP), Compression, fiber wrapping, Strengthening.

I. INTRODUCTION

A fibre-reinforced polymer (FRP) is a chemical compound. The composition of this object comprises a matrix and fibre. It is commonly used in industries such as construction, transportation, and coastal areas to enhance structural integrity and prevent deformation. Moreover, it enhances strength, safety, and durability while minimizing fracture formation. An installation process of this type will require the expertise of a highly skilled individual. The installation of FRP involves several procedures, such as site preparation, where it is important to prevent damp surfaces since they might lead to the creation of bubbles. Surface preparation is the subsequent stage. To guarantee a strong binding between the resin and FRP, it is necessary to clean and roughen the surface. Next, we apply epoxy to the surface and then proceed to install the FRP sheet. There are multiple wrapping patterns used in FRP exterior bonding. We arrange the wrapping material in strip form at different inclinations, such as 0°, 45°, 90°, and U-shaped wrapping styles, to completely envelope the objects in a sophisticated manner.

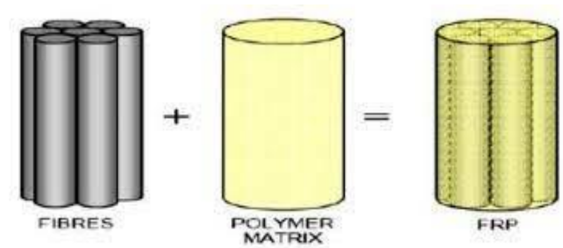


Fig -1: FRP (Fiber-reinforced polymer)

There are several benefits to employing FRP, including its lightweight nature, which prevents an increase in dead load, and its resistance to corrosion. The other benefits include

- Excellent resistance to impact;
- Superior electrical insulating properties;

- Effortless installation;
- Minimal operating costs;
- Exceptional durability;
- Affordable; •Impervious to water;
- Highly recyclable;
- Extended lifespan;
- Minimizes crack development.

When installing FRP on structural components, epoxy resin is commonly used. Epoxy resin, a thick liquid, primarily consists of polyester and phenylethylene components. These resins are highly user-friendly, exhibit rapid curing, and possess excellent heat resistance. Epoxy compounds are synthesised through the chemical interaction between an epoxide and a hardener, or polyamine. Consequently, they will form a robust interconnection that results in a very resilient and rigid framework. The most commonly used epoxy resin is diglycidyl ether bisphenol A. Examples of hardeners include polyaminoamides, aromatic amines, and aliphatic amines. When epoxy cures, it experiences less shrinkage, resulting in increased stability. Epoxies have a greater viscosity compared to polyesters. The majority of epoxies have a beginning range of 900 centipoises. Epoxy resins are applied to the dry fibre sheets on-site and subsequently cured in place. This will ultimately yield fortitude. It functions as a bonding agent that secures the fibre sheet to the substrate.Epoxy has several advantages, including its strong adhesive properties. resistance to chemical substances,high thermal resistance. Excellent mechanical qualities and exceptional electrical insulating properties.

It finds application in the fields of building, automotive, electrical, and aerospace. Epoxies exhibit excellent resistance to alkaline solutions. Epoxies have a higher cost compared to polyesters, and they require more time to cure.

II. TYPES OF FIBER

2.1. Aramid Fiber –Aramid fiber was first developed by Stephanie Kwolek (a Polish-American chemist) in the 1970s. The development of aromatic polyamides was mainly due to the discovery of lyotropic liquid crystalline aramid. They are mainly a bright golden yellow. They have a density of 1.44 g/cm3 and a Young's modulus of 70.5-112.4 GPa. Aramid Fiber is additionally called Kevlar fiber. It is the primary organic fiber with a high tensile modulus and strength. Aramid shares a high degree of orientation with alternative fibers like ultra-high molecular-weight synthetic resin, a characteristic that dominates their properties. Aramid fiber is additionally known for its high durability, toughness, and extremely high-destined organic fiber manufactured from polymeric amide. This fiber has abrasive resistance; they may abrade against one another by weakening the sheets. Aramid fiber is created from artificial products characterized by strength (five times stronger than steel on an equal weight basis) and heat-resistance.

