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Research Paper

Natural Jute Laminate for the Improvement of Strength Properties of Concrete Specimen

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In the last decade, the exploration and investigation of natural ingredients as alternative materials for metal substitutes have been continuously conducted to produce eco-friendly products with sufficiently good strength. The climate and geography of countries like Indonesia provide that such materials are available abundantly and can be easily replanted. Thus, these materials have considerable potential for application in various products. The purpose of this study is to analyze the compressive and tensile strength of a cylindrical column concrete structure reinforced externally with laminate composite materials derived from jute fabric sheets. The specimen manufacturing method uses a vacuum bagging technique with the specimen size specified in the ASTM C39 test standard. After manufacturing, the specimens underwent the treatment of immersion in clean water for 28 days, followed by drying at room temperature for additional 28 days. The column concrete specimens were wrapped with laminate composite materials with variations in several layers of jute fabric. Compressive strength and splitting tensile tests were conducted according to ASTM C39 and ASTM C496 test standards, respectively. The test results showed that applying laminate composite sheaths on the outer surface of the column concrete structure resulted in an increase in strength of up to 100% for both compressive strength and splitting tensile strength. The magnitude of such an increase in strength is reported in this article.

Keywords: natural fiber composite; jute fabric; compressive strength; splitting tensile strength; vacuum bagging.

1. Introduction

Currently, composite materials are used in various manufacturing fields, including aircraft bodies, automotive accessories, electronic equipment, and household appliances. Additionally, they are used to improve the strength and service life of structures such as concrete columns and beams. The use of composite material can result in lighter, stronger, and less expensive products. Furthermore, the composition of these material can be combined with various fillers (natural, synthetic, or hybrid) to meet specific manufacturing requirements [1].

Jute, commonly found in hot and tropical climates, is an easy-to-grow plant with the Latin name Corchorus spp. [2]. This plant is usually used as material for making burlap bags.. Jute is a cultivated plant native to the Mediterranean region. However, India is today's world's largest jute producer, with total production ranging from 1900 to 2000 kton/year [3]. Furthermore, Thailand produces this plant for the Southeast Asian region, accounting for about 5% of the global jute production [4]. In general, this plant's primary product is jute fabric, which has the potential to be developed as a reinforcing material for concrete structures due to its characteristics as a natural reinforcement medium [5, 6].

Laminate composite is a type of composite material consisting of two or more bonded layers. This type of composite includes several layers of reinforcing material oriented in a specific way. These composite reinforcing layers are typically composed of synthetic, natural, and/or hybrid materials. One of the key advantages of laminate composites is their ability to adapt to the loading direction and characteristics of a given structure. This adaptability results in improved structural strength and resistance to damage [7].

Generally, building materials are made of concrete, which is essentially a mixture of cement, sand, and gravel. Concrete is well known for its excellent weather resistance, ability to withstand external loads, and long service life [8]. In the event of damage, however, repairs necessitate specialized treatment, which can result in lost operating time and weight increase for the new structure [9]. As a result, there is a need for innovative approaches to improve concrete in order to create new, better concrete structures without increasing their overall weight. One solution is to wrap the concrete structure partially or completely with laminated composite material to provide reinforcement.

Presently, various industries consider reusing natural materials to reduce the environmental impact of waste generation. Raw materials have physical properties that make them easily biodegradable, recyclable, abundant, inexpensive, and lightweight. However, because these materials lack sufficient mechanical strength, they are prone to damage when subjected to external loads [10]. Several studies have demonstrated that the use of laminate composites, combining synthetic and natural materials, can improve mechanical properties and reduce overall weight [11–13]. As a result, this research focuses on the use of synthetic and natural hybrid laminate composite materials to improve concrete structure.

Jute cloth laminated composite material was used in this study to strengthen the cylindrical concrete column (CCC) structure. As a result, a curved laminated composite structure was formed. The plane stress theory approach for thin-walled structures can be used to calculate the structural strength of the curved structure. According to this theory, the geometry of the curved structure lacks a stress concentration point in the sheath, resulting in greater structural strength [14].

