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APPLICATION OF E-GLASS JUTE HYBRID LAMINATE COMPOSITE WITH CURVED SHAPE ON COMPRESSIVE STRENGTH OF CYLINDRICAL COLUMN CONCRETE

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ABSTRACT
This study provides a better understanding of reinforcing cylindrical concrete columns (CCC) using a hybrid laminated composite material (HLC) composed of jute and e-glass fibers, including the influence of layer quantity on strength and a comparison with previous research. The utilization of these alternative materials may lead to the development of novel and efficient solutions for constructing durable and robust structures. The primary objectives of this research are to assess the effects of employing HLC as a reinforcing layer on CCC compressive strength, optimize the reinforcement process by selecting appropriate layer sequences and types, and analyze the type of fiber damage in relation to the strength of HLC composite material. The materials utilized in this study encompass woven jute fabric sheets, e-glass fiber sheets, and epoxy resin. Compressive strength testing was conducted following ASTM C39 standards. Specimen variations were based on the number and type of reinforcing layers. The results revealed that CCC compressive strength increased by up to 100% with the application of up to three layers of jute compared to an unlayered specimen. Furthermore, CCC compressive strength experienced a remarkable enhancement of up to 150% with the incorporation of HLC composite. Hence, the implementation of HLC demonstrates significant potential for augmenting the strength of concrete structures.
Keywords: *Woven Jute Fabric, Curve Laminate Composite, Hybrid Laminate Composite, Compression Strength*

1. Introduction

Currently, composite materials are extensively utilized across diverse manufacturing sectors, including aircraft fuselages, automotive components, electronic devices, and household appliances. Furthermore, the utilization of these materials has advanced to enhance the durability and longevity of structural elements in construction, such as concrete columns and beams. Employing these materials can result in the creation of products possessing reduced weight, increased strength, and enhanced affordability (Mahmud et al., 2023; Parvez et al., 2023). Moreover, the formulation of these materials can be tailored to accommodate various fillers—whether natural, synthetic, or hybrid—ensuring adaptability to specific manufacturing requirements (Kumar & Kumar, 2023).

Laminated composite refers to a category of composite materials comprising the bonding of multiple layers. This composite variety encompasses several layers of reinforcement materials oriented in specific configurations. Typically, these layers consist of synthetic, natural, and/or hybrid materials (Sharma & Gupta, 2023). The distinctive merit of this composite type lies in its capacity to conform to the loading direction and nature pertinent to a predefined structure, thereby augmenting structural strength and mitigating susceptibility to damage (Hasanuddin et al., 2023).

Typically, the composition of construction materials consists of concrete, a composite comprising cement, sand, and gravel (Xiao et al., 2023). This material is renowned for its remarkable resistance to adverse weather conditions, external forces, and extended operational lifespan. Nonetheless, in the event of structural damage, remediation necessitates specialized procedures, potentially leading to downtime and additional load-bearing demands on the replacement structure (Gravett et al., 2021; Lu et al., 2023). Hence, there exists a requirement for innovative approaches aimed at enhancing concrete structures without augmenting their operational load. One viable approach involves the incorporation of a reinforcing laminate composite structure, which can be partially or wholly applied to the concrete structure (Patil et al., 2023; Xie et al., 2020).

Presently, diverse industries are contemplating the reutilization of natural resources as a means of mitigating the environmental impact stemming from waste generation. Natural materials possess physical attributes that facilitate biodegradability, recyclability, abundant availability, cost-effectiveness, and lightweight properties (Rueda-Bayona et al., 2022; Santosh Gangappa & Sripad Kulkarni, 2020). Nonetheless, these materials often lack the requisite mechanical robustness, rendering them susceptible to damage under external loads (Chau et al., 2022; Thomason, 2023). Additionally, numerous investigations have indicated that the incorporation of synthetic and natural composite laminates can enhance mechanical attributes and diminish operational weight. Consequently, the central focus of this study revolves around the utilization of hybrid synthetic and natural laminated composites to ameliorate concrete structures (Oteng-Abayie et al., 2022).