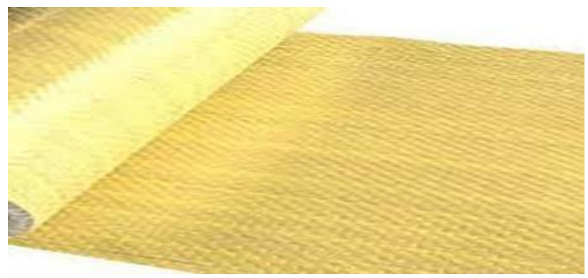


Fig -2: Aramid fiber

2.2. Carbon fiber – Carbon fibre-reinforced polymer (CFRP) is a highly durable and resilient fibre. Carbon fibre-reinforced polymers (CFRPs) have exceptional stiffness. A precursor polymer like polyacrylonitrile (PAN), rayon, or petroleum pitch serves as the main constituent of CFRP. CFRP has a tensile strength of 3500 to 7000 MPa and an elastic modulus of approximately 230 to 650 GPa. It may elongate from 0.6 to 2.4%. It demonstrates anisotropy. It finds several uses in the civil engineering, automotive, aerospace, and shipbuilding industries, among others. Similarly, the wrapping of CRP parts in aluminium or mild steel might result in galvanic corrosion. Carbon fibre-reinforced polymer (CFRP) has emerged as a crucial material in the field of structural engineering. Applications for this economical material include reinforcing concrete, masonry, steel, cast iron, and timber buildings.It can be used to either retrofit an existing structure to improve its strength or to apply pre-stress to a material. Carbon fibre-reinforced polymer (CFRP) can increase the shear strength of reinforced concrete by applying fabric or fibres around the specific area that needs strengthening. When subjected to seismic forces, structural elements such as bridges or building columns can significantly improve ductility and increase collapse resistance. It is a more cost-effective approach.

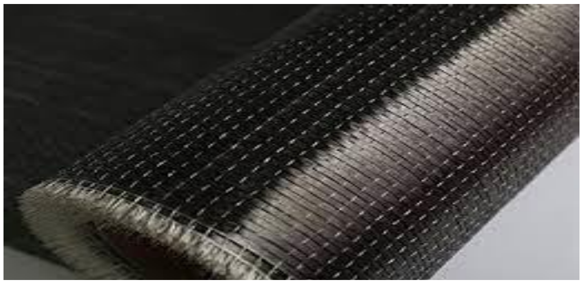


Fig -3: Carbon fiber

2.3. Glass fiber – GFRP (glass fibre reinforced plastic) was initially created in the 1930s. It exhibits isotropy and is relatively inexpensive compared to other fibre-reinforced polymers (FRPs). Glass and plastic combine during polymerization to form GFRP. The commonly used types of glass fibres are E-Glass, A-Glass, S-Glass, C-Glass, and AR Glass. A-glass (alkali glass) and C-glass (chemical glass) exhibit chemical resistance. E-glass, often known as electrical glass, is an excellent electrical insulator. People primarily use S-glass, also known as structural glass, for its exceptional mechanical qualities. Its elongation ranges from 1.2% to 5%, and its tensile strength is between 483 and 4580 MPa. The material's low density allows for a quicker installation process. It possesses exceptional strength and durability, along with remarkable resistance to sea water, chemicals, and other substances. It possesses the property of being incombustible and serves as an effective electric insulator. GFRP has various applications, including its use in both new construction projects and retrofitting projects. Due to its tremendous design versatility, this material may be utilized in a multitude of shapes and styles. It has applications in fountains, the automobile industry, aerospace, docks, cooling towers, facades, panels, and domes.