Several previous studies have been conducted on the mechanical properties of laminated composite materials used as reinforcements for column concrete structures. MAHJOUB *et al.* [15] investigated the use of kenaf fiber to slow down the rate of deformation in column concrete structures. The results showed that using kenaf fiber sheet can reduce the rate of deformation in a CCC structure subjected compressive loads. Separate studies by YU *et al.* [16] and WAYADANDE *et al.* [17] investigated the use of carbon fiber-reinforced polymer (CFRP) material to wrap CCCs under axial compression loads. The results show that the use of CFRP can significantly improve the strength and toughness of the column concrete. NAMBIAR and HARIDHARAN [18] conducted a study on sustainable solutions to mitigate the environmental impact of cement-based materials through the addition of jute. The results obtained showed that the concrete strength increased by up to 35% with the addition of 1% jute in the cement. SHARIF *et al.* [19] investigated the mechanical characterization of laminated composite reinforced with ramie/banana/epoxy. The results showed that the addition of jute fabric significantly increased the composite material's Young's modulus by 10.99%.

A random variable X experiment will yield complex probability density function data. As the number of experiment replicates increases, the random variable equal to the mean (or total) of the results over the trials tends to form a normal distribution pattern [21]. A normal probability mass function (PMF) with an appropriate center and curve width can be used to model the random variable X with different mean (μ) and variance (σ^2). Furthermore, if the value of µis defined as the probability density function's center and the value of σ as its width, then the random variable X will be normally distributed if it falls within the range $\mu - \sigma < X < \mu + \sigma$. The symbol σ represents the random data's standard deviation, which is the square root of σ^2. The resulting curve is a symmetric bell-shaped curve [21]. Thus, if the random variable X is normally distributed, it can be considered representative of the sample.

The primary aim of this study is to determine the effect of using a laminated composite made of jute fabric on the compressive strength and splitting tensile strength of CCC. The study determines the compressive and splitting strengths of CCC wrapped with jute laminated composites, validates the obtained data using the progressive matrix failure (PMF) method, and analyzes the resulting mechanical properties due to compressive and splitting tensile loads.

2. Methodology

The materials used in this study are natural jute fibers in the form of woven sheets purchased at a jute shop in Medan. Epoxy resin and hardener were obtained from a chemical store in the same city. Portland Composite type cement adhering to the SNI 7064 2014 standard was used. River sand, an essential part of the mixture, was purchased at a building material store in Binjai. The physical properties of the cement used are shown in Table 1.

Table 1. Physical specification of cement material [22].

Properties	Unit	Value
Compressive strength:		
3 days	MPa	20
7 days	MPa	34
28 days	MPa	44
Material fineness	m^2/kg	345
Air content	%	6.95
SO_3 content	%	2.1
Early binding	minutes	126
Final binding	minutes	210

Column concrete specimens were made according to the ASTM C39 standard, with a diameter of 50 mm and a height of 150 mm, as shown in Fig. 1. The concrete specimens underwent several treatments, including immersion in clean water for 28 days and subsequent drying in the open air at 1 atm air pressure for additional 28 days. Furthermore, the specimens were wrapped with jute laminated composites with variations as shown in Table 2. The compression and splitting tensile tests were performed using a Hydraulic Universal Testing Machine (UTM) of theWEW-300D model with a capacity of 300 kN. The UTM

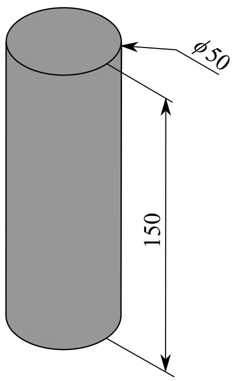

Fig. 1. The specimen size.

Table 2. Variations of the laminate composite wrap.

No	Number of layers	Number of specimen	Code of specimen	
			Compressive testing (CT)	Splitting tensile testing (ST)
1	No layer (control specimen)	3	CT-S0	ST-S0
2	1 layer	3	CT-J1	ST-J1
3	2 layers	3	CT-J2	ST-J2
4	3 layers	3	CT-J3	ST-J3
5	4 layers	3	CT-J4	ST-J4

test equipment and the positioning of the specimen on the test apparatus are shown in Figs. 2 and 3, respectively.

FIG. 2. The testing machine of UTM.