Jute, belonging to the Corchorus spp. and categorized under the Tiliaceae family, is a plant known for its adaptability to growth in warm and tropical regions (Khalid et al., 2021; Majumder et al., 2023). Historically utilized mainly for burlap (sacking), jute holds its origins in the Mediterranean. However, at present, India leads as the foremost jute producer, yielding a substantial annual output of around 1900 to 2000 tons (Baley et al., 2021; Karua et al., 2023). Notably, within the Southeast Asian realm, Thailand contributes to the global jute production with a share of approximately 5% (Baley et al., 2021; Shukla & Mittal, 2022). Primarily manifesting as jute fabric, this plant derivative exhibits the potential to serve as a reinforcing material for concrete structures due to its favorable capacity as a substrate for innate materials (Li et al., 2020; Senniangiri et al., 2022).

Jute fibers and E-glass fibers exhibit distinct characteristics and advantages. Jute fibers are natural fibers known for their environmental friendliness, lightweight nature, and strength (Senniangiri et al., 2022; Wagh et al., 2023). On the other hand, E-glass fibers are synthetic fibers with attributes of strength, heat resistance, and corrosion resistance (Mohammad Shohel et al., 2023; Veeranjaneyulu et al., 2023). When combined, jute fibers and E-glass fibers complement each other's strengths (Shakery & Alizadeh, 2021). Jute fibers contribute to environmental friendliness and lightness, whereas E-glass fibers provide strength, heat resistance, and corrosion resistance. Furthermore, jute fibers are biodegradable natural fibers, thereby reducing environmental impact. Additionally, they possess a lower density compared to E-glass fibers, leading to the creation of lighter composite materials. Jute fibers are easily obtainable and relatively cost-effective, thereby lowering production costs and overall prices (Tong et al., 2023). In contrast, E-glass fibers possess higher tensile strength than jute fibers, thereby enhancing the composite material's strength. Furthermore, E-glass fibers exhibit greater resistance to temperature and corrosion (Thomason, 2023). Consequently, the combination of jute fibers and E-glass fibers can enhance composite material performance in terms of strength, heat resistance, corrosion resistance, lightweight nature, and environmental sustainability (Edward Kennedy & Arul Inigo Raja, 2021).

Several studies have been conducted on the durability of composite materials made from natural fibers. Abir et al. (2023) conducted experiments to assess the impact of adding jute fibers on the mechanical properties of gypsum plasterboard composites. The research findings indicated that the addition of 6% jute fibers resulted in the highest tensile strength. However, the incorporation of 8% fibers led to lower tensile and flexural properties compared to lower fiber content (Abir et al., 2023). Maithil et al. (2023) conducted a study on the tensile strength of polymer composites reinforced with carbon fibers, jute fibers, and a hybrid combination of both. The results showed that the hybridization of carbon and jute fibers in polymer composites yielded a significant increase in mechanical strength compared to single fiber usage, along with reduced production costs and environmental impact (Maithil et al., 2023). Sriranga et al. (2021) investigated the potential utilization of naturally available and cost-free jute fibers as reinforcement in composite materials. The study demonstrated that a composition containing an additional 25% jute fibers exhibited improved strength compared to the base matrix of S-glass fibers and epoxy resin. This indicates that the addition of jute fibers enhances the mechanical properties of composite materials, particularly in terms of strength (Sriranga et al., 2021). Kirubai et al. (2022) explored the application of jute fibers and rice straw powder for the development of hybrid composite materials combined with synthetic silica fibers. The research findings indicated that hybrid composite materials consisting of natural fibers (such as jute and rice straw) and synthetic fillers (silica) exhibited superior mechanical properties compared to materials reinforced with a single fiber type (Kirubai et al., 2022).

