

Numerical simulation and analysis of splitting tensile strength of jute/epoxy laminated composites using ANSYS Workbench 2022

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ABSTRACT

This study investigates the mechanical behavior of jute/epoxy laminated composites when applied as external reinforcement to cylindrical concrete specimens subjected to splitting tensile stress. Natural fiber-reinforced composites, such as jute, have gained significant attention in recent years due to their environmental sustainability, low cost, and reasonable mechanical performance. The primary objective of this research is to evaluate the effectiveness of jute laminate sheathing in improving the tensile strength of cylindrical concrete structures using numerical simulation. A finite element method (FEM) approach was implemented in ANSYS Workbench 2022 to model and simulate various configurations, including specimens without laminates and with one, two, and three layers of jute/epoxy laminates. The model geometry was based on standard cylindrical specimens with a diameter of 50 mm and a height of 150 mm. Material properties were defined based on experimental data, and appropriate mesh and boundary conditions were applied. Results showed that the addition of jute laminates significantly enhanced the splitting tensile strength, with the highest increase of 241% observed in specimens with three layers. The simulation results were validated against experimental data using ANOVA, confirming a strong correlation ($p = 0.5$). This indicates that the ANSYS-based FEM simulation is a reliable tool for predicting the mechanical behavior of natural fiber-reinforced composites in structural applications.

Keywords: Jute laminate composite; splitting tensile strength; finite element method; ANSYS Workbench; concrete reinforcement.

1. Introduction

Concrete is widely used in structural applications due to its superior compressive strength. However, its low tensile strength remains a critical limitation. To address this issue, fiber-reinforced composites have emerged as a viable solution, particularly those utilizing natural fibers such as jute. Jute-based laminates, when combined with epoxy matrices, provide improved tensile strength and fracture resistance. Previous studies have shown that jute fibers, due to their aspect ratio and interfacial bonding with the matrix, can effectively delay crack propagation and enhance structural performance. Moreover, jute is biodegradable, cost-effective, and readily available, making it a sustainable alternative for reinforcing concrete structures [1]–[3]. As global interest in environmentally friendly construction materials increases, jute/epoxy composites offer promising potential [4], [5]. While experimental studies provide empirical evidence of these improvements, numerical simulation offers a deeper understanding of material behavior under controlled virtual conditions [6]. The application of simulation tools like ANSYS Workbench allows engineers to investigate stress distribution and failure modes, minimizing the need for extensive physical testing [7].



In recent years, extensive studies have underscored the growing potential of natural and hybrid fiber-reinforced composites in structural applications. Demonstrated that embedding aluminum sheets within jute/epoxy laminates significantly enhanced both tensile strength and elongation capacity, indicating improved load bearing and deformation resistance [8]. Revealed that chemical modification of jute fibers using KH-560 coupling agents led to stronger interfacial adhesion between fiber and matrix, thereby increasing the crystallinity and thermal stability of the composite system [9]. Who found that combining jute with basalt fibers in hybrid composites improved tensile strength and interlaminar shear properties attributes critical to long-term structural performance [10]. These findings consistently demonstrate that the strategic selection and modification of natural fibers, particularly jute, can result in substantial mechanical property enhancements when embedded in polymer matrices.

Complementing these material developments, recent work has also highlighted the value of computational modeling in predicting and analyzing composite behavior. Showed that jute/E-glass hybrid laminates applied to cylindrical concrete columns enhanced compressive strength by up to 150%, emphasizing their practical potential in construction reinforcement [11]. Advocated the use of finite element method (FEM) simulations for evaluating structural performance, enabling detailed observation of stress distributions and failure responses [12], [13]. Further validated the accuracy of FEM-based ANSYS simulations in modeling real-world mechanical phenomena such as crack propagation and stress localization. Together, these studies reinforce the relevance of integrating natural fiber-based laminates with advanced numerical simulation techniques to not only predict mechanical outcomes but also optimize material configurations for enhanced structural efficiency [14], [15].

This study introduces a distinctive and innovative research approach by integrating finite element method (FEM) simulation with experimental data to comprehensively assess the splitting tensile performance of jute/epoxy laminated composites applied to cylindrical concrete specimens. While existing literature has predominantly concentrated on evaluating the compressive and flexural behavior of concrete composites, this research uniquely highlights the splitting tensile strength—a crucial yet underrepresented mechanical property in structural design. The application of multilayer jute laminates serves not only as a structural reinforcement but also as a medium to study the progressive changes in stress and strain distribution across various configurations [16]. High-resolution FEM simulations were conducted to capture these mechanical phenomena with precision, enabling an in-depth understanding of failure mechanisms and material interactions [17]. Moreover, the research incorporates rigorous statistical validation of the simulation outcomes using tools such as ANOVA and normality distribution tests to ensure that the numerical predictions align closely with empirical observations [18]. This integrated methodology not only strengthens the credibility of virtual simulations but also demonstrates their practicality as predictive tools in engineering applications. By bridging computational and experimental frameworks, this study offers a valuable contribution to the development of sustainable composite-reinforced concrete systems and paves the way for more efficient and cost-effective structural optimization strategies [19].