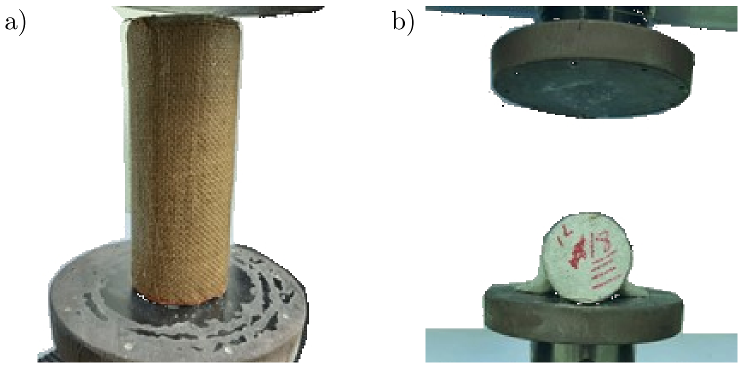

FIG. 3. Specimen positioning on the test equipment: a) CT, b) ST.

The distribution of the test data was evaluated using the PMF method. This evaluation aims to determine whether the test data follows a normal distribution or not. The data was declared valid and it was considered representative of the sample if the test data are normally distributed. In this study, the Minitab software was employed to perform this test and the visualization of the resulting data distribution was conducted through a data distribution plot graph.

3. Results and discussion

The results of the compressive strength testing of laminated composite materials used for CCC structural reinforcement are shown in Fig. 4. In each variation, three tests were carried out (repetitions). The compressive strength of the specimen without a laminated composite sheath (S0) for three sets of test

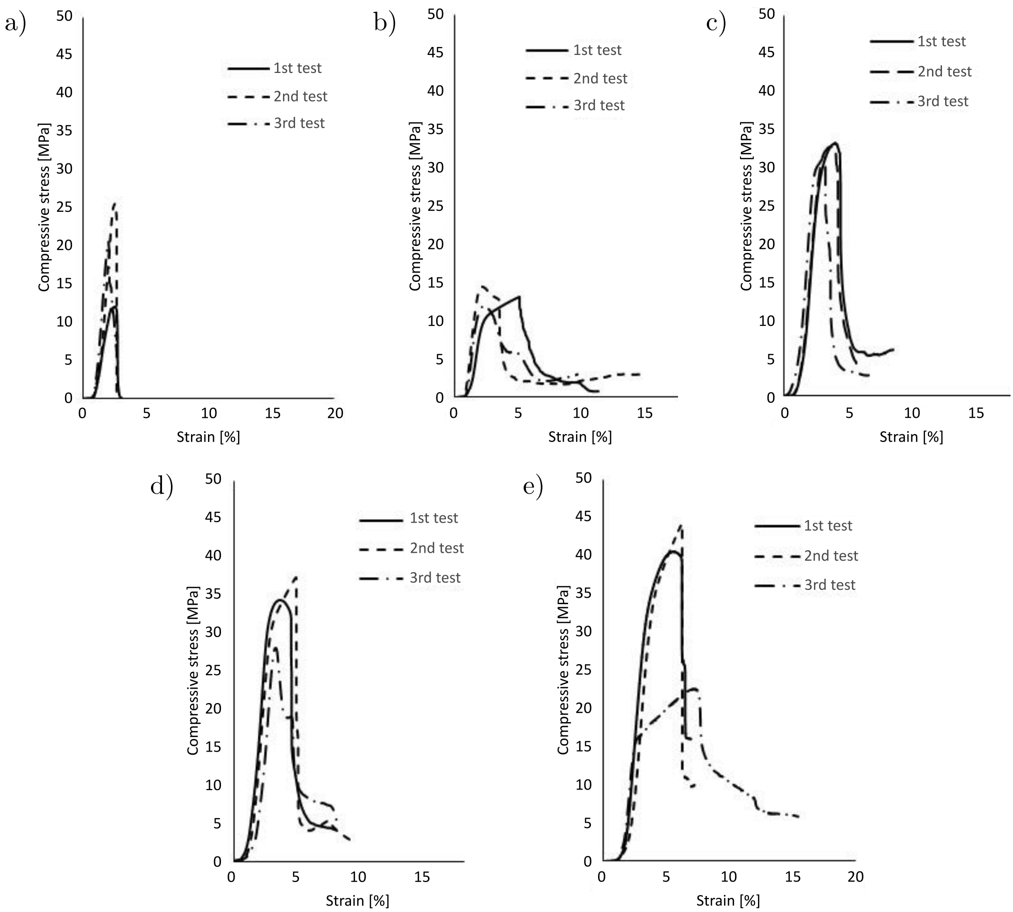

Fig. 4. Compressive strength: a) S0, b) J1, c), J2, d) J3, e) J4.