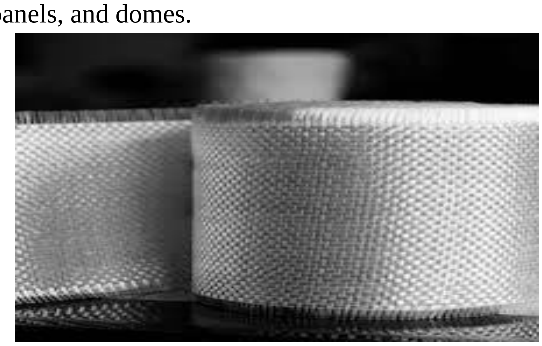


Fig -4: Glass fiber

2.4. Basalt fiber – Basalt fibre, often known as BFRP, is a naturally occurring fibre that is both lightweight and durable. Paul Dhe, an American, pioneered the development of basalt fibre in 1923. Crushed basalt rock is the essential basic material for producing basalt fibre. Lava creates this type of rock as it cools. The colour is golden-brown. The basalt fibre has a tensile strength of 992.4 MPa, an elastic modulus of 7600 MPa, and an elongation of 2.56%. Compared to other fibres, its utilisation in infrastructure is significantly limited. Its chemical makeup closely resembles that of glass fibre, making it a viable substitute for glass fibre. It possesses numerous benefits, including exceptional shear strength, strong resistance to alkaline substances, resistance to radiation and vibration, corrosion resistance, high oxidation resistance, fire resistance, and excellent chemical resistance. It exhibits a high level of electromagnetic wave permeability. Basalt fibre is employed for retrofitting structures by encircling them with the material. The diameter of basalt fibre filaments falls within the range of 10 to 20 μm. Because of its exceptional salt resistance, it finds numerous applications in marine civil infrastructure. The transportation sector uses it for various purposes, including the construction of highways, runways, railways, and pavement linings. Besides these applications, the mining and military sectors also utilize it.

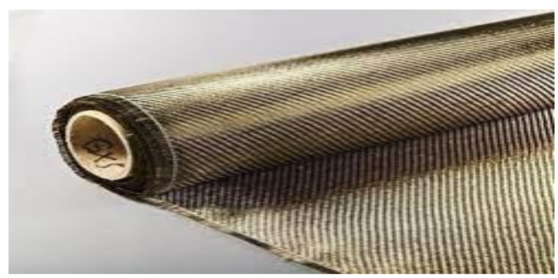


Fig -5: Basalt fiber

III. LITERATURE REVIEW

This study examines the flexural strength of glass fibre-reinforced polymers in concrete mixtures with varying amounts of glass fibre content. The study conducted by Hibretu Kaske Kassa et al. revealed that the failure pattern of the specimens showed that the production of cracks was more pronounced in the concrete without fibre compared to the fibre-reinforced concrete. In their study, D.S. Vijayan et al. [2] examined the effectiveness of concrete columns that were filled with reinforced polymer glass fibre. The load-bearing capacity and stresses of concrete columns were improved by the addition of an external E-glass fibre composite, as demonstrated by the test results. The objective of this study is to quantify the impact of enhancing the load-bearing capacity of GFRP flexible wraps on compressed concrete columns. Milind V. Tondase et al. [3] found that the CFRP wrapping can support up to two times the weight and exhibit three times the flexibility compared to a column without any wrapping. Their research describes the relationship between the toughness index of a reinforced column and the concrete grade, as well as the number of layers of carbon fibre-reinforced polymer (CFRP) sheets. It explains how wrapping CFRP sheets around a concrete column can increase its ability to carry axial loads for a variety of grades of concrete. They have a total of 10 reinforced concrete (RC) columns for axial compression cyclic load testing to evaluate their structural performance and failure patterns. Two of the columns were evaluated as RC square columns, while the remaining columns were filled with polyvinyl chloride (PVC) and wrapped with carbon fibre-reinforced polymer (CFRP). The PVC enclosure showed no warning signs of cracking. The failure was sudden, and the PVC ruptured lengthwise, as studied by Zahoor Ullah and Fawad Khan [4]. Additionally, John Bennet, C.S., et al. [5] examined concrete samples that were encased with glass fibre-reinforced polymers. The compressive strength of concrete components reinforced with glass Fibre Reinforced Polymer (GFRP) mat is 1.7 times greater than that of the control sample. In a similar manner, Kunal R. Bhoi et al. [6] demonstrated the structural integrity of damaged concrete cubes by using GFRP and CFRP wrapping on all four sides. The application of GFRP and CFRP wrapping on M20 and M25 grades reveals that CFRP exhibits superior compressive strength compared to GFRP. The observation of wrapping material failure at the lap joint indicates the need to increase the lap length. K. Ganesh et al. [7] conducted a study on the load-carrying ability of reinforced concrete elements covered in CFRP. The test findings showed that CFRP-wrapped columns performed better than conventional columns, even under eccentric loading.