An experiment with random variables X will produce complex probability density function data. Each time a randomized experiment is replicated, a random variable equal to the mean (or total) of the results over the trials tends to form a normal distribution pattern as the number of replicates becomes large (Berenguer-Rico & Nielsen, 2023; El Bouch et al., 2022; Kurita & Seo, 2022). The random variable X with a different mean (μ) and variance (σ^2) can be modeled as a normal probability mass function (PMF) with the appropriate choice of center and curve width (Horváth et al., 2020; Joe Qin et al., 2021). Furthermore, the value of is defined as the center of the probability density function and the value of σ^2 as the width, then the random variable X will be normally distributed if it is in the range $\mu-\sigma < X < \mu+\sigma$. The symbol σ is the standard deviation of the random data which is the square root of σ^2. The resulting curve is like an asymmetric bell-shaped curve. Thus, the random variable X can be considered representative of the sample if it is normally distributed (Kolkiewicz et al., 2021; Rapino et al., 2023).

In this study, the focus of the research was to determine the effect of the application of laminated jute fabric and hybrid laminated composite (HLC) wrapping of e-glass jute on the compressive strength of CCC. The objectives of this study were to evaluate the effect of using HLC as a reinforcing layer on the compressive strength of CCC, to optimize the reinforcement process by selecting the appropriate sequence and type of coating, and to analyze the type of fiber damage in relation to the strength of the HLC composite material.

2. Research Methods

Sheets of 0.5 x 1 m jute fabric were purchased from the Yarn Warehouse, Bekasi, West Java, Indonesia. E-glass sheets and epoxy resin were purchased from PT. Justus Kimia Raya, Medan, Indonesia. Concrete aggregates consist of cement, sand, and gravel. Cement was purchased from PT Cemindo Gemilang, Medan, Indonesia with the physical specifications shown in Table 1. Sand and gravel were purchased at a building materials store in the Kota Binjai area, North Sumatra, Indonesia. Air vacuum conditions were obtained using a CVC120 model vacuum pump with a suction power of 4.5 MPa.

CCC specimens were made according to ASTM C39 test standards with a diameter of 50 mm and a length of 150 mm. The mold shape of the test object is shown in Figure 1. Based on ASTM C33 and ACI 211.1 standards, the best composition of concrete aggregate (cement, sand, and gravel) for the North Sumatra region, Indonesia is 1:2:3 and the specimen treatment is carried out by immersion in clean water for 28 days and drying in the open air for 28 days.

Table 1 - Physical specification of cement material (Fode et al., 2023)

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

J1, J2, and J3 represent the first, second, and third layers which are jute fabric sheets. This cloth will be used as a protective sheet for the CCC specimen. To form three test objects, each variation will undergo three tests. Additionally, as a control, three CCC specimens without jute fabric were prepared for testing purposes. Next, three different fabric combinations, including jute fabric and E-glass, were examined for HLC (Hybrid Laminated Composite) evaluation. These variations are designated GGJ, JGJ, and JJG, where the 'J' denotes jute fabric sheet and 'G' denotes E-glass fabric sheet. Illustrations of test specimens are shown in Fig. 2.

