

HYBRID LAMINATED COMPOSITE CASING AS CONCRETE REINFORCEMENT

Mohammad Yuhazri bin Yakoob¹ and Achmad Jusuf Zulfikar^{1,2,*}

Received: March 27, 2023; Revised: August 28, 2023; Accepted: September 21, 2023

Abstract

Composite materials are well known for their lightweight, easy to form, high elastic properties, and relatively low production costs. Laminated composites are composite materials that are widely applied in modern building structures such as aircraft walls, automotive cases, dashboards, press boards, etc. In this study, a curved laminated composite material was used as a reinforcing material surrounding the column structure. This study aims to analyze the mechanical strength of curved laminated composite materials as reinforcement for the cylindrical column concrete structure. Compressive testing of composite materials using the ASTM C39 standard. The materials used are jute fabric, e-glass, epoxy resin, and concrete aggregate. Specimens were molded using a vacuum bagging technique to minimize trapped air in the matrix. The curve shape of the laminated composite was obtained from the shape of the ASTM C39 concrete specimen with a diameter of 50 mm and a length of 150 mm. Based on the results of the study, the compressive strength of the structure increased up to 100% when the jute fabric was given up to 2 layers. Furthermore, the strength of the structure will increase up to 150% in the application of jute e-glass hybrid laminate composite.

Keywords: Jute Fabric, Curve Laminate Composite, Hybrid Composite, Compression Strength

Introduction

At this time, the application of composite materials has been found in various manufacturing fields such as aircraft bodies, automotive accessories, electronic equipment, household appliances, etc. The application of this material has also been developed to increase the strength and service life of building structures such as concrete columns and beams. The application of this material can produce products that are lighter, stronger, and cheaper (Gribniak *et al.*, 2021). In addition, the composition

of this material can also be combined with various fillers (natural, synthetic, and or hybrid) so that it can adapt to manufacturing needs (Shekar and Ramachandra, 2018). However, this material has a high level of complexity in the production process, especially for special specifications such as aircraft, spacecraft, military, etc. (Kilimtzis *et al.*, 2023; Wang *et al.*, 2023). In addition, due to the layered composition of the material, it will be difficult to detect early damage. Therefore, further studies are

¹ Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia. E-mail: yuhazri@utem.edu.my

² Department of Mechanical Engineering, Faculty of Engineering, Universitas Medan Area, Jl. Kolam No. 1, Medan Estate, Kodya Medan, Sumatera Utara, Indonesia. E-mail: zulfikar@staff.uma.ac.id

* Corresponding author

DOI:

Suranaree J. Sci. Technol. 30(5):010258(1-10)

needed to produce materials with better mechanical properties (Zimmermann and Wang, 2020; Kastratović *et al.*, 2021).

Laminate composite is a type of composite material consisting of two or more layers bonded together (Huang *et al.*, 2022). This type of composite is composed of several layers of reinforcing material that has a certain orientation. In general, these composite reinforcing layer materials are made of synthetic, natural, and/or hybrid materials (Joseph *et al.*, 2022). The advantage of this type of composite is its ability to adapt to the nature and direction of loading orientation on a predetermined structure so that the strength of the structure increases and is not easily damaged (Ye, 2003).

In general, the construction of building materials is made of concrete which is an arrangement of cement, sand, and gravel. This material is well known for its excellent weather resistance, external load resistance, and long service life (Talikoti and Kandekar, 2019). However, if this structure is damaged, handling repairs requires special treatment which can result in lost operating time and an increase in the weight of the new structure (Kovler and Chernov, 2009). Therefore, innovation activity is needed to improve it to produce a new, better concrete structure without increasing its working weight. One solution is to provide a reinforcing structure of laminated composite material by wrapping the concrete structure partially or completely.

At this time, various industries have considered the reuse of natural materials to reduce the impact of environmental damage due to the generated waste. Natural materials have physical properties that are easily biodegradable in nature, can be recycled again, are abundantly available, inexpensive, and light in weight. However, these materials do not have high enough mechanical strength so they are easily damaged when subjected to external loads (Chethan *et al.*, 2019). Furthermore, several studies have shown that the application of synthetic and natural composite laminated composites can improve mechanical properties and reduce working weight (Abu Shaid Sujon *et al.*, 2020; Nagaraj *et al.*, 2020; Ouarhim *et al.*, 2020; Ganesan *et al.*, 2021). Therefore, the focus of this study is the use of synthetic and natural hybrid laminate composite materials to improve the concrete structure.