The research aims to: (1) evaluate the effectiveness of jute/epoxy laminate reinforcement on the splitting tensile strength of cylindrical concrete specimens using numerical simulations, and (2) analyze the stress and strain distribution to understand the damage mechanisms under tensile loading. Additionally, the study seeks to validate the simulation model by comparing it with experimental data and performing statistical analysis to assess its reliability.

2. Method

This research was carried out within a structured timeline from February to March 2025 at the Impact Fracture and Research Center (IFRC), Universitas Sumatera Utara. The facility offered comprehensive computational infrastructure and technical expertise essential for conducting finite element simulations and evaluating structural performance. Throughout the research period, key activities including simulation modeling, validation, and statistical analysis were executed in a systematic and sequential manner. The overall workflow encompassed critical stages such as geometric modeling, mesh generation, boundary condition assignment, and simulation validation. The IFRC laboratory was specifically chosen for its expertise in structural simulation and its established use of ANSYS Workbench, which ensured the reliability, accuracy, and reproducibility of the numerical analyses performed.

The simulations were carried out using a Lenovo ThinkPad laptop (**Error! Reference source not found.**), equipped with a high-performance Intel Core i7 processor, 16 GB of RAM, and dedicated graphics processing, ensuring smooth operation of complex simulation tasks. The software environment included ANSYS Workbench 2022 (Figure 2) as the primary platform for finite element analysis and Microsoft Excel for post-processing and statistical computations. The materials used in the simulations were based on prior experimental data, involving cylindrical concrete specimens (diameter 50 mm, height 150 mm) reinforced with 1–3 layers of jute/epoxy laminates, each 2 mm thick. Material properties—such as tensile strength and modulus of elasticity were taken from experimental characterizations and incorporated into the material definitions in ANSYS [20]. The structural configurations and experimental layering variations are summarized in Table 1, which provides tensile force values and tensile stress ranges for each test specimen.



Figure 1. Laptop with Core i7 Processor



Figure 2. Ansys Workbench

Table 1. Experimental results

No.	Variations	Average Tensile Force (N)	Average Tensile Strength (MPa)
1	CS	17390.33	8.88
2	J1	56455.33	11.82
3	J2	52615.67	24.03
4	J3	59342.67	30.27

The research procedure began with the development of specimen geometry in SolidWorks, which was then imported into ANSYS Workbench 2022. The final geometry used in simulations is shown in Figure 3. The simulation model consisted of a concrete cylinder wrapped with jute/epoxy laminate layers of varying thicknesses: 2 mm, 4 mm, and 6 mm. Meshing was carried out using tetrahedral elements to achieve detailed stress resolution, and care was taken to maintain mesh quality for simulation convergence. Boundary conditions were applied to replicate experimental conditions: the base of the specimen was fixed, while axial tensile loading was applied at the top, as illustrated in Figure 4. The simulation was run incrementally to capture failure progression and stress concentration development. Simulated results, including maximum stress and deformation values, were extracted for each laminate configuration and compared against baseline data.