Fig. 1. CCC specimen mold based on ASTM C39 standard

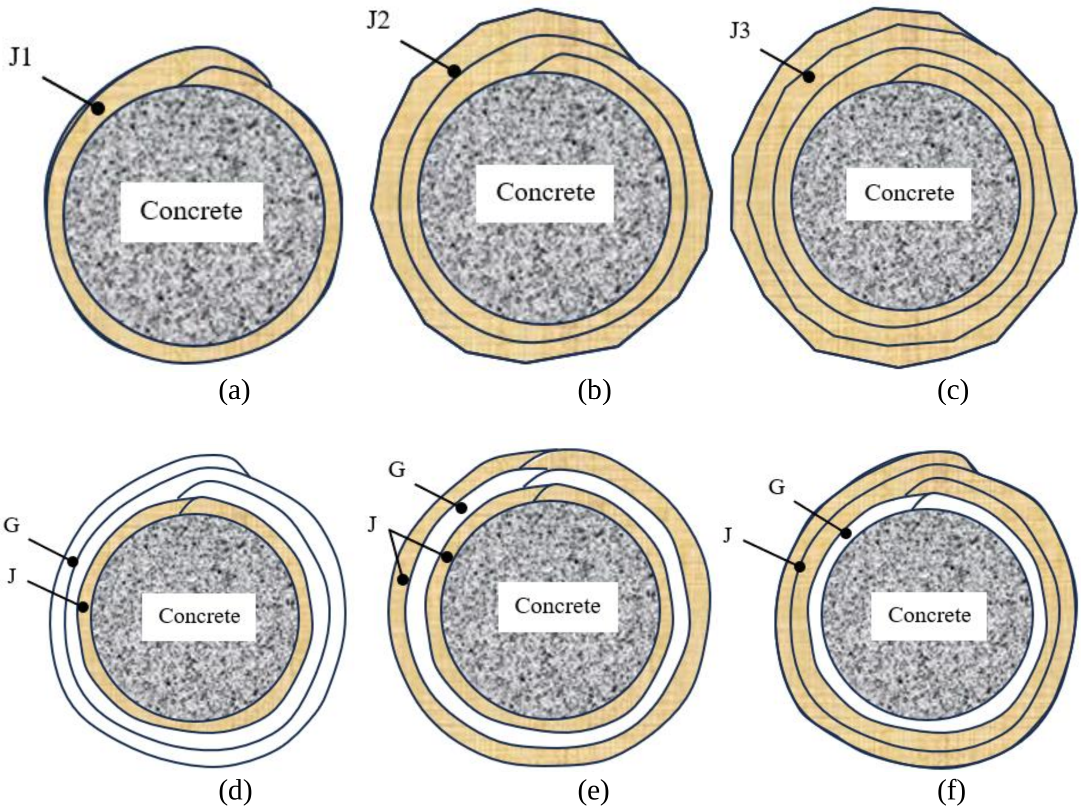


Fig. 2. Sketches of the CCC wrap variations: (a) J1, (b) J2, (c) J3, (d) GGJ, (e) JGJ, and (f) JJG.

The procedure for making test specimens begins with measuring the mass of each constituent of the concrete aggregate, namely cement, sand, and gravel, as in Figure 3. Next, the aggregate is mixed carefully and poured into the test specimen mold as shown in Figures 4. a and b. After being left for 3 days in the mold, the specimens were extracted and soaked in clean water for 28 days as shown in Figure 4. c. Then, the specimens were dried in the open air for 28 days to achieve optimal hardness as shown in Figure 4.d. A layer of jute and its hybrids is applied to the concrete surface according to the variations mentioned and molded using the vacuum bag method. This process is shown in Figure 4. e and f.

(a) (b) (c)

Fig. 3. Aggregate mass measurement: (a) cement, (b) sand, and (c) gravel

(a) (b)

