

# Evaluation of Retrofitting Methods for Reinforced Concrete Members using Coconut Coir-Reinforced Composites and Epoxy Bonding

Crystal Maurick Cura  
Department of Civil  
Engineering FEU Pampanga  
Pampanga, Philippines

Jimuel Quiambao  
Department of Civil Engineering  
FEU Pampanga  
Pampanga, Philippines

Noreen Ella Tinamisan  
Department of Civil Engineering  
FEU Pampanga  
Pampanga, Philippines

**Abstract** - The effectiveness of coconut husk fiber-epoxy composite as a retrofitting material for reinforced concrete beam (RCB) was investigated in this study. The objective of this research was to find the tensile strength of coconut husk fiber-epoxy composite, the bond strength between the composite and the concrete surface, and the flexural behavior of RC beams retrofitted with the composite material. The treated coconut husk fibers were externally bonded to the soffit of the reinforced concrete beams using epoxy resin. Laboratory testing was performed according to ASTM standards, which include ASTM D3039 for tensile strength, ASTM D7522 for bond strength (pull-off test), and ASTM C78 for flexural strength using the third-point loading method. The results showed that the coconut husk fiber-epoxy composite had sufficient tensile strength, which exceeded 57 MPa. The bond strength value varied between 0.405 MPa and 0.936 MPa. Failures according to Modes G and E occurred. The two failures according to Mode G occurred inside the concrete, which indicated that the bond strength exceeded the concrete strength, while the other failure occurred in Mode E, which showed that the bond strength was achieved. The result of the flexural test showed a significant improvement in the bending strength of the retrofitted beams compared to the control beams. The statistical analysis using the independent samples t-test confirmed that the improvement in the flexural strength was statistically significant at a significance level of 5%. The results have shown that the combination of coconut husk fibers and epoxy resin can be considered as a viable alternative material for strengthening reinforced concrete members.

**Keywords** – *coconut husk fiber; epoxy bonding; retrofitting; flexural strength; bond strength*

## INTRODUCTION

Concrete is widely used in construction due to its strength, durability, and availability. However, reinforced concrete beams deteriorate over time because of cracking, weather exposure, overloading, and aging. These conditions may lead to reduced structural performance and the need for retrofitting to restore or improve load-carrying capacity. Traditional retrofitting methods, such as steel plate bonding and the use of carbon or glass fiber-reinforced polymer (FRP) systems, are proven effective but are often costly and require specialized installation procedures. As a result, researchers are exploring natural fibers as alternative strengthening materials.

Synthetic fibers such as glass or carbon, steel reinforcements, epoxy resins, or high-strength cementitious

overlays are commonly used in traditional retrofitting techniques. These can improve structural capacity but may be incompatible with traditional substrates (for example, stiffness mismatch, retained moisture, chemical incompatibility, or aesthetic intrusion). Furthermore, most of these materials have significant embodied carbon footprints and are expensive.

There is a need for retrofitting materials that can satisfy such criteria's like effectiveness, compatibility to the past structural elements, low impact to environment, and the availability in the Philippines. Some of the criteria is intended to reduce the cost of material itself and the transport cost. In the Philippines, there are a lot of natural fibers. There are few studies that natural fibers increase the strength of concrete when it has epoxy and natural fibers. The behavior that they obtain from the testing and study is useful for strengthening existing concrete structures and for improving the seismic performance of deficient concrete structures [1].

Coconut husk fiber is an abundant waste product in the Philippines and other tropical countries. It comes from unripe coconut; it is also a natural fiber that is extracted from the husk of coconut. Coconut fiber is also known as one of the producers of natural waste in the world, it produces at least 30 million tons of coconut. Structural mortars with 0.5% coir by weight increased compressive and flexural strength by 84.3% and 43.3%, respectively, compared to an unreinforced control [2]. Study show that moderate dosages and short fiber lengths like 15 mm give improved behavior in mortar systems. In addition, by using locally available fiber reinforcement instead of highly embodied synthetic materials and eliminating agro-waste, the use of coir is consistent with sustainability goals and circular economy thinking [3]. Researcher also states several advantages of using coconut fibers. They are resistant to fungi, rot, moth, moisture and dampness; give an excellent insulation against temperature and sound; non-combustible, tough and durable, resilient, flame-retardant, totally static-free and easy to clean [4].

This work shows alignment with several United Nations SDGs through its focus on sustainable, resilient, and environmentally responsible structural retrofitting practices. First, the contribution to SDG 9 (Industry, Innovation, and Infrastructure) is made by developing an innovative retrofitting approach, which uses natural fiber epoxy composites to enhance the structural performance and extend the service life

of existing concrete members. Next is this research addresses SDG 11 (Sustainable Cities and Communities) by promoting retrofitting strategies that enhance building safety and resilience and minimize urban-area vulnerabilities to various hazards. The use of coconut husk fiber, a plentiful agricultural byproduct, aligns the study with SDG 12 (Responsible Consumption and Production) by encouraging waste utilization, material circularity, and resource-efficient engineering solutions.