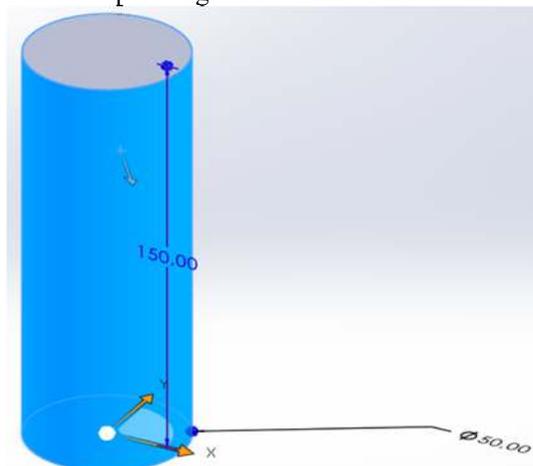


Figure 3. Shape and size of the simulation model

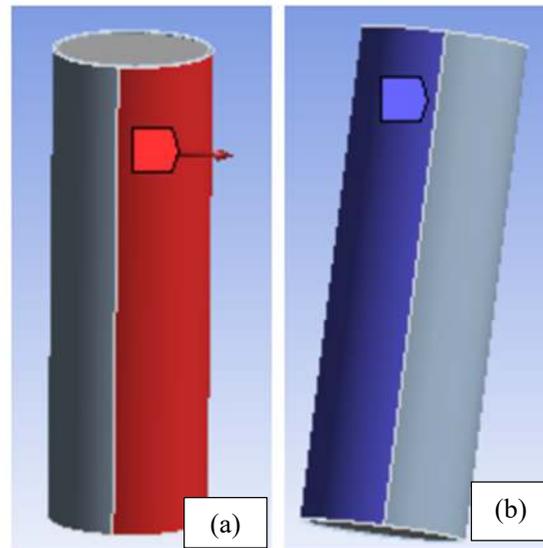


Figure 4. Boundary conditions: (a) force applied and (b) fixed support

The numerical results derived from ANSYS simulations were subjected to statistical analysis to evaluate their alignment with experimental observations. Tensile strength values from three specimens for each configuration, namely CS, J1, J2, and J3—were averaged and summarized in Table 1. To assess the consistency and reliability of the simulation outcomes, a one-way ANOVA was performed using Microsoft Excel. The analysis yielded a p-value of 0.5, indicating no statistically significant difference between the simulated and experimental results. This finding validates the simulation model as an accurate and predictive tool. Additionally, the observed failure patterns across different laminate configurations further support this conclusion. Specimens incorporating additional jute layers demonstrated more uniform and progressive damage propagation, highlighting the mechanical benefits offered by the hybrid laminates. Both statistical and visual analyses confirm the effectiveness of ANSYS Workbench in accurately simulating the splitting tensile behavior of fiber-reinforced concrete.

3. Result and Discussion

The first objective of this study was to evaluate the effectiveness of jute/epoxy laminated composites in enhancing the splitting tensile strength of cylindrical concrete specimens through numerical simulation. The results, obtained from simulations conducted using ANSYS Workbench 2022, revealed a substantial increase in tensile strength as the number of jute laminate layers increased. The control specimens without reinforcement (CS) exhibited an average tensile strength of 0.888 MPa. In contrast, specimens reinforced with 2 mm (J1), 4 mm (J2), and 6 mm (J3) thick jute/epoxy laminates recorded average tensile strengths of 1.182 MPa, 2.403 MPa, and 3.027 MPa, respectively. These values correspond to increases of 33.1%, 170.5%, and 241% over the unreinforced specimens. The sharp improvement in tensile capacity demonstrates the reinforcing capability of the jute/epoxy laminates, which act as a tensile stress barrier, absorbing and redistributing loads more effectively. However, it is also evident that strength enhancement follows a nonlinear trend. The largest performance gain occurred between the one-layer and two-layer configurations, while the incremental benefit from the second to the third layer was comparatively smaller, suggesting diminishing returns at higher laminate thickness. These findings confirm the practical utility of jute laminates for structural retrofitting applications and validate the role of numerical simulation as a reliable tool for performance assessment. The findings of this study are consistent with those reported, whose ANSYS-based numerical simulations demonstrated that increasing the thickness of natural fiber laminates, including jute, led to notable improvements in both tensile strength and material stiffness, particularly in the 0° fiber orientation and at a thickness of 3 mm [21]. Additionally, the results align with those, who utilized ANSYS 17.1 to investigate various stacking sequences of glass/jute hybrid laminates. Their study revealed that both the fiber combination and laminate

thickness significantly influenced tensile strength, with a clear trend of increasing strength as the number of jute layers increased [22].

