Strengthening of RC Beams Encased in Aramid Fibre Reinforced Polymer Sheets

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Abstract-This project investigates the efficacy of strengthening undamaged reinforced concrete (RC) beams using aramid fibre reinforced polymer (AFRP) sheets through two different wrapping configurations: U-wrapping and 3-Layers of 100 mm strips. The study aims to enhance the load-carrying capacity and reduce deflection in RC beams measuring 1.7 meters in length, 100 mm in breadth, and 150 mm in depth. The experimental approach involves comprehensive testing, including assessing compressive strength using 150 mm cube specimens, split tensile strength with 150 mm diameter by 300 mm height cylindrical specimens, and flexural strength testing on beam specimens. Additionally, non-destructive testing will utilize a rebound hammer, strategically wrapped within a single layer in 100 mm cube specimens, to evaluate structural integrity and surface hardness. Anticipated outcomes will demonstrate the effectiveness of AFRP sheets in enhancing the strength of undamaged RC beams and highlight the rebound hammer's suitability for assessing AFRP-reinforced concrete non-destructively. This study contributes valuable insights to structural engineering, focusing on the enhancement and durability of existing concrete structures using advanced composite materials.

Index Terms: AFRP, strengthening, Wrapping, Reinforced concrete beams.

I. INTRODUCTION

The strengthening of reinforced concrete (RC) structures has become increasingly significant in the field of structural engineering due to the need for enhancing the load-bearing capacity and extending the lifespan of existing structures. Among the various materials used for this purpose, Aramid Fiber Reinforced Polymer (AFRP) has gained attention due to its high strength-to-weight ratio, excellent fatigue resistance, and corrosion resistance. AFRP sheets are particularly effective in reinforcing RC beams, which are critical components in many infrastructures such as bridges, buildings, and industrial facilities. The ultimate load carrying capacity for 0% damage degree beams are increased after strengthening with single layer and double layer of 100 mm width AFRP strip is 27.59% and 48.27% respectively compared with control beam. Ultimate load carrying capacity in beams is found to be increasing with increase in layer of AFRP strip [1]. This study focuses on investigating the efficacy of strengthening undamaged RC beams using AFRP sheets, utilizing two distinct wrapping configurations. Compared with existing specimen, the crack occurring interval and width, and so forth of specimen reinforced with aramid fiber sheet were found to be narrower. This is judged to exist because loads were delivered evenly due to the effect of aramid fiber sheet [2] . Reinforced concrete beams strengthened with fully wrapped aramid fiber has taken 140% more moment at first crack as well as ultimate torsional moment, when compared with controlled beam [3] . The primary objective is to enhance the load-carrying capacity and reduce deflection in these beams, which are essential parameters for structural performance and safety. The experimental approach involves a comprehensive testing regimen that includes assessing the compressive, tensile, and flexural strengths of concrete specimens. From the impact loading test results, the maximum and residual displacement of the strengthened beams can be restrained by up to 35% and 85%, respectively, compared with non-strengthened beams [4] . These mechanical properties are fundamental to understanding how the AFRP sheets contribute to the overall enhancement of the RC beams. Additionally, the study employs non-destructive testing methods, specifically using a rebound hammer, to evaluate the structural integrity and surface hardness of the AFRP-reinforced concrete. The rebound hammer test is a widely used technique that provides quick and useful insights into the concrete's surface properties without causing damage. The anticipated outcomes of this research are expected to demonstrate the significant benefits of using AFRP sheets in strengthening undamaged RC beams. It should be noted that the RH test measurements are highly related to the near surface of the test object. Therefore, it is recommended that the RH tests can be combined with other nondestructive test methods (such as UPV tests) to improve concrete compressive strength estimations [5] . These benefits include increased load-bearing capacity, reduced deflection, and enhanced durability of the beams. Furthermore, the study aims to validate the rebound hammer's suitability as a non-destructive evaluation tool for AFRP-reinforced concrete, offering a practical approach for ongoing structural assessment. The relationships between the coefficients of the examined conversion models are then established, with the aim of reducing the unknowns in the calibration procedure[6] . It underscores the importance of innovative reinforcement techniques in improving the performance and longevity of concrete structures, thereby addressing the growing demands for robust and durable infrastructure solutions.

II. MATERIAL PROPERTIES AND MIX PROPORTION

A.Materials

Cement: In the project, Ramco PPC Cement fly ash-based variant was utilized, incorporating its distinctive properties into the study. The specific gravity test result of 2.88 indicates the density of the cement, which is crucial for accurately determining the mix proportions and ensuring the structural integrity of the project. This particular type of cement is chosen for its fly ash composition, which enhances its properties such as durability and workability.