Nitin Mehta and Rakesh Kumar [8] proposed a technique for improving the durability and load-bearing capability of beams by affixing a CFRP sheet with different arrangements. They conducted investigations to evaluate the impact of externally bonded carbon fiber-reinforced polymer sheets on the load-bearing capacity of reinforced concrete beams. In addition, they have undertaken studies on the flexural behaviour of reinforced concrete beams that were reinforced using carbon fibre-reinforced polymer fabric. A. R. Khan and S. Fareed [9] conducted a study that examines how reinforced concrete columns wrapped with CFRP respond to uniaxial compressive loads. Their study sought to empirically assess the behaviour of plain and reinforced concrete rectangular columns when wrapped with CFRP under a uniaxial compressive load. The study also aimed to compare the efficacy of various wrapping techniques (fully wrapped, partially wrapped, and intermittent wraps) on rectangular columns using carbon fibre-reinforced polymer wraps. The compression of concrete in the concrete cover region caused the failure of fully wrapped columns, while the concrete inside the steel core remained undamaged. The partially wrapped (PW) and intermittently wrapped (IW) samples showed similar behaviour. Both specimens failed due to concrete crushing at the vulnerable section of the column, resulting in the CFRP's collapse. The concrete within the steel core area showed only minimal or insignificant damage. The use of 2/3rd partial wrapping and intermittent wrapping strategies did not show effectiveness in improving the load-carrying capacity and ductility of specimens. In their work, Ratish Y. Chengala et al. [10] examined the potential of employing CFRP to enhance the axial load-bearing capability of reinforcing columns. The researchers found that, under the same environmental conditions, the wrapped concrete cylinder exhibited a higher overall response than the control cylinder. Abdul Saboor Karzad and his colleagues conducted a study on the efficacy of externally bonded carbon fibre-reinforced polymer (EB-CFRP) in reinforcing reinforced concrete (RC) beams. They specifically focused on EB-CFRP's ability to restore the shear strength of beams with low shear capacity.

The study conducted by Anilkumar D. et al. [12] utilised carbon fibre-reinforced polymer sheets as an exterior adhesive reinforcement in concrete constructions to enhance flexural and shear strength, retrofitting operations, and concrete containment.

Additionally, Drishya Babu and Rajesh A.K. [13] conducted a study comparing the strength of concrete when combined with glass fibre versus when glass fibre is used to wrap concrete columns. In a similar vein, Gad Vikas V. et al. [14] conducted a study on the creation and testing of various structural models such as cubes, beams, and columns. They performed compression, tensile, and flexural tests to get valuable data. The investigation has determined that the compressive strength of the carbon fibre sheet is 8% greater than that of the unwrapped cubes. Additionally, the tensile strength of the carbon fibre wrap on the column is 55% higher compared to the unlamented column. Additionally, they have determined that the flexural strength of a carbon fibre wrap applied to a beam is 55% higher than that of an unaltered beam. In addition, a study conducted by Bhagyashri D. Sangai and Ankush R. Pendhari [15] examined the use of glass fibre-reinforced polymer (GFRP) wrapping on concrete cubes. The study concluded that GFRP wrapping can enhance the strength of concrete columns when subjected to axial loading. In their study, R. Sudhakar and P. Partheeba [16] examined the enhancement of the axial compressive strength of RCC columns that were retrofitted using a GFRP system oriented in the direction of the applied axial load. In their study, Santosh Kumar Behera et al. [17] examined a general overview and recommended methods to enhance the inherent strength of the ribs through the use of CFRP and GFRP wrapping. Mahesh Kumar M. et al. [18] present the impact of elevated temperatures on the performance of concrete that is externally constrained by FRP sheets. In addition, a study conducted by K. P. Jaya and Jessy Mathai [19] examined the structural response of a beam column that was reinforced with Glass Fibre Reinforced Polymer (GFRP) and Carbon Fibre Reinforced Polymer (CFRP). CFRP-wrapped specimens show an average 98.3% increase in strength capacity compared to those without CFRP wrapping. In addition, A. Belouara et al. [20] demonstrated the axial compression characteristics of square-reinforced concrete (RC) columns that were externally restricted with carbon fibre-reinforced polymer (CFRP). Increasing the number of CFRP sheets improves the compressive strength of the restricted column. Furthermore, J. M. Lees et al. [21] have shown the viability of employing non-laminated carbon fibre-reinforced polymer (CFRP) straps as external post-tensioned shear reinforcement in concrete. The inclusion of the straps seems to enhance the fracture angle, leading to a significantly more rigid structure compared to the similar unreinforced parts. In addition, S.A. Rasal et al. [22] conducted a study on the recycled aggregates obtained from concrete specimens and found that they result in high-quality concrete. When the recycled aggregates were used in a ratio of 25:75 with the fresh aggregates, the results were similar to those obtained when using 100% fresh aggregates. In addition, Aniket Mestri et al. [23] conducted a study on the concrete mix of M35 grade. They created and constructed the mix by partially substituting granulated blast furnace slag (GBFS) with fine aggregate and replacing bagasse ash (BA) with cement.