The second objective focused on analyzing the distribution of stress and strain within the concrete specimens to understand the mechanisms of tensile failure under splitting loads. The results from ANSYS simulations, as summarized in Table 2, provided detailed visualizations of stress concentrations and strain evolution throughout each configuration. In control specimens (CS), maximum stress values reached only around 6.09 MPa, with high strain localization near the cylinder's midsection. This indicated an early onset of crack initiation and failure in the absence of external reinforcement. Specimens reinforced with jute laminates, a clear shift in the stress pattern was observed. Specimens with 4 mm and 6 mm jute layers (J2 and J3) displayed more distributed stress fields and lower peak strain values, signifying improved resistance to deformation and delayed failure progression. This is attributed to the presence of the jute/epoxy layer, which effectively restrains radial expansion and provides a more uniform stress path. Furthermore, in reinforced specimens, the strain contours extended over a broader area, indicating enhanced energy dissipation prior to failure. The simulation plots (Figure 5 and Figure 6) show that with increasing laminate thickness, stress redistribution becomes more homogeneous, reducing the likelihood of brittle fracture. These outcomes reinforce the mechanical advantage of fiber-reinforced laminates in increasing ductility and toughness, which are critical for structural integrity under tensile stress. The results of this study are consistent with the findings, that developed a nonlocal damage-based numerical model to predict dynamic tensile failure in concrete. Their simulations successfully captured stress distribution and crack initiation, highlighting the effectiveness of numerical modeling in representing failure mechanisms [23]. This study further emphasizes the critical role of strain-rate simulations in understanding damage propagation and energy absorption in concrete subjected to dynamic tensile loading. Additionally, the findings support those reported, who employed a lattice-based model in spalling test simulations to evaluate the dynamic tensile strength of concrete. Their results demonstrated that a broader distribution of strain and stress contours in reinforced materials enhances crack resistance and increases the material's energy dissipation capacity [24].

Table 2. Distribution of average stress and strain

Variations	Average Tensile Strength (MPa)		Average Tensile Strain (mm/mm)	
	Minimum	Maximum	Minimum	Maximum
CS	0.888	6.09	2.67E-05	1.96E-04
J1	1.182	62.86	7.86E-06	5.74E-04
J2	2.403	31.12	8.75E-06	1.31E-04
J3	3.027	27.43	1.11E-05	1.15E-04

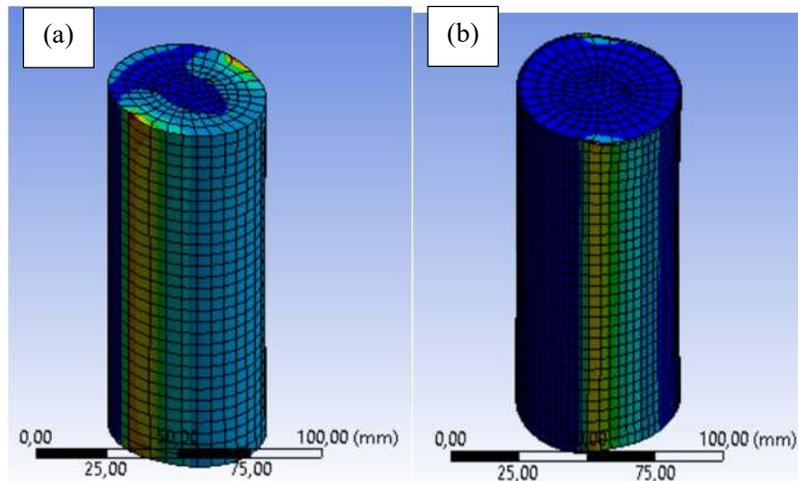


Figure 5. Distribution of splitting tensile strength from simulation results: (a) CS, (b) J1

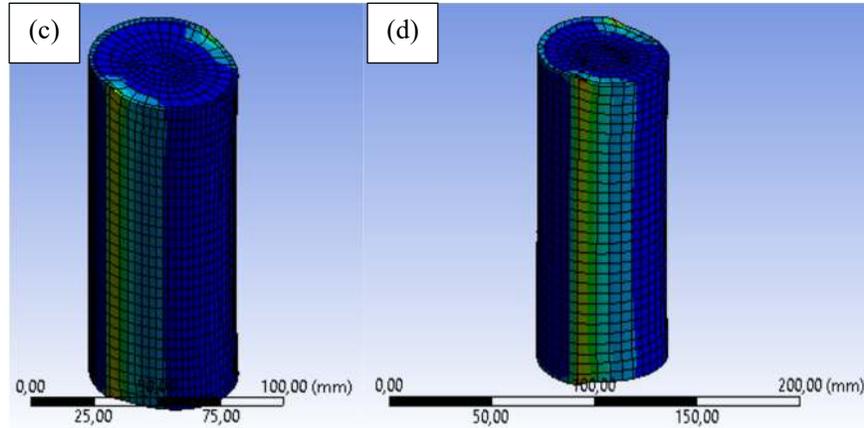


Figure 6. Distribution of splitting tensile strength from simulation results: (c) J2, and (d) J3