Fine aggregate: M-Sand, utilized as the fine aggregate in the project, exhibits a specific gravity of 2.67, reflecting its density concerning water and essential for assessing its compactness and overall quality.

Coarse Aggregate: In the study, coarse aggregate with a maximum size of 20 mm is utilized. The specific gravity test yields a result of 2.8, indicating its density, while the fineness modulus is determined to be 7.58, providing insights into its particle size distribution.

Water: Water is a fundamental component in the preparation of concrete specimens for the project. It serves as a key ingredient in the concrete mix, facilitating the hydration process of cement and enabling the formation of a strong, durable matrix.

Admixture: Superplasticizer Tec Mix 550 is a crucial component in our project aimed at enhancing the performance of concrete through water reduction. Its advanced formulation facilitates significant reduction in the water-to-cement ratio, thereby improving the workability and durability of concrete structures. The incorporation of Tec Mix 550 enables us to achieve higher levels of compressive strength while minimizing the risk of segregation and bleeding during the casting process.

Steel for Reinforcement: For beam reinforcement, this project utilizes four 12mm diameter steel bars for primary reinforcement, complemented by ten 8mm diameter stirrups spaced at 150mm intervals. This configuration ensures optimal structural support and integrity, reinforcing the beam against bending and shear forces, enhancing its load-bearing capacity and durability.

AFRP sheet: In the retrofitting process of RC beams, Aramid Fibre Reinforced Polymer (AFRP) sheets serve as essential materials. Aramid fibres are characterized by their superior thermal properties, resistance to chemicals and outstanding mechanical properties [7]. AFRP sheets are composed of aramid fibres embedded in a polymer matrix, offering high tensile strength, lightweight properties, and excellent corrosion resistance. When applied to reinforced concrete (RC) beams, AFRP sheets provide enhanced structural strength and durability, effectively reinforcing and retrofitting the beams against external loads and environmental factors. Their flexibility allows for easy application and adaptation to various beam shapes and sizes, making them a versatile solution in retrofitting projects. Additionally, AFRP sheets offer a cost-effective alternative to traditional retrofitting methods while ensuring long-term performance and structural integrity of RC beams.

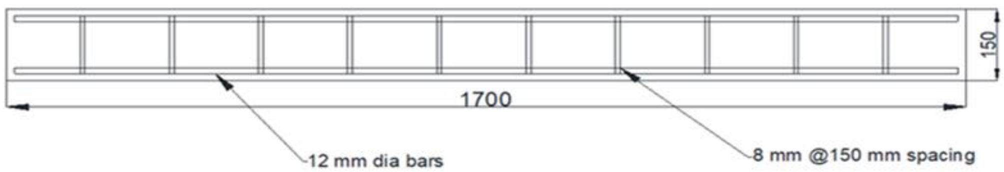


Figure 1 Reinforcement details of Beam

Table 1: Physical properties of AFRP

Properties	*Value*	*UOM*
Thickness	0.22	mm
Fabric Aerial Weight	220	g/m2
Breaking Strength	226	N
% Elongation	3.5	%
Tensile Modulus	86	Gpa
Weave Style	Plain	-

Epoxy resin and Hardener: In this study, the synergistic combination of Epoxy Resin LY 556 and Hardener HY 951, mixed in a precise ratio of 10:1, proves instrumental in bonding Aramid Fibre Reinforced Polymer (AFRP) sheets to concrete samples. This innovative approach enhances the structural integrity and durability of the concrete, offering superior reinforcement properties. The epoxy resin's adhesive strength, coupled with the hardener's catalytic effect, ensures a robust bond between the AFRP sheets and the concrete substrate. This project presents a promising solution for improving the performance and longevity of concrete structures, particularly in applications requiring enhanced structural reinforcement.

B. Mix Proportioning

To design concrete samples according to IS 10262:2019 for M30 grade, with mix ratio 1:1.8:3.1:0.4, and 1.2% of superplastizer used for water reducer. First, determine the required strength for cubes, cylinders, and beams. For cubes and cylinders, typically cast using 150mm moulds, while beams require 100mm x 150mm x 1700mm moulds. Calculate the quantities of cement, fine aggregate, coarse aggregate, and water based on the mix ratio. Insure thorough mixing to achieve uniform consistency. Fill the moulds in layers, compacting each layer properly. Cure the samples under controlled conditions, usually moist curing for 28 days.