results is shown in Fig. 4a. Furthermore, the compressive strength of specimens with 1, 2, 3, and 4 layers of jute material labeled J1, J2, J3, and J4 are shown in Figs. 4b–4e, respectively. In the figures, to distinguish between each iteration of the test, the first test is indicated by a solid line, the second test by a dashed line, and the third test by a dashed-dotted line. Furthermore, the appearance of the specimen damage and the results of the data distribution test using the PMF method are shown in Figs. 5 and 6, respectively. Finally, the data from the test results are averaged to provide an overall view of the compressive strength phenomenon. The average compressive strength is shown in Fig. 7.

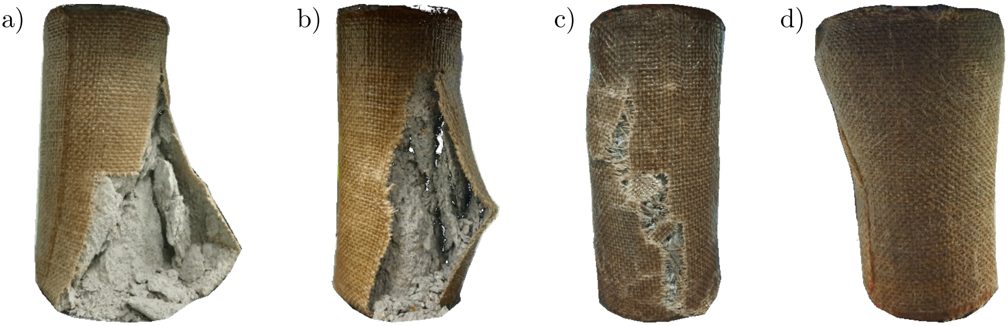

FIG. 5. Damage to the compression specimens: a) CT-J1, b) CT-J2, c) CT-J3, d) CT-J4.

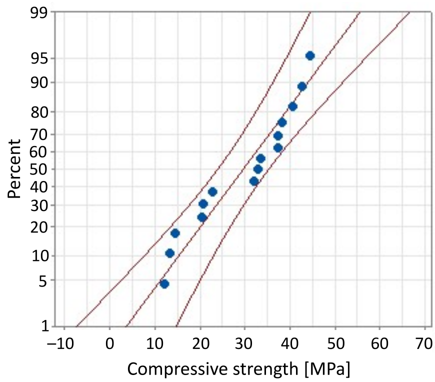

FIG. 6. Probability plot of data distribution (compressive testing).

The results of the study show that the data obtained from the compression test in several variations showed a normal distribution (Fig. 6). Based on the Shapiro-Wilk method for the normality test, the T_3 value for the compressive test data is 0.94. This value is greater than the confidence value of $\alpha > 5\%$, which is 0.92. Thus, the data from the test results are declared valid and considered to be representative of the sample. Furthermore, the structure of the specimen with four layers of jute sheathing was able to withstand damage to the CCC

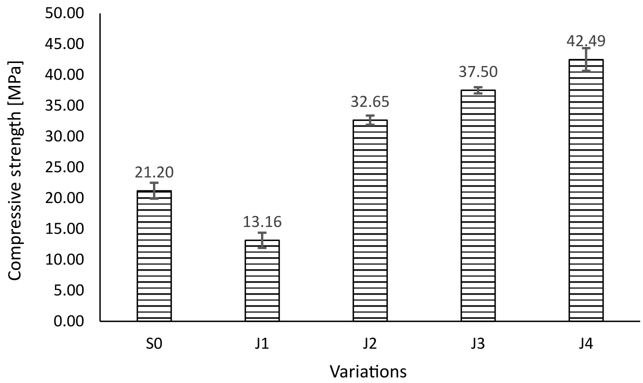

FIG. 7. Average (mean) compressive strength.