## RESEARCH METHODS

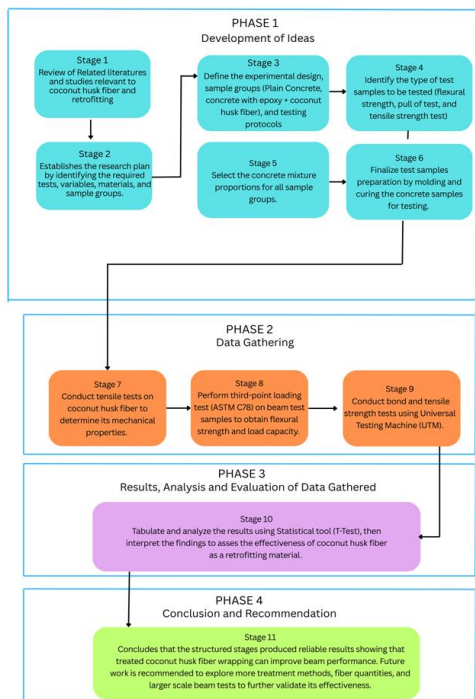


Fig. 1: Methodological Framework

### PHASE 1: Development of Ideas

#### Stage 1 – Review of Related Literature

This process begins with a review of past research, publications, and papers on coconut husk fiber and retrofit methods. The purpose of the literature review is to provide insight into recent research on the use of coconut fibers in construction, including their preparation, performance, and ability to strengthen concrete buildings. The review evaluates effective approaches from several studies, highlighting any flaws or issues that might still need to be fixed. The gaps, those topics or issues not thoroughly covered by earlier studies are identified. In order to assure the relevance, accuracy, and potential for the research to contribute to the area, the information acquired during this stage provides background information for the current study and guides the selection of procedures, materials, and tests.

#### Stage 2 – Development of the Research Plan

In this stage, the complete research plan for the study is created based on the results from the Review of Related Literature. The goal is to decide which tests will be performed,

which variables will be measured, and what materials and equipment are needed before making the actual test samples. This stage involves choosing the suitable ASTM testing standards (ASTM D3039, ASTM D7522, and ASTM C78), identifying the type and number of specimens needed for each test, and setting the fiber percentages to be used in the experiment. The results of this stage act as a guide for the next phase, which is the Preparation of Test Samples.

### Stage 3 – Treatment of Coconut Husk Fiber

This stage focused on the treatment, preparation, and application of coconut husk fibers used as external reinforcement for reinforced concrete beam specimens. The fibers were externally bonded to the beam surfaces using epoxy resin, with lamination plastic used only as a pressing aid during application (ACI Committee 440, 2017; FHWA, 2010).

Raw coconut husk fibers were initially washed with clean water to remove dirt, dust, pith residues, and other surface impurities that could affect bonding. The fibers were then manually cleaned and sorted to remove short or damaged strands, and only long and uniform fibers were selected to ensure consistency [5].



Fig. 2: Washing and Manual Cleaning of Raw Coconut Husk Fibers Prior to External Bonding Application

The cleaned fibers were subjected to alkaline treatment by soaking them in a 5% sodium hydroxide (NaOH) solution at room temperature for 2 to 4 hours [6]. This process removed surface impurities such as lignin and waxes and improved fiber epoxy adhesion. After treatment, the fibers were rinsed repeatedly with clean water until a neutral pH was achieved and then air-dried in a shaded, well-ventilated area until a stable moisture content of approximately 8–12% was reached [7].



Fig. 3: Alkaline treatment of coconut husk fibers through immersion in 5% NaOH solution

Prior to application, the epoxy resin and hardener were weighed and mixed according to the recommended ratio used in this study to ensure proper curing. The mixed epoxy was applied directly onto the prepared beam surface. The treated coconut husk fibers were then placed on the wet epoxy layer and manually pressed to ensure full contact (ACI Committee 503, 2016; FHWA, 2010).



Fig. 4: Application of mixed epoxy resin onto the prepared beam surface

A layer of lamination plastic was placed over the fibers to prevent direct hand contact and to assist in pressing the fibers into the epoxy. Manual pressure was applied over the plastic sheet to remove trapped air bubbles and excess epoxy and to ensure uniform fiber impregnation. After pressing, the lamination plastic was removed, and additional epoxy was applied as needed to fully coat the fibers (ACI Committee 440, 2017).

The fiber wraps were applied to reinforced concrete beams measuring 150 mm × 150 mm × 533.4 mm, internally reinforced with four (4) 12 mm diameter longitudinal steel bars and 8 mm diameter stirrups. The fibers were applied at the soffit of the beams (ACI Committee 440, 2017).



Fig. 5: Application of additional epoxy to fully coat the externally bonded coconut husk fibers

The fiber reinforcement was installed on the soffit (bottom surface) of the reinforced concrete beams, which is the tension side under bending. The application was placed in tension side to improve the flexural strength of the beams. The fiber sheets were carefully placed and firmly pressed onto the soffit to ensure full contact with the concrete and to remove trapped air.

Two (2) layers of coconut husk fiber externally bonded with epoxy resin were applied to each beam to provide enough bonding area and increase the thickness of the strengthening layer. After application, the wrapped beams were inspected for defects such as air voids, uneven thickness,

or incomplete epoxy coverage. The specimens were then allowed to cure at room temperature before labeling and preparation for mechanical testing (ACI Committee 503, 2016; ASTM D7522).



Fig. 6: Application of two-layer epoxy-externally bonded coconut husk fiber reinforcement on the beam soffit

#### Stage 4 – Identification of Test Samples

In this stage, the study identified and justified the appropriate test specimens required for the experimental program. Reinforced concrete beams were selected as the primary specimens because they represent an actual structural element where flexural behavior, bond performance, and the effectiveness of external retrofitting can be clearly observed and evaluated (ACI Committee 318, 2019; ACI Committee 440, 2017). To maintain uniformity and ensure valid comparison among all test groups, each beam specimen was standardized to dimensions of 150 mm × 150 mm × 533.4 mm. This beam size was selected because it is sufficiently large to exhibit realistic structural behavior while remaining suitable for laboratory casting, handling, and testing equipment limitations (ASTM C78/C78M)

Each beam specimen was internally reinforced using four (4) 12 mm diameter steel bars as longitudinal reinforcement to resist flexural stresses, while 8 mm diameter steel bars were used as stirrups to provide shear resistance and maintain the position of the longitudinal reinforcement [8]. The reinforcement layout was kept consistent for all specimens to ensure uniformity and to allow direct comparison between control beams and beams retrofitted with coconut husk fiber wraps [9].