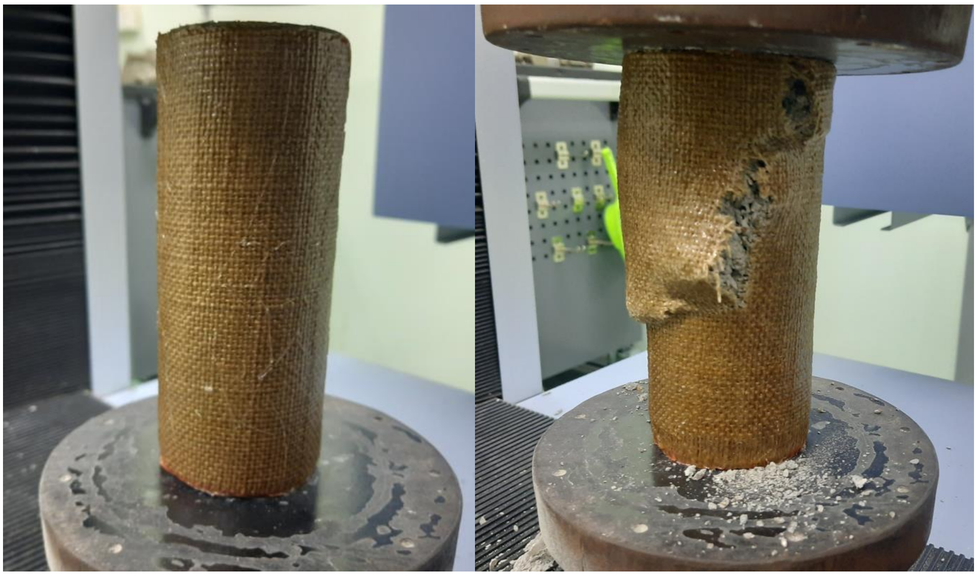
(c) (d) (e)

(f) (g)

Fig. 4. The process of making specimens: (a) mixing concrete aggregate, (b) molding specimens, (c) soaking in clean water, (d) drying in the open air, (e) wrapping of woven jute fabric, (f) vacuum air process, and (g) specimens that have been vacuumed.

Research activities and compressive strength testing were carried out at the Integrated Research Laboratory (LPT), University of North Sumatra, Medan, Indonesia. Compression testing using the Universal Testing Machine (UTM) type Hydraulic UTM model WEW-300D with a capacity of 300 kN (Figure 5). The test is carried out on the test object until it is damaged as shown in Figure 6.

Fig. 5. Compressive strength test equipment type UTM WEW-300D



(a) (b)

Fig. 6. Compressive Test Conditions: (a) Specimen Before Being Subjected To Compressive Load, And (b) Specimen After Failure.

The test data will be validated using the PMF method to check whether the data is normally distributed or not. The test results will be displayed in the form of a normally distributed data graph (NDD), where the data must be within the lower control limits (LCL) and upper control limits (UCL). Data that meets these requirements are in the range LCL < X < UCL. In this study, the analysis of the test results is to see the trend of changes in the strength of the CCC structure due to the effect of applying laminated composite wrap in the form of curved structures, both with jute and HLC fabrics. Furthermore, the results of this study will be compared with the results of previous studies to obtain the overall characteristics of the material produced and other phenomena.

3. Results and Discussions

The data from the compression test of the CCC specimen reinforced with laminated composites from jute fabric and its hybrids are shown in Figure 7. In this study, the validity of the test data was checked using the PMF method and the test results are shown in the form of NDD graphs shown in Figures 8 and 9. Based on the results of the examination, the test data for each variation proved to be in the NDD condition because these data were still close to the range of μ-σ < X < μ+σ. Thus, the data are spread close to the sample mean value and can be assumed to be representative of the sample.