structure without compromising the jute layer. This condition is clearly shown in Fig. 5d. Furthermore, the compressive strength of the specimens was enhanced by the addition of a laminated composite sheath made of jute material. The maximum compressive strength of 42.49 MPa was obtained when using four jute layers (Fig. 7). Furthermore, the percentage increase in compressive strength was observed with adding laminated composite sheaths consisting of two, three and four layers as much as 2, 3, and 4 layers, resulting in improvements of 50%, 70%, and 100%, respectively. These results agree with the results of the study conducted by SHARIF *et al.* [19], which demonstrated that the application of jute fiber in concrete improved the compressive strength by more than 100%, reaching 59.18 MPa or more than 100%. Furthermore, the results of this study also support the results of the investigation conducted by SALMAN [24] on the mechanical properties of materials due to the effects of jute incorporation. Her research showed that the compressive strength of the material increased up to 150%.

The results of the splitting tensile strength test for each variation of the laminated composite layer are shown in Fig. 8. The splitting tensile strength of the CCC structure without jute sheath (S0) in three test repetitions is shown in Fig. 8a. The splitting tensile strength of the jute sheath variations: J1, J2, J3, and J4 is shown in Figs. 8b–8e, respectively. The surface appearance of the CCC damage is shown in Fig. 9. The results of the test on the distribution of the test data using the probability density function method are shown in Fig. 10. Finally, the average splitting tensile strength value is shown in Fig. 11.

In Fig. 8, it is observed that applying a jute sheath to CCC leads to an increase in the splitting tensile strength. In the test graph, the splitting tensile strength increased significantly starting from the use of two layers of jute sheathing. However, the damage to the specimens presented in Fig. 9 shows almost the same pattern. This indicates that although the strength is increasing, the

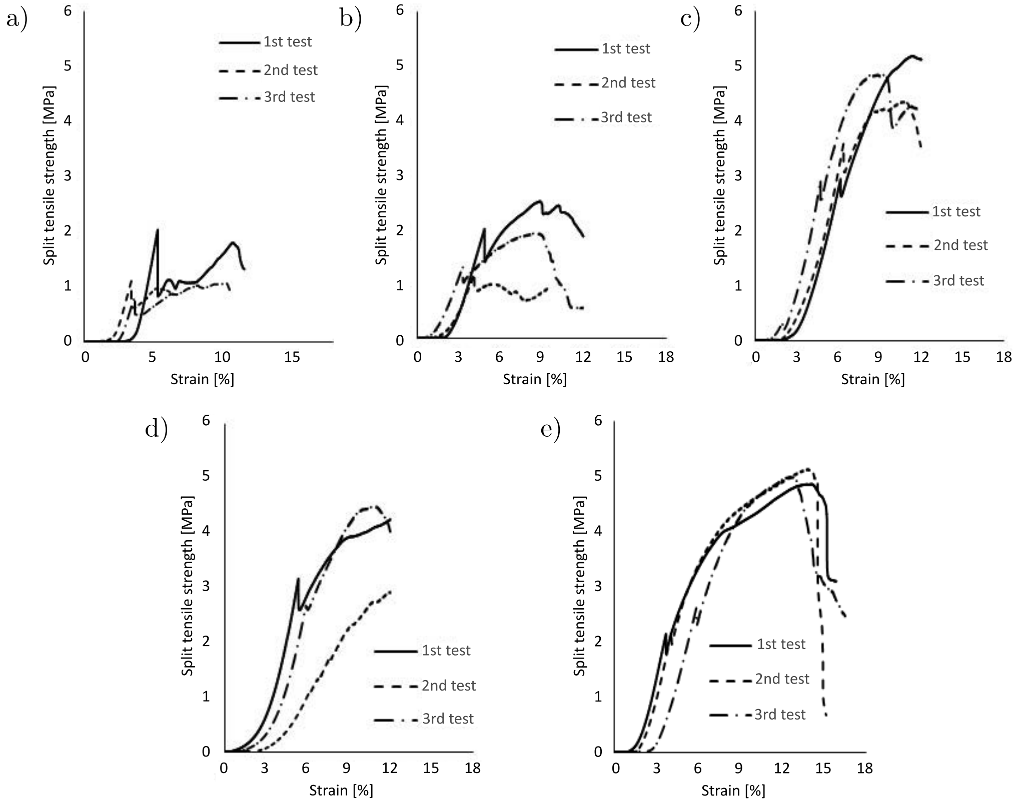

FIG. 8. Splitting tensile strength: a) S0, b) J1, c) J2, d) J3, e) J4.