Fig. 7: Longitudinal and stirrup reinforcement arrangement of the beam specimen prior to external fiber application

Identifying the type, shape, dimensions, and reinforcement details of the beam specimens at this stage was necessary to ensure proper preparation of materials, molds,

and reinforcement cages. This also enabled alignment of the fiber wrapping configuration, casting procedures, and mechanical testing requirements within the overall experimental design [10]. Establishing these parameters early in the study provided a clear basis for the succeeding stages of specimen preparation, testing, and analysis. As a result, this stage contributed to the reliability, consistency, and accuracy of the experimental results obtained from the beam tests (ASTM E1820).

C192/C192M, 2023). Aggregates were checked for cleanliness and moisture condition, and the concrete was mixed mechanically until a uniform and homogeneous mixture was achieved.

The concrete was placed into the molds in layers and compacted manually using a steel tamping rod to remove trapped air and ensure proper consolidation. The sides of the molds were lightly tapped to help release air pockets. After placement, the top surface of each specimen was leveled and finished, and the molds were covered to minimize early moisture loss, consistent with standard casting procedures (ASTM C192/C192M, 2023).

Type of Test	Concrete Mix Type	Number of Samples	Remarks
Tensile Strength	Coconut Husk Fiber	3	To evaluate the tensile capacity of the treated fiber (ASTM D3039)
Bond Strength	Concrete with Epoxy + Coconut fiber composite	3	To measure the adhesion performance of the composite on the concrete surface (ASTM D7522)
Flexural Strength	Plain Concrete Beam (No Epoxy, No Coconut Fiber)	3	Baseline flexural capacity for comparison (ASTM C78)
	Concrete with Epoxy + Coconut Fiber	3	To test the flexural performance of combined reinforcement

Table 1: Testing Matrix

### Stage 5 – Determining Mixture Proportions

In this stage, the appropriate concrete mix design is selected for all sample groups. The correct ratio of cement, sand, gravel, (1:1.5:3) water, and fiber is determined to maintain uniformity and achieve the desired concrete strength.



Fig. 8: Materials for the concrete mix design used for all beam specimens

### Stage 6 – Preparing and Curing Samples

All concrete specimens were prepared using the planned mix proportions to ensure consistency across the entire test set, following standard concrete specimen preparation procedures. The process began with the fabrication of molds using 12-mm crocodile phenolic boards, selected for their stiffness, water resistance, and ability to form accurate 150 mm × 150 mm × 533.4 mm beam specimens. The boards were cut, assembled, and sealed at the joints to prevent leakage during casting. Reinforcement cages were then positioned inside the molds with proper spacing to maintain the required concrete cover in accordance with structural design provisions (ACI Committee 318, 2019). Concrete mixing followed the designed proportions, and all materials were measured by weight to ensure accuracy, as recommended for laboratory concrete preparation (ASTM



Fig. 9: Placement of internal steel reinforcement cages inside the beam molds with proper concrete cover

After 24 hours, the beams were demolded and transferred to the curing area, where they underwent standard curing for 28 days to allow proper hydration and strength development. Moisture was maintained through continuous wet curing to ensure uniform curing conditions for all specimens, as recommended in concrete curing guidelines [11].

Following the 28-day curing period, the beams were air-dried and prepared for retrofitting. The epoxy coconut husk fiber reinforcement was then applied according to the established procedure (ACI Committee 440, 2017). The retrofitted beams were subsequently cured for an additional 7 days to allow the epoxy to fully harden and develop adequate bond strength prior to mechanical testing, consistent with epoxy composite curing recommendations (ACI Committee 503, 2016). This curing process ensured that both the concrete and the external reinforcement achieved their intended performance, resulting in reliable and comparable test results.



Fig. 10: Demolding, curing, and retrofitting of beam specimens with coconut husk fiber reinforcement prior to mechanical testing

### PHASE 2: Data Gathering

#### Stage 7 – Tensile Strength of Fiber-Epoxy Composite (ASTM D3039)

This stage focused on determining the tensile strength of the coconut husk fiber epoxy composite in accordance with ASTM D3039 (ASTM International, 2020). The objective of this test was to evaluate the tensile behavior of the fiber epoxy composite material prior to its application in the retrofitting of reinforced concrete beam specimens. In compliance with ASTM D3039, the test specimens were prepared as rectangular composite coupons rather than testing individual fibers (ASTM International, 2020). The specimens were fabricated using alkali-treated coconut husk fibers manually placed and impregnated with epoxy resin, following the same fiber preparation and epoxy application procedure used in the beam retrofitting process, consistent with composite fabrication procedure [12]. The fibers were aligned longitudinally along the loading direction to ensure consistent stress transfer during testing, as recommended in composite material testing studies [13].

Each specimen had an approximate length of 250 mm and a width of 25 mm, with a thickness representative of the externally bonded composite layer used in the beam specimens. The overall dimensions, including grip length and gauge length, were selected in accordance with ASTM D3039 requirements (ASTM International, 2020). After fabrication, the composite coupons were allowed to cure at room temperature following the epoxy manufacturer's recommendations and were conditioned for at least 24 hours prior to testing, consistent with epoxy composite curing practices [14]. Before testing, all specimens were visually inspected to ensure proper fiber alignment, uniform thickness, and the absence of visible defects.



Fig. 11: Fabrication of alkali-treated coconut husk fiber-epoxy composite coupons for tensile testing according to ASTM D3039

The tensile test was conducted using a Universal Testing Machine (UTM) equipped with appropriate grips to prevent specimen slippage [15]. Each specimen was carefully mounted to ensure axial alignment with the applied load. Tensile loading was applied at a constant crosshead speed as specified in ASTM D3039 until failure occurred (ASTM International, 2020). During the test, the maximum load and corresponding elongation were recorded automatically by the testing machine. These values were used to calculate the tensile strength of the coir fiber epoxy composite. The failure mode of each specimen was also observed and documented to confirm that failure occurred within the gauge length, as recommended in tensile testing protocols (ASTM International, 2020).