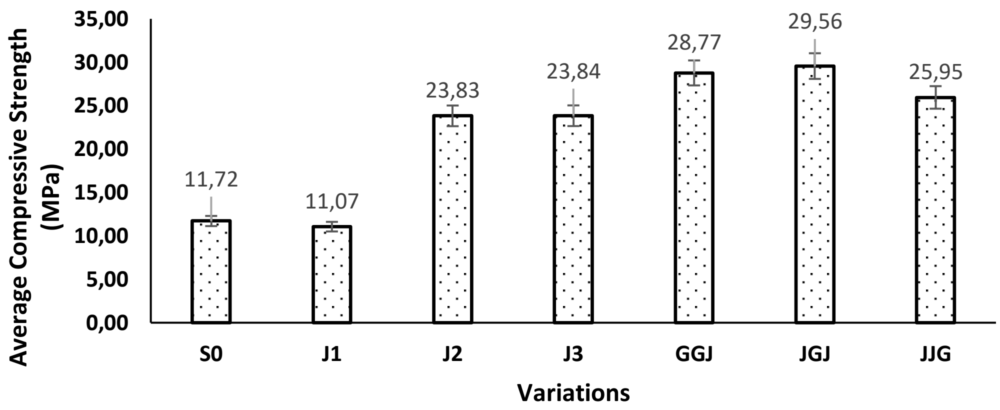


Fig. 7. Average Compressive Strength Of CCC Specimens By Wrap Variation

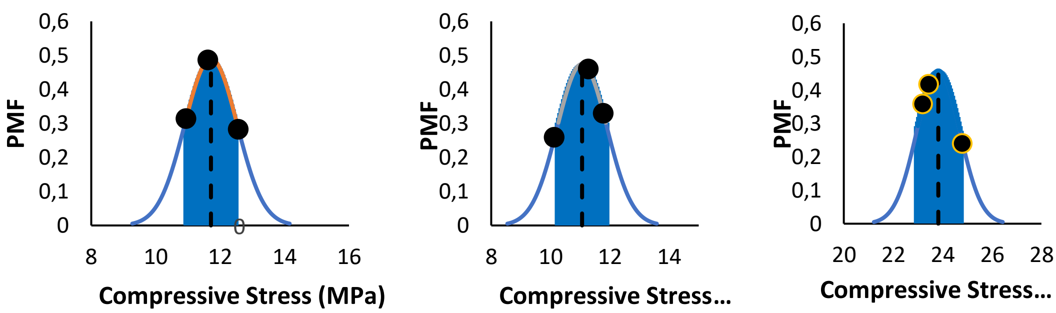


Fig. 8. Graph of NDD on variations of: (a) S0, (b) J1, (c) J2, and (d) J3

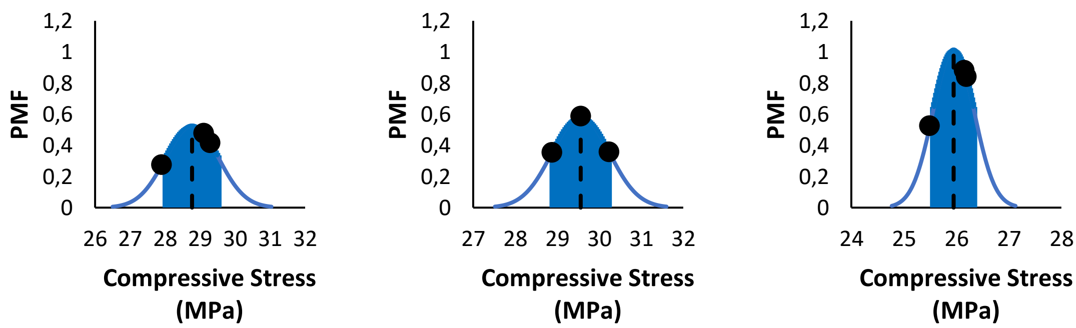


Fig. 9. Graph of NDD on variations of (a) GGJ, (b) JGJ, and (c) JJG

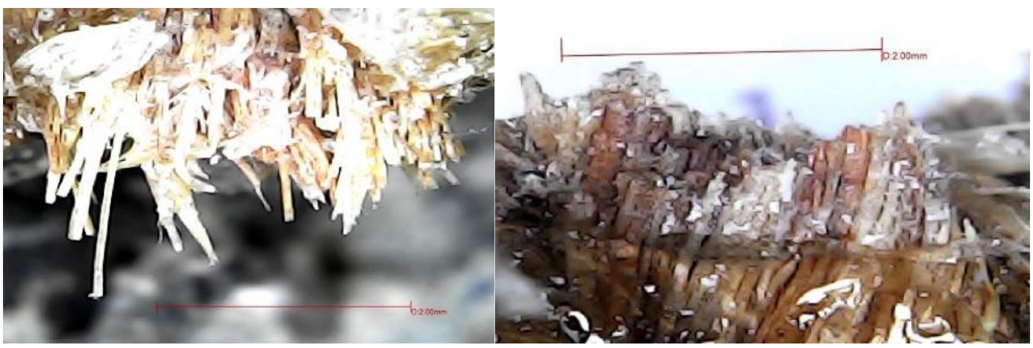
Based on the test data, the compressive strength of S0 and J1 has almost the same average value of 11 MPa. Thus, the addition of 1 layer of jute cloth did not have a significant effect on increasing the compressive strength of CCC when compared to no wrap. Furthermore, the compressive strength experienced a significant increase in the application of 2 and 3 layers of jute fabric wrap. The average compressive strength of 2 and 3 layers of jute wrap was 23.83 and 23.84 MPa, respectively. The compressive strength has increased up to 100% compared to without wrapping. The results of this study support the results of investigations carried out by Abir et al. (2023), where the addition of jute fiber to the composite was able to increase its mechanical properties by up to 593% (Abir et al., 2023). This study also supports the results of research conducted by Karua et al. (2023), where 2.44% jute fiber mixture can increase the compressive strength of composite materials by up to 140% (Karua et al., 2023). However, the results of this study are in contrast to the results of a study by Majumder et al. (2023). Mixing jute fiber in mortar actually reduces the compressive strength by up to 80% at a composition of 2% fiber 5 mm long (Majumder et al., 2023).

The application of HLC to CCC causes a significant increase in compressive strength, which is up to 150% without wrapping. The average compressive strength in each variation of GGJ, JGJ, and JJG was 28.77, 29.56, and 25.95 MPa, respectively. Among these variations, the application of a jute fabric as the first layer to cover the CCC surface had