Jute is a plant that is easy to grow and is often found in hot and tropical regions. This plant is included in the Tiliaceae family with the Latin name *Corchorus* spp (Ali *et al.*, 2019). In general, this plant is used as a material for burlap (sacking) (Majumder *et al.*, 2022). Jute is a cultivated plant

originating from the Mediterranean. However, the largest jute producing country today is India with total production ranging from 1900 to 2000 tons/year (Saleem *et al.*, 2020; Song *et al.*, 2021). Furthermore, for the Southeast Asian region, the country that produces this plant is Thailand which accounts for about 5% of the world's jute production (Townsend, 2020; Senthilrajan *et al.*, 2022). In general, this plant product is in the form of jute fabric which is used to have the potential to be developed as a reinforcing material for concrete structures because it has fairly good ability as a retaining medium for innate materials (Ali *et al.*, 2019; Islam *et al.*, 2022).

In this study, a laminated composite of jute fabric and hybrid jute e-glass will be used to strengthen the cylindrical concrete column (CCC) structure. Thus, the laminated composite structure formed is curved. The structural strength of the curve can be calculated using the plane stress theory approach for thin wall structures (Gere, 2017; Wei and Xu, 2022). Based on this theory, the geometry of the curve structure does not have a stress concentration point on the wrap so that it can produce better structural strength (Himmelbauer *et al.*, 2022).

Several previous studies have been carried out to obtain the mechanical properties of laminated composite materials as reinforcement for column concrete structures. Mahjoub *et al.* (2016) have investigated the application of kenaf fiber to inhibit the rate of deformation in column concrete. The results show that the application of kenaf fiber sheet restraint can inhibit the rate of deformation of the columnar concrete structure due to compressive loads (Mahjoub *et al.*, 2016). Wayadande and Pol. (2018) Yu *et al.* (2018) have separately investigated the application of Carbon fiber-reinforced polymer (CFRP) material to wrap cylindrical concrete under axial compression loads. The results show that the application of CFRP can effectively increase the strength and toughness of the column concrete (Wayadande and Pol, 2018; Yu *et al.*, 2018). Mohammed *et al.* (2019) have investigated the effectiveness of providing fiber-reinforced polymer (FRP) jackets on damaged concrete beam structures. The results showed that the application of an FRP jacket was able to increase the tensile strength of the concrete and the epoxy resin was able to distribute the load evenly (Mohammed *et al.*, 2019). Talikoti and Kandekar (2019) have investigated the application of aramid fiber sheets as a compressive cube concrete wrapper. The results show that the compressive strength of the concrete has increased by up to 140% and the weight of the concrete has decreased by up to 40% (Talikoti and Kandekar, 2019).

An experiment with random variables X will produce complex probability density function data (Ross, 2014). 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. 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 (Blitzstein and Hwang, 2015). Furthermore, the value of μ 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 (Montgomery and Runger, 2003). Thus, the random variable X can be considered representative of the sample if it is normally distributed (Devore, 2012).

In this study, the main focus of the research was to find out the effect of applying laminated jute fabric and hybrid laminate composite (HLC) jute e-glass wrap on increasing the compressive strength of CCC. Several layers of jute fabric covering the CCC will be tested for compressive strength. The same thing was done for the HLC. This study aims to obtain the compressive strength of CCC covered with jute fabric and its hybrids, check the data validation using the PMF method, and analyze the compressive strength to obtain its mechanical properties.

Materials and Methods

Sheets of 0.5×1 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. The physical and mechanical properties of jute materials are shown in Table 1. Concrete aggregates consist of cement, sand, and gravel. Cement was purchased from PT Cemindo Gemilang, Medan, Indonesia with the physical specifications shown in Table 2. 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 test specimens were made according to the ASTM C39 test standard with a diameter of 50 mm and a length of 150 mm (Committee, 2014). The shape of the specimen mold is shown in Figure 1.