IV. STUDY OBJECTIVES

- To investigate the tensile and compressive strengths of CFRP control concrete cubes and GFRP control concrete cubes.
- Study the effects of glass fibre and carbon fibre reinforcement on the tensile and compressive strengths of concrete cubes.

1. Single wrapping.
2. Double wrapping.
3. Triple wrapping.

- To compare the empirical findings of carbon and glass fibres.

V. METHODOLOGY

Initially, we will acquire materials based on the needs of the study. We will conduct a detailed analysis of the properties of the components, including cement, sand, aggregate, and so on. We will construct a concrete mix design for grades M15 and M20 using these components. We will manufacture standard cubes measuring 150 mm by 150 mm by 150 mm and a cylindrical specimen with a diameter of 100 mm. The concrete will then cure for 28 days.

Surface preparing

Remove the coating of concrete surface with grinder (if any). Polishing the surface.

I. SETTING OUT

Before proceeding, make sure to thoroughly clean and dry the concrete surface.

II. APPLY PRIMER

Coat the concrete surface with primer adhesive.

III. APPLY PUTTY/LEVELING

Apply putty for the purpose of repairing and levelling, if necessary.

IV. FIBER CUTTING

Trim the carbon fibre to match the specified dimensions.

V. PREPARING IMPREGNATION ADHESIVE

Calculating the weight and mixing adhesive in accordance with the specified ratio. To ensure a uniform colour and prevent the formation of air bubbles, thoroughly mix the adhesive. Apply the impregnation adhesive once the priming adhesive has fully dried.

VI. APPLY THE CARBON/GLASS FIBER

The carbon fibre (300 GSM) and glass fibre (400 GSM) are applied to the surface of concrete cubes according to the specified design, using different layers (1, 2, 3 layers). Ensuring a uniform and even surface across its entire length. Next, the epoxy adhesive is applied once more to the carbon or glass fibre.

VII. CHECK GAP OR BUBBLES

Ensure that the adhesive thoroughly permeates the fibre, that the surface is level, and that there are no air bubbles present.

The subsequent section of the paper discusses the findings of the investigation.

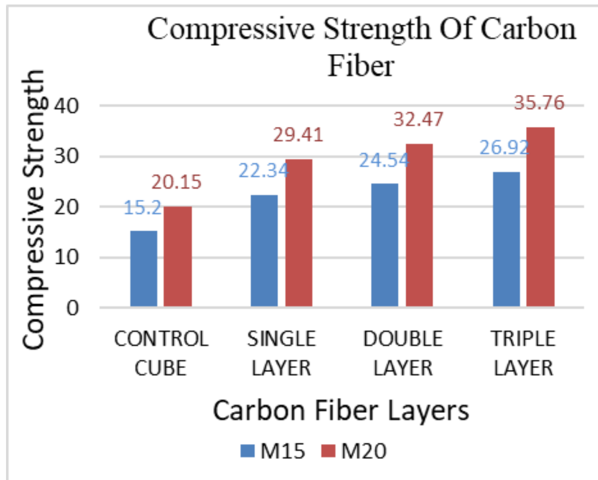
VI. RESULT AND DISCUSSION

We perform testing once the entire process is complete. We base the following discussion on the test results. The next sections will compare the experimental results with the analytical values, calculated in accordance with the ACI 440.2R-08 FIB standards.