a higher average compressive strength than e-glass. Thus, in the process of strengthening the CCC structure with the application of an HLC wrap, it is necessary to consider the use of a jute fabric as the initial layer covering the CCC to obtain better compressive strength. The results of this study support the results of investigations carried out by Maithil et al. (2023), where the application of a hybrid composite of jute fiber and synthetic carbon fiber was able to increase its mechanical properties by up to 300% (Maithil et al., 2023). The results of this study also support the investigation that has been carried out by Vivek et al. (2022), where a mixture of jute fiber with 5% copper wire was able to increase its compressive strength by up to 15% (Vadivel Vivek et al., 2022).

Figure 10 depicts the pattern of damage to the composite wrap made of laminated jute and HLC. The jute fabric does not have a significant impact on CCC, as seen by the damage that occurs in 1 jute layer, as illustrated in Figure 10 a. It is plain to see that CCC damage happens frequently and shreds the case at any point on its surface. As a result, applying a jute cloth with up to 1 layer did not increase the CCC strength. However, jute fabrics with two and three layers showed an improvement in strength. Visual inspection of the damage pattern in Figures 10 b and c revealed that the damage was confined to a single area. This demonstrates that the jute fabric's strength is generally distributed throughout the CCC surface and that the damage only affects one of the weaker areas. This damage pattern matched that of the specimens with HLC coating, as seen in Figures 10 d, e, and f. In other words, the application of an HLC coating and perhaps other materials can boost the strength of the CCC even further.

(a) (b) (c) (d) (e) (f)

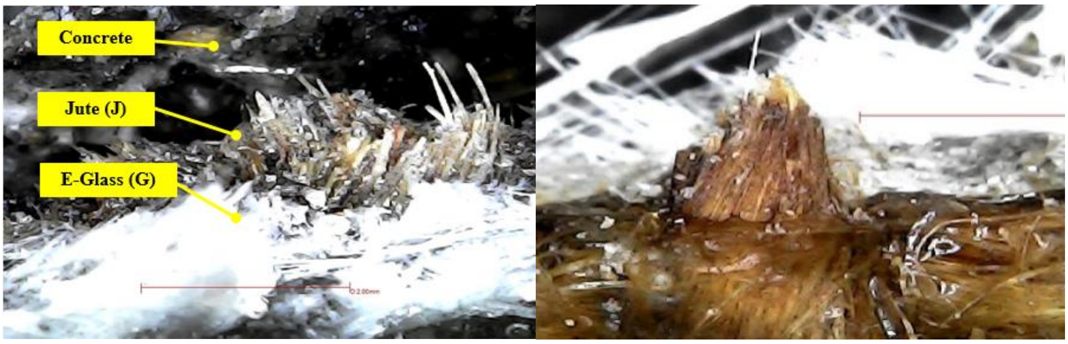
Fig. 10. Damage To The Surface Of The Jute Layer In Variations Of (a) J1, (b) J2, (c) J3, (d) GGJ, (e) JGJ, and (f) JJG