In this study, the standard for concrete aggregate mixing is based on the recommendations of ACI 211.1-91, which is the Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. The selection of composition ratios is based on the experience of civil engineering engineers in the city of Medan, North Sumatra, Indonesia. The composition of the concrete aggregate consisting of cement, sand, and gravel is 1:2:3. The specimens were treated by immersing them in clean water for 28 days and drying them in open air for 28 days, following the guidelines of the American Concrete Institute standard ACI 308R-2016, titled "Guide to External Curing of Concrete (ACI Committee 308, 2016).

Table 1. Physical and mechanical properties of woven jute fibers (Martini *et al.*, 2023)

Mechanical & Physical Properties	Unit	Value
Length	mm	1800-3000
Diameter	mm	0.1-0.2
Density	kg/m ³	1500
Young's Modulus	GPa	32
Yield Strength	MPa	350
Strain	%	1.7

Table 2. Physical specification of cement material (Bye, 2011)

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



Figure 1. CCC specimen mold based on ASTM C39 standard

The jute fabric is varied in 3 layers, from 1 to 3 layers which are coded J1, J2, and J3. This sheet will be used to cover the CCC specimen. Each variation will be tested 3 times so that 3 specimens are prepared. As a control, 3 specimens of CCC without jute cloth were prepared to be tested as well. For HLC, testing was also carried out in 3 variations of jute and e-glass fabrics. The variation is GGJ, JGJ, and JJG. Code G for e-Glass sheet and J for Jute fabric. The rightmost arrangement of each variation is the first layer that directly covers the CCC specimen.

Research activities and compressive strength testing were carried out at the Laboratorium Penelitian Terpadu (LPT), Universitas Sumatra Utara, Medan, Indonesia using the Universal Testing Machine (UTM) type Hydraulic UTM model WEW-300D with a capacity of 300 kN. The UTM test equipment used is shown in Figure 2. The test is carried out on the specimen until it is damaged. Thus, the pattern of specimen damage due to compressive loads can be known and studied further.



Figure 2. Compressive strength test equipment type UTM WEW-300D

Concrete aggregate mixture is poured into specimen molds as shown in Figure 1. The mixture is left to dry for 3-5 days to reduce the moisture content, facilitating the demolding process. Subsequently, the specimens are immersed in clean water for 28 days to achieve optimal hydration. Afterward, the specimens are allowed to cure in open air for 28 days to attain optimum concrete strength. Furthermore, the concrete specimens are encased with a laminated composite material with variations of jute (J) layers ranging from 1 to 3 layers, and hybrid variations of GGJ, JGJ, and JJG,

where G represents e-glass fiber sheets. Compression testing is performed using a Hydraulic Universal Testing Machine (UTM) model WEW-300D with a capacity of 300 kN. The specimens are positioned with the axis parallel to the loading axis on the UTM machine. The loading rate is set at 1 mm/minute. Testing is conducted until the specimens experience failure.

The test data will be validated using the PMF method to check the condition of the data in a normally distributed state. The test results will be shown in the form of a normally distributed data (NDD) graph, where the data must be within the lower control limit (LCL) and upper control limit (UCL). The data that meets these requirements are within the range of $LCL < X < UCL$.

Analysis of the results of the compression test is to see trends in changes in the strength of the CCC structure due to the influence of applying a laminated composite wrap in the form of a curve structure, either with jute fabric or HLC. Furthermore, the results of this study will be compared with the results of previous studies to obtain the overall characteristics of the resulting material and other phenomena.

Results and Discussion

The data from the compression test of the CCC specimen reinforced with laminated composites from jute fabric and its hybrids are shown in Figure 3. The average strength value is shown in Figure 4. 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 5 and 6. 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 $\mu - \sigma < X < \mu + \sigma$. Thus, the data are spread close to the sample mean value and can be assumed to be representative of the sample.

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. Although the average strength value of J1 is smaller compared to S0, if we look at their averages, the strengths of these two variations are actually the same, both at 11 MPa. This is because, in one layer of jute fabric, each end of the fabric sheet only meets each other, resulting in no frictional force on the surface of the jute fabric that helps strengthen the concrete. Therefore, the strength is the same as without the reinforcement.