Results:

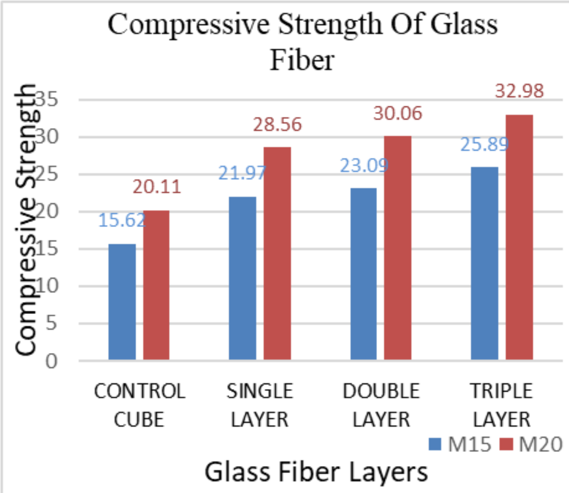
6.1 Compressive strength of concrete cubes wrapping with carbon fiber

GRADE	M15	M20
CONTROL CUBES	15.20	20.15
SINGLE LAYER	22.34 (46.97%)	29.41 (45.95%)
DOUBLE LAYER	24.54 (61.44%)	32.47 (61.14%)
TRIPLE LAYER	26.92 (77.10%)	35.76 (77.46%)



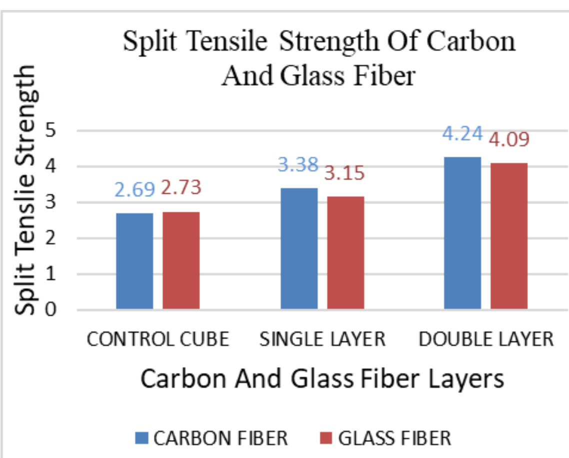
6.2 Compressive strength of concrete cubes wrapping with GLASS fiber

GRADE	M15	M20
CONTROL CUBES	15.62	20.11
SINGLE LAYER	21.97 (40.65%)	28.56 (42.01%)
DOUBLE LAYER	23.09 (47.82%)	30.06 (49.47%)
TRIPLE LAYER	25.89 (65.75%)	32.98 (63.99%)



6.3 Spilt Tensile Strength of Concrete Cylinders wrapping with carbon and glass fiber

GRADE	M15	
FIBER	CARBON	FIBER
CONTROL CUBES	2.69	CONTROL CUBES
SINGLE LAYER	3.38 (25.65%)	SINGLE LAYER
DOUBLE LAYER	4.24 (57.62%)	DOUBLE LAYER



CONCLUSION

- The compressive strength of conventional concrete with M15 grade increases by 46.97% when wrapped with a single layer of CFRP and by 40.65% when wrapped with a single layer of GFRP.
- The compressive strength of conventional concrete with M15 grade increases by 61.44% when wrapped with double layers of CFRP, and by 47.82% when wrapped with double layers of GFRP.
- Compared to conventional concrete's M15 grade, wrapping cubes in a triple layer of CFRP raises their compressive strength to 77.10% and GFRP to 65.75 percent, respectively.
- A single layer of CFRP enhances the compressive strength of conventional concrete M20-grade cubes to 45.95%, while a single layer of GFRP boosts it to 42.01%.
- Double layer wrapping in of cubes results in an improvement in the compressive strength of ordinary concrete M20 grade to 61.14% for carbon fibre reinforced plastic (CFRP) and 49.47% for glass fibre reinforced plastic (GFRP).
- In conventional concrete M20 grade, the triple layer wrapping of cubes results in a compressive strength improvement of 77.46% for CFRP and 63.99% for GFRP.
- The tensile strength of conventional concrete with M15 grade increases by 25.65% when wrapped with a single layer of CFRP and by 15.38% when wrapped with a single layer of GFRP. The tensile strength of ordinary concrete with M15 grade increases by 57.62% when wrapped with double layers of CFRP and by 49.81% when wrapped with double layers of GFRP.

The findings demonstrated that the concrete cube samples exhibited an increase in both their compressive and tensile strengths as a consequence of the addition of additional fibre layers. Both the compressive and tensile strengths of CFRP are greater than those of GFRP.

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