(a) (b)

(c)

Fig. 11. Optical Observations At 75 Times Magnification Of The Composite Structure At Variations of (a) J1, (b) J2, and (c) J3



(a) (b)

(c)

Fig. 12. Optical Observations Of 75 Times Magnification Of The Jute Fiber Structure In HCL Composites At Variations Of (a) GGJ, (b) JGJ, and (c) JJG

Figure 11 displays the findings of observations made using an optical microscope with a magnification of up to 75 times to determine the type of damage to the fiber. Figure 11a depicts the J1 variation's fiber damage in terms of form. Due to the improper binding of the jute fiber by the epoxy matrix in this situation, it is unable to endure the applied external load and sustains damage first. In addition, the jute fiber responds to the stress in such a way that it seems to be emerging from the embedded matrix. On the other hand, the J2 and J3 variations, as depicted in Figures 11b and c, demonstrated a reasonably strong bond between the epoxy matrix and jute fibers. The fracture between the matrix and the fibers happens in almost the same place, and the direction and shape of the fibers appear to be more regular. The composite's entire structure may receive equal amounts of load thanks to the matrix, which also boosts the strength of the fiber.

Thus, the laminated composite's strength can raise the total strength of CCC.

The results of the same observation on the shape of the fiber damage in the HLC specimen are shown in Figure 12. The shape of the fiber damage in the GGJ variation is shown in Figure 12a. In this condition, jute fiber gives a good response to the given load. The shape of the jute fiber damage indicates that the fiber resists external loads maximally until it finally breaks. Furthermore, the presence of jute fiber between the concrete and the e-glass also serves as a strong binder between the concrete and the e-glass sheet. Furthermore, the shape of the fiber damage in the JGJ and JJG variations is shown in Figures 12b and c. In this condition, the fiber and matrix provide a good response to the external load given. Based on the form of damage, the combination of jute fiber and e-glass can better withstand the applied load resulting in the highest increase in CCC strength of the other two types of HLC specimens. Finally, the application of the HLC wrap on the CCC can work well together increasing the overall strength of the CCC.

4. Conclusion

The experimental findings indicate that the addition of a single layer of jute wrap (S0 and J1) did not lead to a significant improvement in the compressive strength of CCC when compared to the unwrapped condition, as both exhibited nearly identical average values of 11 MPa. However, a noteworthy enhancement in compressive strength was observed when employing 2 or 3 layers of jute fabric wrap. The mean compressive strength for 2 and 3 layers of jute wrap was 23.83 and 23.84 MPa, respectively, signifying a substantial increase of up to 100% when contrasted with the unwrapped state. The application of HLC to CCC significantly increased the compressive strength by up to 150% without wrapping. Among the variations, the use of jute fabric as the first layer to cover the CCC surface had a higher average compressive strength than e-glass. Therefore, in the process of strengthening the CCC structure with the application of an HLC wrap, it is recommended to use jute fabric as the initial layer. The application of jute fabric to CCC does not significantly improve the strength when only one layer is used. However, two and three layers of jute fabric showed an improvement in strength. The damage pattern of the specimens with jute fabric and HLC layer is similar, which suggests that the application of the HLC layer and other materials can further improve the strength of CCC.

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