This stage provided reliable tensile property data for the coir fiber epoxy composite, which are essential for

evaluating its suitability as a sustainable material for structural retrofitting applications [16].



Fig. 12: Tensile testing setup of coconut husk fiber-epoxy composite specimens using a Universal Testing Machine

### Stage 8 – Bond Strength Test (Pull-Off Test) (ASTM D7522)

The bond strength between the coconut husk fiber epoxy layer and the concrete surface was evaluated using the ASTM D7522 pull-off test, which measures the resistance of the retrofit system to tensile forces applied perpendicular to the concrete surface (ASTM International, 2020). Two (2) layers of coconut husk fiber impregnated with epoxy resin were applied on the bottom (soffit) of each beam to provide sufficient bonding area and retrofit thickness, following externally bonded fiber-reinforced polymer (FRP) retrofitting practices (ACI Committee 440, 2017).

A 50.8 mm diameter steel loading disc (dolly) was attached to the fiber-epoxy surface using a high-strength epoxy adhesive. The dollies were placed on the retrofitted soffit area, positioned at the center of the fiber epoxy layer and away from beam edges, corners, and visible defects to avoid uneven stress during testing, consistent with pull-off test recommendations (ASTM International, 2020).

After the adhesive had fully cured, the dolly was connected to the pull-off testing device. A tensile force was applied perpendicular to the surface at a controlled rate until failure occurred (ASTM International, 2020). Failure was observed either at the interface between the fiber epoxy layer and the concrete surface, within the concrete substrate, within the fiber epoxy layer, or as a combination of these modes, as described in FRP-concrete bond studies [17]. The maximum load at failure was recorded and divided by the area of the dolly to determine the bond strength.



Fig. 13: Bond strength testing setup of coconut husk fiber-epoxy retrofitted beams using the ASTM D7522 pull-off method

In accordance with ASTM D7522, at least three (3) pull-off tests were conducted on each test surface to obtain an average bond strength value (ASTM International, 2020). The type of failure observed at each test point was also recorded to evaluate the quality of the bond between the retrofit system and the concrete surface. This test provided a clear assessment of the bonding performance of the two-layer coconut husk fiber epoxy retrofit applied on the beam soffit, which is critical in evaluating the effectiveness of externally bonded composite retrofitting systems (ACI Committee 440, 2017).

### Stage 9 – Flexural Strength Test (ASTM C78)

The ASTM C78/C78M Standard Test Method for Flexural Strength of Concrete was followed in determining the concrete's flexural strength (ASTM International, 2020). The test uses prismatic concrete beams that are typically 150 mm × 150 mm × 533.4 mm, with smooth and flawless surfaces, and are cast and cured in compliance with ASTM C192/C192M laboratory specifications (ASTM International, 2023).

Before applying the coconut husk fiber-epoxy retrofit, the beams were first subjected to preloading up to approximately 50% of their maximum flexural capacity. This step was carried out to represent the actual condition of structural members in the field, where beams are typically already carrying service loads and may have developed initial cracks prior to strengthening. The selected preload level was sufficient to produce visible flexural cracks at the bottom (tension side) of the beam without causing complete failure. After reaching the target load, the beams were unloaded and prepared for the application of the coconut husk fiber epoxy composite.

Using preloaded or pre-cracked beams is a common approach in strengthening studies because it provides a more realistic evaluation of retrofit performance. Samindi, Piatek, and De Silva (2023) explained that testing externally bonded composites on preloaded beams better reflects actual structural conditions. Similarly, the study emphasized that strengthening systems should be assessed under service-like conditions to properly evaluate their effectiveness [17].

Third-point loading was used to apply load at two locations, each one-third of the span from the supports, with a span equal to three times the depth of the beam, as specified in ASTM C78/C78M (ASTM International, 2020). A constant and continuous load was applied until the beam failed.



Fig. 14: Flexural testing setup for concrete beams in accordance with ASTM C78/C78M

The test report included information on specimen size, span, loading arrangement details, curing method, and observed flexural performance, in addition to the maximum load and beam dimensions, consistent with standard concrete flexural testing procedures. This method provides a consistent and reliable way to calculate the bending strength of concrete for use in structural design and quality control [11].

### PHASE 3: Results, Analysis, and Evaluation Stage 10 – Data Analysis and Interpretation

All the data results obtained from the tensile strength test, bond test, and flexural test were first organized in tables, separating each mix group and test type. The raw data, such as maximum load, bond strength, and flexural strength, were converted into computed mechanical properties based on the formulas prescribed by ASTM standards (ASTM International, 2020). After processing the values for each specimen, statistical parameters such as the mean, standard deviation, and coefficient of variation were calculated to quantify the consistency and reliability of each test, as recommended in engineering data analysis practices [18].

The statistical analysis of the experimental data was performed using an independent samples t-test to compare the mean values of the control beams and the beams retrofitted with coconut husk fiber epoxy. The t-test was selected because the study involved the comparison of two independent groups. A significance level of  $\alpha = 0.05$  was used, which is commonly adopted in engineering and material research studies [18]. If the computed p-value was less than 0.05, the difference between the two groups was considered statistically significant. Graphical support was provided through visual representations in the form of bar charts of mean values with error bars, failure-pattern photographs, and stress-load comparisons, consistent with recommended scientific data presentation methods.

This approach systematically processed the data from raw measurements through statistical analysis, enabling the assessment of whether wrapping with coconut husk fiber improves bond strength, flexural behavior, and overall retrofit performance of the concrete beams (ACI Committee 440, 2017).