III. EXPERIMENTAL PROGRAM

In the experiment program, various tests were conducted on concrete samples to assess the efficacy of different patterns of AFRP (advanced fiber-reinforced polymer) wrapping. Compressive, split tensile, and flexural tests were performed to gauge the strength of the specimens. The study aimed to compare the performance of AFRP wrapping in undamaged concrete specimens. By analyzing the results of these tests, researchers sought to understand how different wrapping patterns affect the structural integrity and durability of concrete under various loading conditions, providing valuable insights for enhancing reinforcement strategies in construction and infrastructure projects.

A. Mechanical Properties

Compressive Strength : Nine cubes were cast and tested for compressive strength using a compression testing machine with a capacity of 2000 KN at 7, 14, and 28 days after curing for conventional cubes. Additionally, two cubes were tested for Aramid Fibre Reinforced Polymer (AFRP) wrapping configurations:

one fully wrapped on all four sides and the other wrapped in a U-shape.

Split Tensile Strength: Four cylinders were cast and tested at 7 and 28 days of curing using a compression testing machine with a capacity of 2000 KN. One cylinder underwent testing with Aramid fibre-reinforced polymer (AFRP) sheet wrapping, with one fully wrapped around the circumference of the specimen.

Flexural Strength: A total of three beams underwent flexural testing. One beam was tested conventionally. One beam was partially wrapped with U-shaped wrapping, extending until the supporting ends, for undamaged specimen. The remaining one beams were wrapped with strips of 100 mm width to cover the calculated crack area which is observed in the control Beam.

Table 2: Mix design for M30

Description	*Cement*	*FA*	*CA*	*Water*	*Admixture*
Quantity of materials (kg/m^3)	394.32	666	1226	171	4.73
Mix proportion (by weight)	1	1.7	3.1	0.4	0.0120

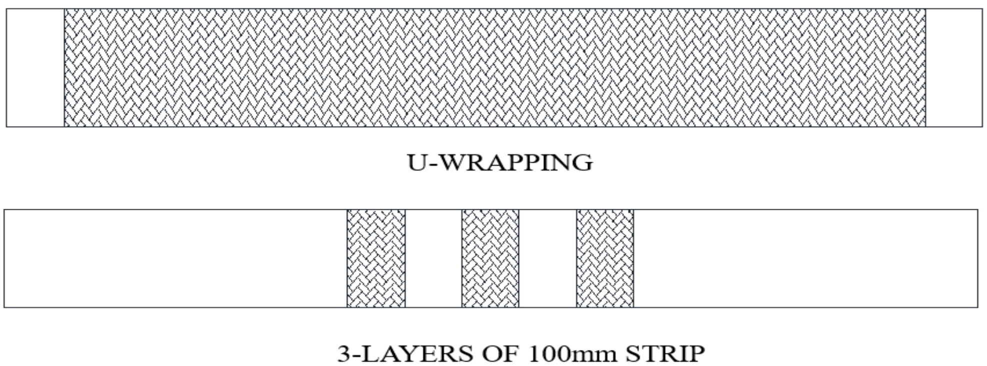


Figure 2 Type of wrapping configuration

B. Testing of Concrete Specimens

The compression testing machine was used to test specimens in the form of both cubes and cylinders, a beam specimen underwent testing in a flexural testing machine loading up to 500 KN. For measuring deflection LVDT machine equipped with Prosof-14-B software was employed. This software facilitated accurate reading and monitoring of defection during the load application process.

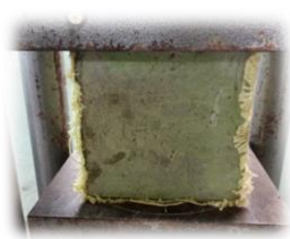


Figure 3 Compressive Strength Test

Figure 4 Split tensile strength Test

Figure 5 Flexural test set up

C. Test Results
After the concrete specimen was strengthened with AFRP sheets, the test was conducted and the results were recorded in a

Compressive Strength Test:
At 7 days, the cube specimens achieve 63% of the target mean strength, which is typical for early-stage concrete curing. By 14 days, the compressive strength reaches 88% of the target mean strength, indicating continued hydration and strength gain. By 28 days, the specimens achieve 98.5% of the target mean strength, demonstrating that the concrete has nearly reached its full design strength, as 28 days is the standard curing period for assessing concrete strength. Furthermore, the application of Aramid Fiber Reinforced Polymer (AFRP) enhances the compressive strength of the concrete specimens. When the cubes are wrapped in AFRP using a U-WRAP method, the strength increases by 10.1% compared to the control specimen at 28 days. Similarly, when using a Fully-WRAP method, the compressive strength increases by 15.4%. This suggests that AFRP wrapping, particularly the Fully-Wrap method, significantly improves the structural performance of concrete, potentially offering a viable technique for strengthening existing concrete structures.