The third objective was to validate the numerical simulation results against experimental data using appropriate statistical tools to ensure model accuracy. This purpose, tensile strength data from both simulation and previous experiments were compared using a one-way ANOVA test. The statistical analysis, conducted in Microsoft Excel, yielded a p-value of 0.5, as presented in Figure 6. This value indicates no statistically significant difference between the simulated and experimental results, affirming the consistency and reliability of the finite element model developed in ANSYS Workbench 2022. The close agreement between numerical and experimental outcomes suggests that the simulation approach accurately captures the mechanical behavior of reinforced concrete under splitting tension. Furthermore, visual comparison of failure patterns (Figure 7 and Figure 8) revealed a high degree of similarity between simulated and physical specimens, particularly in terms of crack localization and fracture propagation. Reinforced specimens (J1–J3) showed more controlled and gradual cracking patterns, while unreinforced specimens exhibited abrupt failures. The statistical validation not only enhances confidence in the predictive capabilities of the simulation but also establishes FEM as a credible alternative to labor-intensive experimental methods, especially for preliminary design assessments and material optimization. This finding contributes to the broader adoption of simulation-based engineering in composite material research. The findings of this study are in agreement with those, who demonstrated that a finite element model (FEM) developed using ANSYS can accurately predict the load–deflection behavior of reinforced concrete beams. Their numerical results exhibited a maximum deviation of only –11.15% from the experimental data, indicating a high level of model accuracy and effective validation between the simulation and physical testing [25]. Moreover, the present study also aligns with the findings, who developed a numerical model in ANSYS 2022R2 and validated it through a four-point bending test. The simulation results closely matched the experimental observations in terms of crack patterns and ultimate flexural capacity, confirming the reliability of finite element simulation as a predictive tool for structural performance assessment [26].

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
rata rata spesimen	4	9,316	2,329	1,082503		
rata rata simulasi	4	7,49997	1,874993	1,020017		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0,412246	1	0,412246	0,392144	0,5	5,987378
Within Groups	6,307559	6	1,05126			
Total	6,719805	7				

Figure 7. Display of ANOVA calculation results with the help of Minitab software

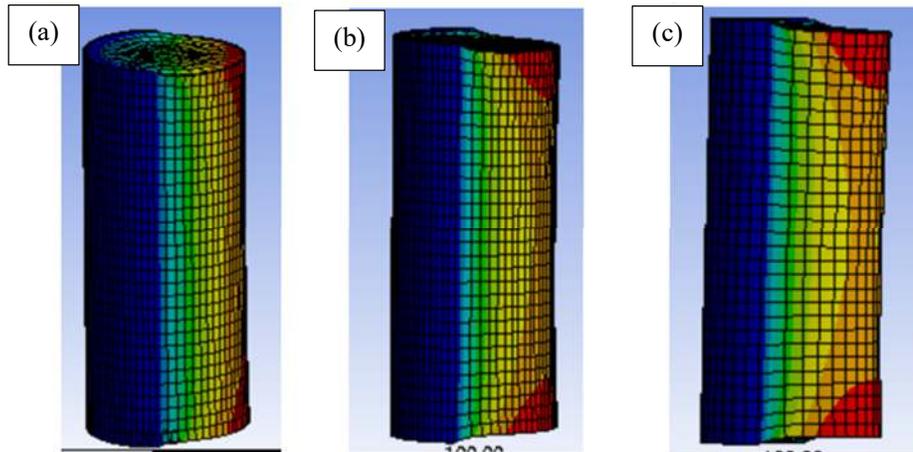


Figure 8. Simulation of damage patterns of concrete specimens wrapped in jute laminate: (a) J1, (b) J2, and (c) J3

4. Conclusion

The study effectively demonstrated that jute/epoxy laminate composites play a crucial role in enhancing the splitting tensile strength of cylindrical concrete specimens. Through comprehensive numerical simulations performed using ANSYS Workbench 2022, it was observed that the incorporation of jute laminates with thicknesses of 2 mm, 4 mm, and 6 mm led to remarkable increases in tensile strength—by 33.1%, 170.5%, and up to 241%, respectively—compared to unreinforced control specimens. These improvements confirm the ability of natural fiber composites to redistribute tensile loads and delay crack initiation under stress. Furthermore, the stress and strain contour plots produced from the simulations indicated more uniform load distribution and reduced strain localization in reinforced specimens, suggesting improved ductility and failure resistance. The accuracy of the simulation model was confirmed through statistical validation using a one-way ANOVA test, which yielded a p-value of 0.5, implying no statistically significant difference between simulated and experimental data. This establishes the reliability of the finite element method (FEM) in predicting real-world behavior. As such, the study provides strong evidence that ANSYS-based FEM simulation is a practical and efficient tool for evaluating structural performance. The findings contribute to the advancement of eco-friendly materials and demonstrate the promising application of jute-reinforced composites in modern structural engineering.

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