## RESULTS

After completing the actual testing, this chapter presents the results of the study on the mechanical properties of coconut husk fiber combined with epoxy resin. The findings include its tensile strength, bond strength, and flexural strength. Furthermore, a comparison is made between the plain reinforced concrete beam and the reinforced concrete beam strengthened with coconut husk fiber and epoxy resin to evaluate the effectiveness of the composite as a retrofitting material.

Trial	Thickness (mm)	Width (mm)	Area (mm)	Yield point	Tensile Strength (MPa)
Tensile 1	4.15	37.98	158	38.14	57.55
Tensile 2	3.60	37.47	135	44.72	67.05
Tensile 3	3.39	39.62	134	44.89	67.34

**Table 2: Tensile Strength of Coconut husk fiber with Epoxy resin from Actual testing**

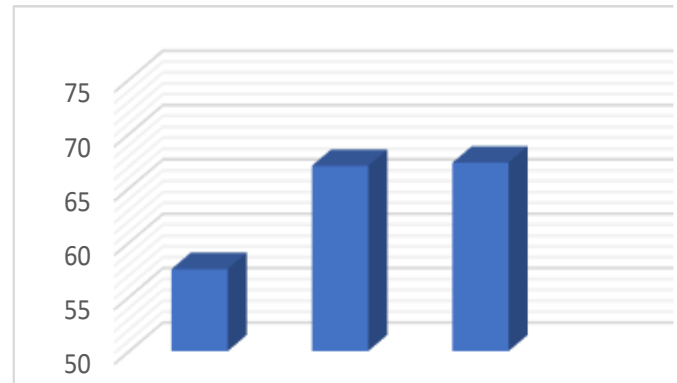
Table 2 presents the tensile test results of the coconut husk fiber–epoxy composite specimens obtained from the actual testing. The table shows that the tensile strength values ranged from 57.55 MPa to 67.34 MPa.

Among the three trials, Tensile 1 recorded a tensile strength of 57.55 MPa, which is the lowest value among the specimens tested. Tensile 2 showed a higher tensile strength of 67.05 MPa, while Tensile 3 recorded the highest value of 67.34 MPa. These results indicate that most of the specimens were able to resist tensile stresses above 67 MPa before failure, suggesting that the composite material exhibited good tensile performance under direct tension.

The slight differences in the recorded values are expected because natural fibers such as coconut coir are not perfectly uniform. Variations in fiber thickness, internal structure, and the distribution of fibers within the epoxy matrix can influence the tensile performance of each specimen. Natural fibers like coconut coir commonly show variability in mechanical properties due to their biological origin and non-uniform structure [19].

Despite these natural variations, the results remain relatively consistent. The coefficient of variation of 8.71% obtained in this study falls within the typical range of 4% to 11% for natural fiber composites [19]. This suggests that the variation observed in the tensile strength results is within the acceptable range and is mainly attributed to the natural characteristics of the fiber rather than errors during testing.

Overall, the results presented in Table 2 show that the treated coconut husk fiber–epoxy composite was able to develop relatively high tensile strength values, indicating good interaction between the fiber reinforcement and the epoxy matrix. This behavior supports previous findings that proper fiber treatment and good bonding between fiber and matrix can significantly improve the mechanical performance of natural fiber composites (Rachmat et al., 2023).



**Fig. 15: Tensile Strength of Coconut husk fiber with Epoxy resin from Actual testing**

Figure 15 presents the bar graph of the tensile strength results of the coconut husk fiber–epoxy composite specimens based on the data in Table 2. The graph compares the tensile strength values obtained from the three trials.

As shown in the figure, Tensile 1 recorded a tensile strength of 57.55 MPa, while Tensile 2 and Tensile 3 recorded higher values of 67.05 MPa and 67.34 MPa, respectively. The bars for Tensile 2 and Tensile 3 are almost equal in height, indicating that the two specimens produced nearly the same tensile strength.

The figure also shows that the tensile strength increased from the first trial to the second trial and remained nearly the same in the third trial. This indicates consistent tensile performance of the composite specimens, which is expected when the fiber and epoxy matrix interact effectively [19].

With tensile strength values reaching over 67 MPa, the results indicate that the coconut husk fiber–epoxy composite is capable of resisting relatively high tensile stresses. This supports its potential use as an externally bonded reinforcement material for structural retrofitting, particularly in areas subjected to tensile forces [17].

Trial	Dolly Diameter (mm)	Bond Area (mm <sup>2</sup> )	Maximum Loads (Newtons)	Bond Strength (MPa)
1	50	3017.7	1950	0.646
2	50	2963.0	1200	0.405
3	50	2792.6	2615	0.936

**Table 3: Bond Strength of Coconut husk fiber with Epoxy resin from Actual Testing**

Table 3 shows the bond strength results of the coconut husk fiber–epoxy composite based on the pull-off test. The bond strength values ranged from 0.405 MPa to 0.936 MPa, showing some differences among the three specimens.

The recorded bond strength values were 0.646 MPa, 0.405 MPa, and 0.936 MPa, with corresponding maximum loads of 1950 N, 1200 N, and 2615 N. These results show that the composite was able to bond well with the concrete surface.

In terms of failure mode, Trials 1 and 2 showed Failure Mode G, which means that the failure happened within

the concrete itself. This indicates that the bond between the coconut husk fiber–epoxy composite and the concrete was strong since the concrete failed first before the bond broke.

Meanwhile, Trial 3 showed Failure Mode E, where the failure occurred at the interface between the composite and the concrete. This means that the bond at the surface was reached during the test

Having both Failure Mode G and Mode E is normal in this type of testing. It shows that the bonding performance was generally good, with most specimens showing strong bonding, while one specimen reached the bond limit at the interface.

The differences in the results may be due to small variations in surface preparation, epoxy application, or curing. However, even with these differences, the composite was still able to form a reliable bond with the concrete.

Overall, the results show that the coconut husk fiber–epoxy composite has good bonding performance and can be used as a strengthening material for concrete.