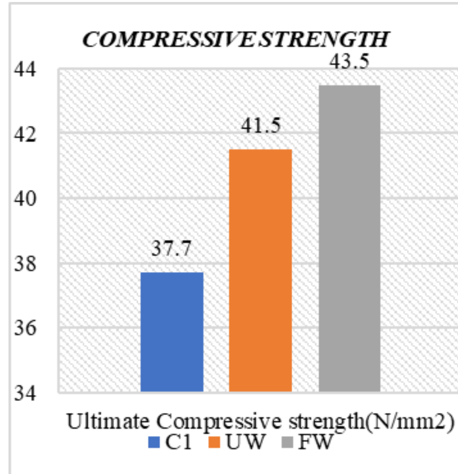


Figure 6 Comparison of Compressive strength

Split Tensile Strength Test:
The fully wrapped cylinder with AFRP shows a percentage increase of approximately 17.8% in split tensile strength compared to the conventional cylinder. This increase is due to the reinforcing effect of AFRP, which enhances the tensile resistance of the cylinder.

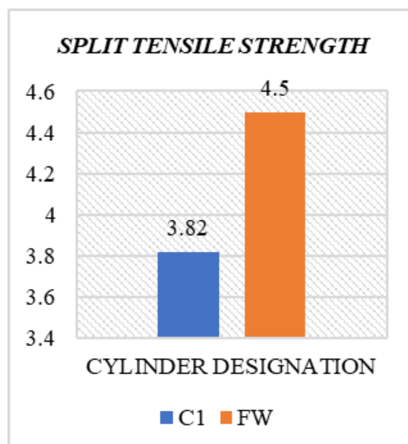


Figure 7 Split Tensile Test

Flexural Strength Test:
The enhancement of beam performance through Aramid Fiber Reinforced Polymer (AFRP) wrapping demonstrates significant improvements in load-bearing capacity and deflection characteristics. For conventional beams, the maximum load is 46.86 kN with a maximum deflection of 11 mm. When U-wrapped with AFRP, the ultimate load capacity increases by 31.5%, while the maximum deflection decreases by 18.18%, indicating both increased strength and stiffness. Conversely, a 100 mm strip

wrap on undamaged beams results in a 10.6% increase in ultimate load but also a 9.09% increase in maximum deflection, suggesting a trade-off between strength gain and flexibility. The superior performance of the U-wrap method can be attributed to its comprehensive coverage and more uniform reinforcement distribution, providing a more effective structural enhancement compared to strip wrapping.

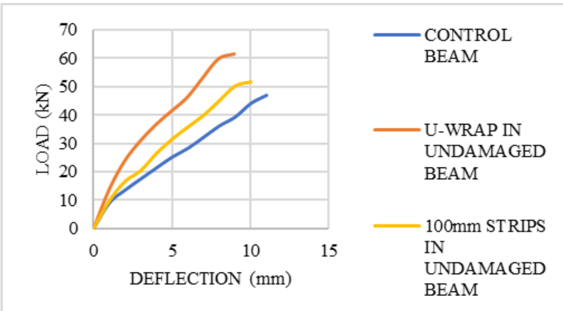
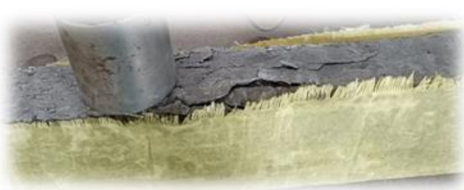


Figure 8 Load versus Deflection graph for Different Wrapping Condition with AFRP

Crack pattern:
The cracks observed in the cube and cylinder, which were enveloped with AFEP, were significantly reduced compared to the control specimens. A comparison of crack patterns was conducted between the control beam and the wrapped beam. It was observed that both beams exhibited similar flexural and shear crack patterns. Flexural cracks emerged vertically under pure bending, while shear cracks developed in beams wrapped with strips. It was observed that in the undamaged beam, crushing occurred on the top near the load cell in the U-wrap. This phenomenon can be attributed to the reinforcement provided by AFRP. The application of AFRP sheets led to a decrease in the number of cracks and crack widths. The figures illustrate the crack patterns of the control beam and the wrapped beams.