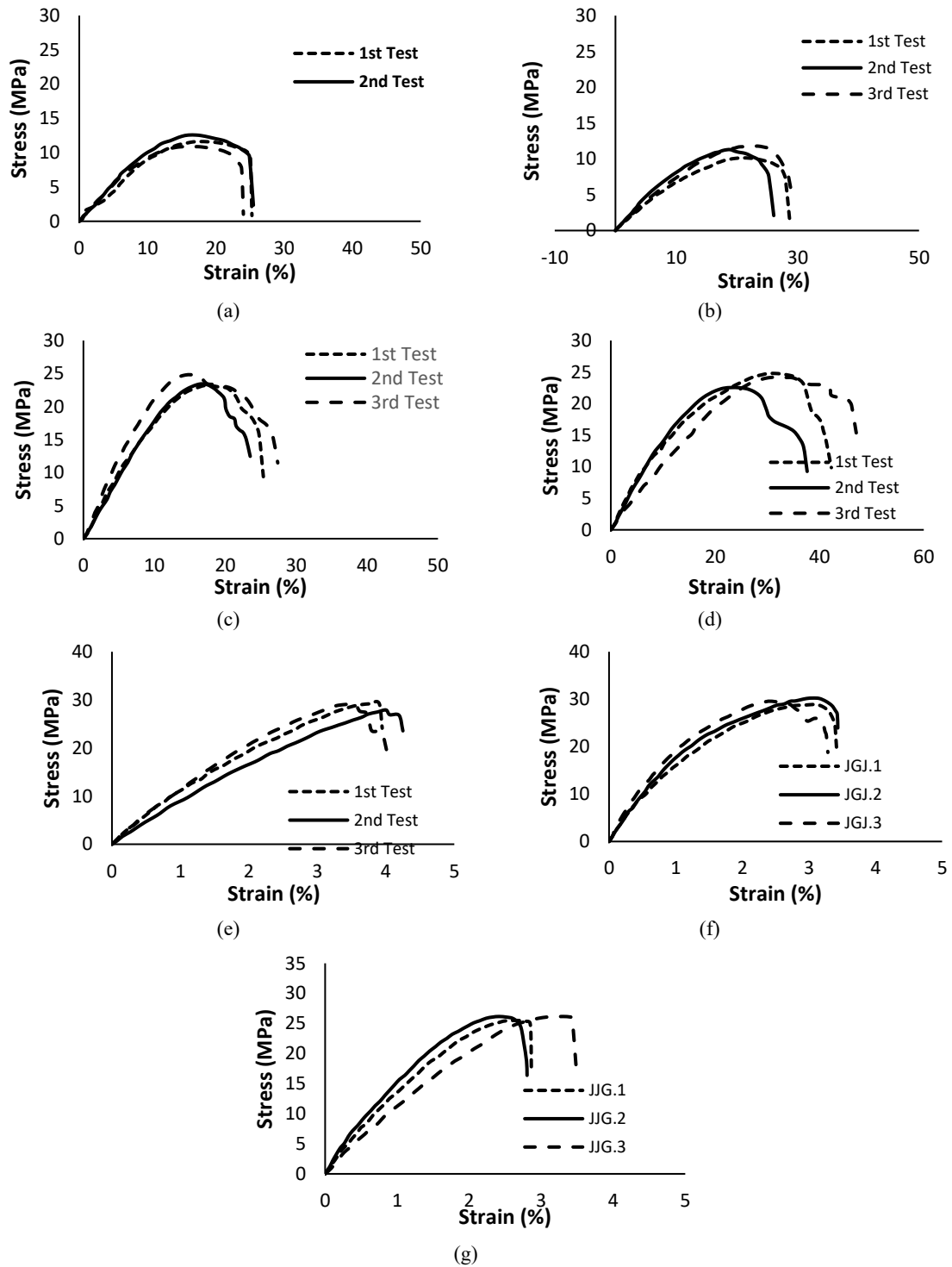


Figure 3. Graph of compression test results: (a) S0, (b) J1, (c) J2, (d) J3, (e) GGJ, (f) JGJ, and (g) JJG