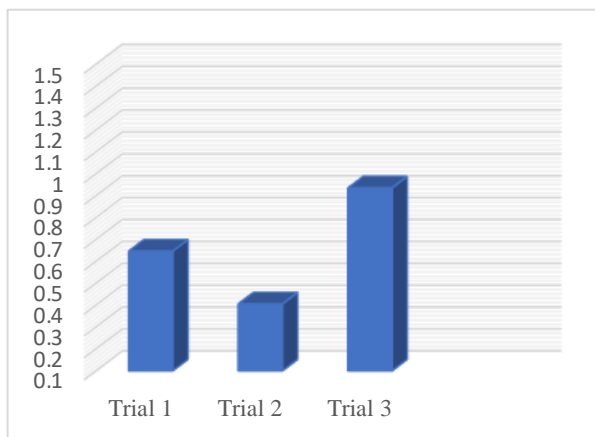


Fig. 16: Bond Strength of Coconut husk fiber with Epoxy resin from Actual Testing

Figure 16 presents the bar graph showing the bond strength results of the coconut husk fiber epoxy composite for the three trials. The graph visually compares the bond strength values obtained from the pull-off test

Based on the graph, Trial 1 recorded a bond strength of 0.646 MPa, while Trial 2 showed the lowest value of 0.405 MPa. In contrast, Trial 3 achieved the highest bond strength of 0.936 MPa, which is represented by the tallest bar in the graph.

The graph highlights the variation in bonding performance among the specimens. Trials 1 and 3 show higher bond strength values compared with Trial 2. Such variations may occur due to differences in surface preparation, epoxy penetration, and curing conditions, which can affect the adhesion between the composite material and the concrete

surface (Pallempati, 2014).

Despite the variation, the results indicate that the coconut husk fiber epoxy composite was able to develop measurable bond strength with the concrete surface. Adequate bonding between the composite and concrete is essential for effective stress transfer in externally bonded reinforcement systems (Carrillo, 2012).

Sample Identification	Date Sampled	Age in Days	Machine Reading (kN)	Flexural Strength F	MPa
Flexural Load 1 (FL – 1)	12/22/25	32	71.18	1333	9.20
Flexural Load 2 (FL – 2)	12/22/25	32	60.30	1130	7.79
Flexural Load 3 (FL – 3)	12/22/25	32	56.21	1053	7.26
Pre-Loaded 1 (PL – 1)	12/22/25	32	35.76	670	4.62
Pre-Loaded 2 (PL – 2)	12/22/25	32	30.70	575	3.97
Pre-Loaded 3 (PL – 3)	12/22/25	32	29.74	557	3.84

Table 4. Flexural Strength of Plain Reinforced Concrete Beam

Table 4 presents the flexural strength results of the plain reinforced concrete beams tested under third-point loading in accordance with ASTM C78 (ASTM International, 2020). The table shows the bending performance of the beams without any external strengthening or retrofitting.

The control beams recorded flexural strengths of 4.62 MPa for Pre-Loaded 1, 3.97 MPa for Pre-Loaded 2, and 3.84 MPa for Pre-Loaded 3. These values represent the natural bending capacity of the reinforced concrete beams before any retrofitting material was applied.

The values are relatively close to each other, indicating that the beams were cast, prepared, and cured under similar conditions. When concrete specimens are produced using consistent materials and proper curing procedures, only small variations in flexural strength are usually observed.

During the flexural test, cracks first appeared at the bottom portion of the beam, which is the tension zone under bending. As the load increased, the cracks propagated upward until failure occurred. This behavior is typical for reinforced concrete beams because concrete is relatively weak in tension. Once the tensile stress exceeds the modulus of rupture, cracking occurs and failure follows shortly afterward [11].

Overall, the results in Table 4 show the typical flexural response of reinforced concrete beams without external reinforcement and serve as a baseline for comparison with the retrofitted specimens.

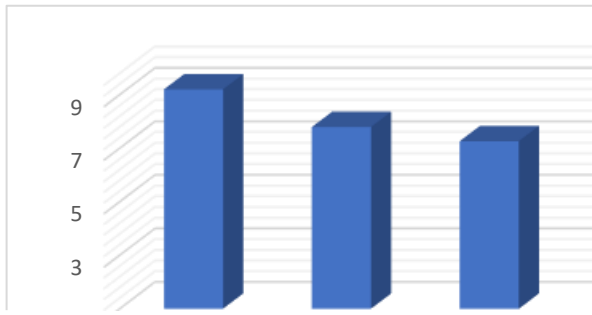


Fig. 17: Flexural Strength of Plain Reinforced Concrete Beam

Figure 17 presents the bar graph illustrating the flexural strength of the control reinforced concrete beams based on the results shown in Table 4. The graph provides a visual comparison of the bending strength of the three specimens.

As shown in the figure, Flexural Load 1 recorded the highest flexural strength of 9.20 MPa, followed by Flexural Load 2 with 7.79 MPa, and Flexural Load 3 with 7.26 MPa. The differences in the height of the bars indicate the variation in flexural strength among the beams.

The figure shows that the first beam developed a slightly higher flexural capacity, while the second and third beams recorded lower but comparable values. Such variations are common in concrete testing because factors such as aggregate distribution, internal microcracks, and curing conditions can influence the strength of concrete specimens.

Despite these differences, the results indicate that the control beams exhibited relatively similar flexural performance under bending loads. This behavior is consistent with the typical response of reinforced concrete beams subjected to flexural loading [11].

Overall, the bar graph visually represents the flexural strength of the control beams and provides a reference for evaluating the effectiveness of the retrofitting material.