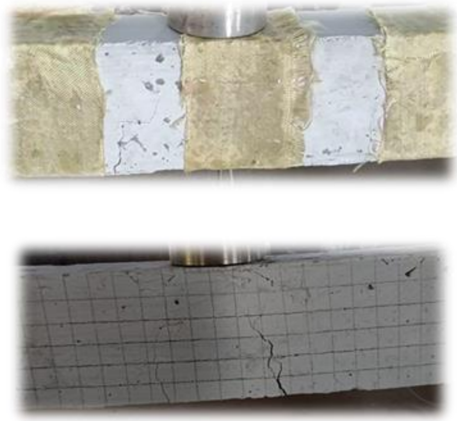


Figure 9 Crack pattern observed in Beam

IV. NON-DESTRUCTIVE CONCRETE TEST

Rebound Hammer Test
For accurate testing, ensure the surface is smooth, clean, dry, and prepared with an abrasive stone if necessary. Avoid rough surfaces caused by incomplete compaction, grout loss, spalling, or tooling, as they yield unreliable results. The impact point should be at least 25 mm from any edge or discontinuity. Hold the rebound hammer at right angles to the concrete surface, whether testing horizontally on vertical surfaces or vertically on horizontal surfaces. Press the hammer plunger perpendicularly to the concrete, read the rebound value after impact, and take at least three readings around each observation point, maintaining a minimum 20 mm distance between them. Use the calibration chart to convert the rebound index to compressive strength.

Specimen Size : cube (100 mm)
Type of Surface : vertically downwards

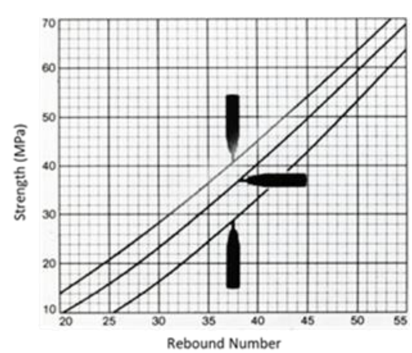


Figure 10 Calibration chart

Table 3 :Rebound Index tabulation

Sl. No	*Rebound Index*	*Quality of Concrete*	*Compressive Strength Based on Rebound Index(MPa)*
1	25	Fair	22
2	31	Good Layer	30 (36.36 ↑)

Figure 11 Rebound Hammer Test

The AFRP wrap has evidently improved the compressive strength of the concrete cube compared to the conventional cube, as indicated by the higher rebound number. The AFRP wrap likely provided additional reinforcement to the cube, enhancing its structural integrity and ability to withstand compressive forces. This improvement could be due to the enhanced tensile strength and durability provided by the AFRP material, which effectively strengthens the concrete structure. It's important to consider factors such as the quality of the AFRP material, application method, curing conditions, and the composition of the concrete mix when assessing the effectiveness of the AFRP wrap.

CONCLUSION

The application of AFRP sheets markedly improves the compressive and tensile strength of concrete and the structural performance of beams, demonstrating significant benefits in structural reinforcement and crack mitigation. These findings highlight the effectiveness of AFRP in enhancing overall structural integrity and load-bearing capacity.

i. The application of AFRP sheets significantly enhances the compressive strength of concrete cubes and cylinders, as well as the structural performance of beams. Wrapping in a U-shape resulted in a 10.6% increase in compressive strength compared to conventional cubes, while fully wrapping led to a notable 15.3% increase. This demonstrates the superior efficacy of full AFRP wrapping in augmenting compressive strength, surpassing the gains achieved through U-shaped wrapping. Additionally, fully wrapped cylinders showed a significant 17.8% improvement in split tensile strength, rising from 3.82 N/mm² to 4.5 N/mm².
ii. The U-wrap with AFRP significantly enhanced the structural performance of undamaged beams, increasing the ultimate load capacity by 31.5% and reducing maximum deflection by 18.18%. In comparison, the 100 mm strip wrap showed a more modest improvement, with a 10.6% increase in ultimate load but an increase in maximum deflection by 9.09%.
iii. The superior performance of the U-wrap is attributed to better coverage and more effective reinforcement distribution. AFRP wrapping substantially reduces the number and width of cracks in beams, cubes, and cylinders, indicating enhanced structural integrity.
iv. Both control and wrapped beams exhibit similar flexural and shear crack patterns, though the AFRP wrap mitigates crack propagation. In the U-wrapped undamaged beam, top crushing near the load cell suggests significant reinforcement, highlighting the effectiveness of AFRP in enhancing load-bearing capacity. Furthermore, the AFRP wrap significantly improved the compressive strength of the concrete cube by 36.36%, as evidenced by the higher rebound number.
v. This enhancement is likely due to the additional reinforcement and increased tensile strength provided by the AFRP material, which strengthens the concrete structure. These findings underscore the advantageous impact of comprehensive AFRP reinforcement in structural enhancement projects.

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