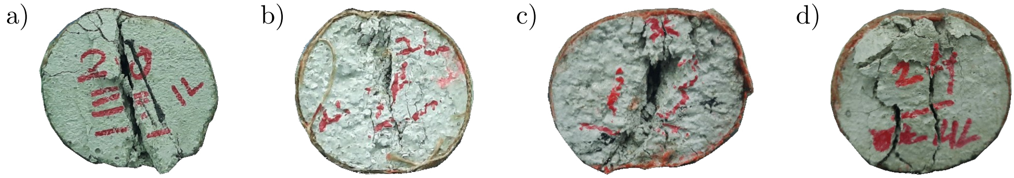

FIG. 9. Damage to the splitting tensile specimens: a) ST-J1, b) ST-J2, c) ST-J3, d) ST-J4.

laminated jute composite is still unable to withstand shear loads arising from splitting tensile loads.

The distribution of test data, calculated based on the PMF method and shown in Fig. 10, indicates that the data is normally distributed around the average value. Based on the normality test of the Shapiro-Wilk method, the T_3 value of the data from the splitting tensile test is 0.95 and greater compared to the confidence threshold of $\alpha > 5\%$, which is 0.92. As a result, the test data are declared valid and considered representative of the sample. In Fig. 11, the maxi-

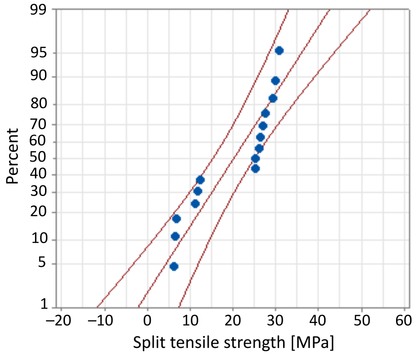

FIG. 10. Probability plot of data distribution (splitting tensile testing).

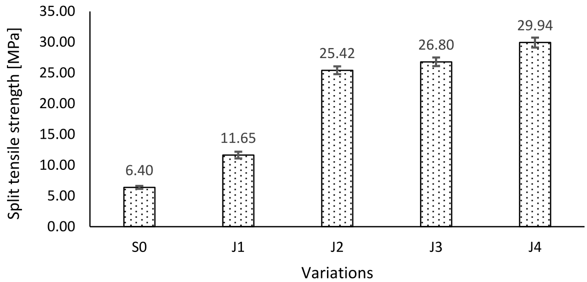

FIG. 11. The average (mean) splitting tensile strength values for different jute sheathings.

mum average strength of 29.94 MPa is obtained for four jute layers. However, this strength is not significantly different from the strength of 2 and 3-layer jute, i.e., 25.42 and 26.80 MPa, respectively. A significant increase in splitting tensile strength occurred in 2, 3, and 4-layer jute configurations, showing improvements of over 290%, 300%, and 350%, respectively. These findings support the results of research conducted by ISLAM and AHMED [23]. Based on these results, the application of a jute layer had a significant impact on CCC strength. Furthermore, our results support the results of the investigation conducted by SALMAN [24], which found that the use of jute fiber increased the overall strength.

4. CONCLUSION

The average compressive strength of CCC reinforced with 1, 2, 3, and 4 layers of jute laminated composite was 13.16, 32.65, 37.5, and 42.49 MPa, respectively. Likewise, the average tensile strength of CCC reinforced with 1, 2, 3, and 4 layers of jute laminated composite was 11.65, 25.42, 26.8, and 29.94 MPa, respectively. Based on the calculation results of the PMF method, the data from the compression and splitting tensile tests exhibit a normal distribution

Thus, the data can be declared valid and representative of the sample. Based on the average compressive strength and splitting tensile strength, it can be seen that the addition of natural fiber composites from jute woven sheet material can increase its mechanical strength. Thus, this natural material has a good potential to be developed as an alternative for material development.

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