Sample Identification	Date Sampled	Age in Days	Machine Reading (kN)	Flexural Strength F	MPa
Pre-Loaded Reinforced Concrete Beam Retrofitted (PL-1F)	12/22/25	44	77.29	1148	9.99
Pre-Loaded Reinforced Concrete Beam Retrofitted (PL-2F)	12/22/25	44	56.56	1060	7.31
Pre-Loaded Reinforced Concrete Beam Retrofitted (PL-3F)	12/22/25	44	71.10	1334	9.20

Table 5: Flexural Strength of Plain Reinforced Concrete Beam Strengthened with Coconut husk fiber and Epoxy Resin

Table 5 presents the flexural strength results of the reinforced concrete beams strengthened with coconut husk fiber and epoxy resin. After retrofitting, the beams were tested again to evaluate the effect of the strengthening material on their bending performance.

The strengthened beams recorded flexural strength values of 9.99 MPa for PL-1F, 7.31 MPa for PL-2F, and 9.20 MPa for PL-3F. These values are generally higher than those recorded for the control beams, indicating that the retrofitting improved the flexural capacity of the beams.

The increase in strength is attributed to the placement of the coconut husk fiber composite at the bottom portion of the beam, which is the tension zone during flexural loading. When the beam was loaded, the fiber reinforcement helped carry part of the tensile force, reducing the tensile stress in the concrete and allowing the beam to resist higher bending loads [17].

During testing, the strengthened beams also showed slower crack development compared with the control beams. Although cracks still formed under loading, they propagated more gradually. Externally bonded fiber reinforcement is known to help control crack propagation and improve the flexural behavior of reinforced concrete beams [22].

Overall, the results in Table 5 indicate that the coconut husk fiber-epoxy composite improved the flexural performance of the reinforced concrete beams.

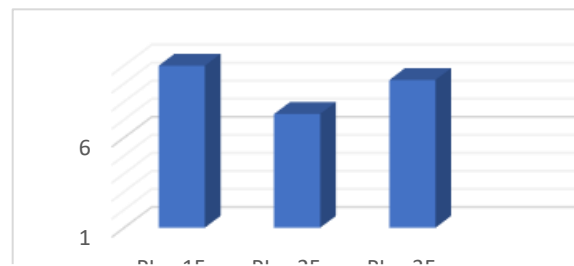


Fig. 18: Flexural Strength of Plain Concrete Beam Strengthened with Coconut husk fiber and Epoxy Resin

Figure 18 presents the bar graph comparing the flexural strength of the strengthened beams. The graph visually shows the differences in performance among the three retrofitted specimens.

Based on the graph, PL-1F recorded the highest flexural strength of 9.99 MPa, followed by PL-3F with 9.20 MPa, while PL-2F showed the lowest value of 7.31 MPa. The difference in the height of the bars reflects the variation in flexural capacity among the beams.

The figure shows that the strengthened beams were able to achieve flexural strengths close to 10 MPa, which is higher than the values recorded for the control beams. This improvement indicates that the coconut husk fiber reinforcement contributed to the increased bending capacity of the beams.

The improvement in flexural performance is related to the placement of the fiber composite at the tension side of the beam, where tensile stresses occur during bending. Externally bonded fiber reinforcement helps carry part of the tensile force and improves the flexural resistance of reinforced concrete members [17].

Overall, the bar graph supports the results presented in Figure 18 and shows that the use of coconut husk fiber and epoxy resin improved the flexural performance of the reinforced concrete beams.

### STATISTICAL ANALYSIS USING INDEPENDENT T-TEST

Group Statistics					
Group	N	Mean	Std. Deviation	Std. Error Mean	
MPa	Retrofitted	3	8.8333	1.37711	.79508
	Unretrofitted	3	4.1433	.41789	.24127

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
MPa	Equal variances assumed	3.921	.019	5.645	4	.005	4.69000	.83088	2.38312	6.99688
	Equal variances not assumed			5.645	2.365	.020	4.69000	.83088	1.59527	7.78473

### Interpretation

Table 6 presents the results of the Independent Sample T-Test used to determine whether there is a significant difference in the flexural strength between the retrofitted concrete beams reinforced with coconut husk fiber–epoxy composite and the unretrofitted or plain concrete beams.

Based on the group statistics, the retrofitted beams obtained a mean flexural strength of 8.8333 MPa, while the unretrofitted beams recorded a lower mean value of 4.1433 MPa. This shows that the beams strengthened with the coconut husk fiber–epoxy composite were able to carry higher bending loads compared to the beams without strengthening.

Before comparing the means, the Levene's Test for Equality of Variances was examined to check if the two groups had similar variances. The test produced a significance value of 0.119, which is greater than the 0.05 level of significance. This indicates that the assumption of equal variances is satisfied, allowing the interpretation to use the equal variances assumed results in the t-test.

The Independent Sample T-Test produced a t-value of 5.645 with 4 degrees of freedom and a two-tailed significance value of 0.005, which is lower than the 0.05 significance level. This result indicates that the difference in flexural strength between the retrofitted and unretrofitted beams is statistically significant. In addition, the mean difference of 4.69000 MPa shows that the retrofitted beams demonstrated considerably higher bending strength compared to the control beams.

The 95% confidence interval, ranging from 2.38312 MPa to 6.99688 MPa, further supports this finding because the interval does not include zero. This means that the increase in flexural strength is consistent and not due to random variation.

Based on these results, the null hypothesis (H<sub>0</sub>) stating that there is no significant difference between the flexural strength of retrofitted and unretrofitted beams is rejected. This confirms that the strengthening method using coconut husk fiber combined with epoxy resin significantly improves the bending performance of reinforced concrete beams.

Overall, the findings suggest that the coconut husk fiber–epoxy composite has strong potential as an alternative strengthening material for reinforced concrete structures, particularly in enhancing their flexural capacity.

### CONCLUSIONS

This study led to several key conclusions. The use of coconut husk fiber combined with epoxy resin as an external strengthening composite for reinforced concrete members was successfully assessed, and the results showed that this natural fiber composite can be considered a feasible alternative material for strengthening applications. The tensile strength test confirmed that the coconut husk fiber–epoxy composite has sufficient tensile capacity, indicating that the material is capable of resisting pulling forces when used as external reinforcement for concrete structures. In terms of flexural performance, the retrofitted reinforced concrete beams achieved an average flexural strength of 8.8333 MPa, which is significantly higher than the 4.1433 MPa recorded for the unretrofitted beams, resulting in an increase of 4.6900 MPa and demonstrating a significant improvement in bending performance. Statistical analysis using the Independent t-test further validated this improvement, yielding a t-value of 5.645 and a p-value of 0.005, which is lower than the 0.05 level of significance, thereby indicating a statistically significant difference and leading to the rejection of the null hypothesis. Additionally, during flexural testing, the retrofitted beams exhibited better crack control and improved bending behavior compared to the control beams, suggesting that the composite layer enhanced the overall structural response. The bond strength test revealed both Failure Mode G and Failure Mode E, with most specimens exhibiting Failure Mode G, where failure occurred within the concrete, indicating a strong bond between the composite and the concrete, while one specimen showed Failure Mode E, where failure occurred at the interface. These results demonstrate that the coconut husk fiber–epoxy composite was able to form a good bond with the concrete and effectively transfer stress. Overall, the bond strength findings suggest that the composite system can provide reliable bonding when used as external reinforcement. In general, the results of this study confirm that coconut husk fiber–epoxy composite has strong potential as a sustainable and alternative material for strengthening reinforced concrete beams, particularly in improving their flexural performance.

## ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to their adviser and panel members for their guidance and valuable insights throughout this study. Appreciation is also extended to the institution for providing the necessary support and resources. Finally, the authors thank their families for their encouragement and support.

## REFERENCES

- [1] R. Dancel, "Abaca fiber with epoxy as a retrofitting material," *International Journal of Mechanical and Production Engineering*, vol. 6, no. 2, pp. 66–70, 2018.
- [2] M.-J. Monsalve-Arias, O.-F. Higuera-Cobos, and C.-A. Pedraza-Yepes, "Development of structural type mortars reinforced with coconut (*Cocos nucifera*) fiber: Chemical, thermal, and mechanical behavior," *Journal of Composites Science*, vol. 9, no. 6, p. 300, Jun. 2025.
- [3] M. Alenezi, M. Alotaibi, Y. Alharbi, and A. Alharthi, "Strength and water absorption behavior of untreated coir in cement mortars," *Construction and Building Materials*, vol. 398, p. 130983, 2025.
- [4] M. Ali, "Coconut fibre – A versatile material and its applications in engineering," 2011. [Online]. Available: <https://www.researchgate.net/publication/266566174>
- [5] M. Jawaid and H. P. S. A. Khalil, "Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review," *Carbohydrate Polymers*, vol. 86, no. 1, pp. 1–18, Aug. 2011.
- [6] R. H. Setyanto, K. Diharjo, P. Setyono, and I. M. Miasa, "The influence of alkali treatment on physical and mechanical properties of coir fiber," *Journal of Materials Science Research*, vol. 2, no. 4, pp. 80–86, 2013.
- [7] V. Fiore, G. Di Bella, and A. Valenza, "The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites," *Composites Part B: Engineering*, vol. 68, pp. 14–21, 2015.
- [8] J. K. Wight and J. G. MacGregor, *Reinforced Concrete: Mechanics and Design*. Upper Saddle River, NJ, USA: Prentice Hall, 2009.
- [9] J. F. Chen and J. G. Teng, "Shear capacity of fiber-reinforced polymer-strengthened reinforced concrete beams," *Journal of Structural Engineering*, vol. 129, no. 5, pp. 615–625, 2003.
- [10] G. Monti and M. Liotta, "Tests and design equations for FRP-strengthening in shear," *Construction and Building Materials*, vol. 21, no. 4, pp. 799–809, 2007.
- [11] P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*, 4th ed. New York, NY, USA: McGraw-Hill, 2014.
- [12] S. Ru, C. Zhao, S. Yang, and D. Liang, "Effect of coir fiber surface treatment on reinforced epoxy resin composites," *Polymers*, 2022.
- [13] C. Obele and E. Ishidi, "Mechanical properties of coir fiber reinforced epoxy resin composites," 2015. [Online]. Available: <https://files.core.ac.uk/download/pdf/234685413.pdf>
- [14] S. R. Choudhari and M. L. Umate, "Epoxy based composite material from coconut fiber," *International Journal of Scientific Research in Science and Technology*, vol. 11, no. 5, pp. 386–390, 2024.
- [15] Y. F. Arifin *et al.*, "Equipment for testing the tensile strength of natural fibers," *IOP Conference Series: Earth and Environmental Science*, vol. 1184, no. 1, 2023.
- [16] M. Nissar *et al.*, "Coconut coir fiber composites for sustainable architecture," *Journal of Composites Science*, vol. 9, no. 10, p. 516, 2025.
- [17] J. G. Teng, J. F. Chen, S. T. Smith, and L. Lam, *FRP-Strengthened RC Structures: Design and Practice*. 2002.
- [18] D. C. Montgomery, *Design and Analysis of Experiments*, 9th ed., 2022.
- [19] G. Stipo *et al.*, "Mechanical performances of natural textiles for eco-friendly composite materials," *Fibers*, vol. 13, no. 11, p. 148, 2025.
- [20] H. Pallemati, E. Beneberu, and N. Yazdani, "Evaluation of external FRP-concrete bond in repaired bridge girders and columns," 2016.
- [21] O. R. M. Carrillo, "Evaluating the bond durability of FRP-concrete systems subjected to environmental exposures," n.d.
- [22] T. C. Triantafillou, "Shear strengthening of reinforced concrete beams using epoxy-bonded FRP composites," 1998.