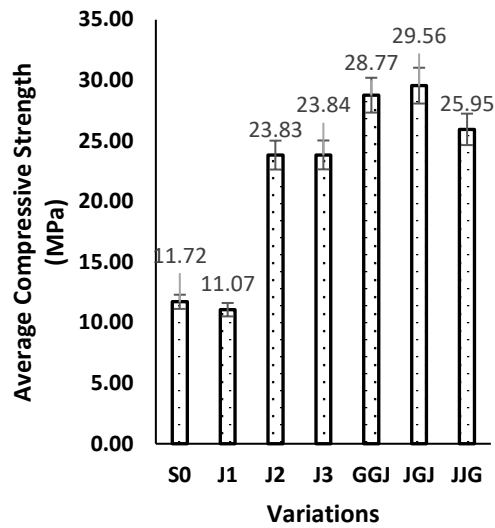


Figure 4. Average compressive strength of CCC specimens by wrap variation

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. This is due to the use of multiple layers of jute wrapping, where the surfaces of the jute sheets adhere to each other, thereby increasing the interfacial frictional force. Consequently, this frictional force enhances the strength and structural resilience of the concrete against external loads. The more surfaces of the jute sheets that adhere, the greater the interfacial frictional force becomes. These results support the results of a study that has been carried out by Talikoti and Kandekar (2019) and Wayadande and Pol (2018), where the application of a laminated composite wrap can increase CCC compressive strength by up to 140% (Wayadande and Pol, 2018; Talikoti and Kandekar, 2019).

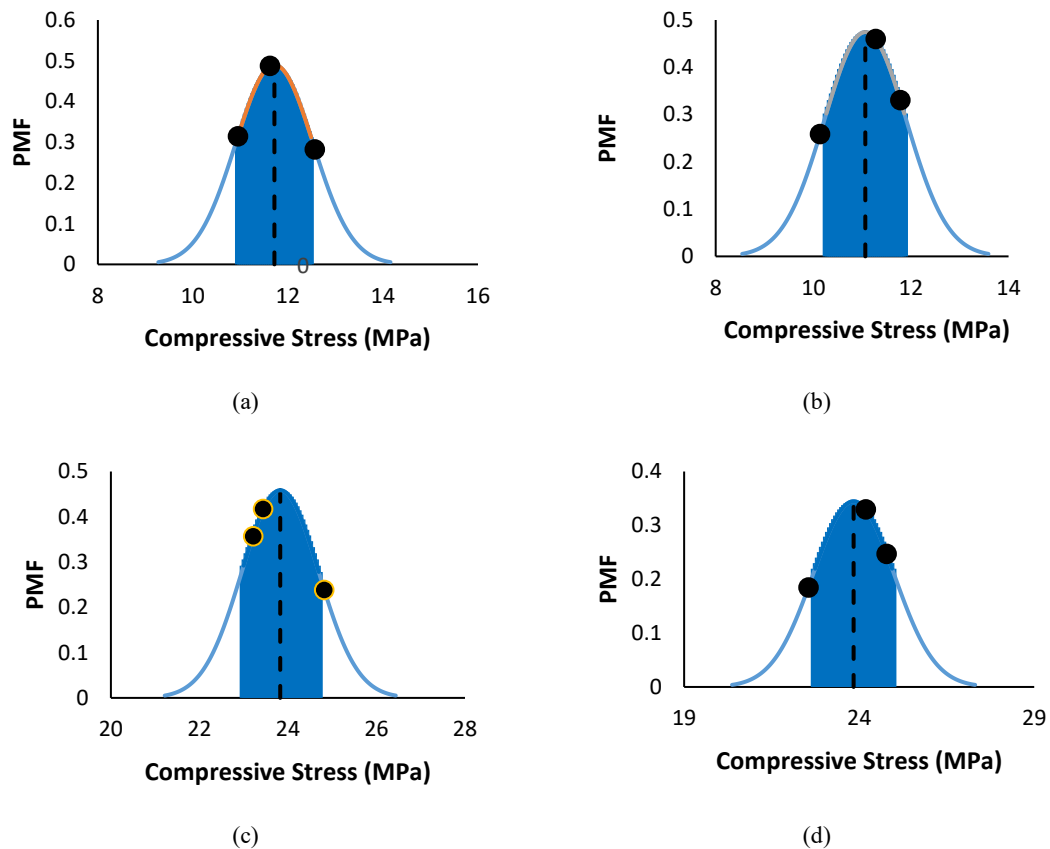


Figure 5. Graph of NDD on variations of: (a) S0, (b) J1, (c) J2, and (d) J3

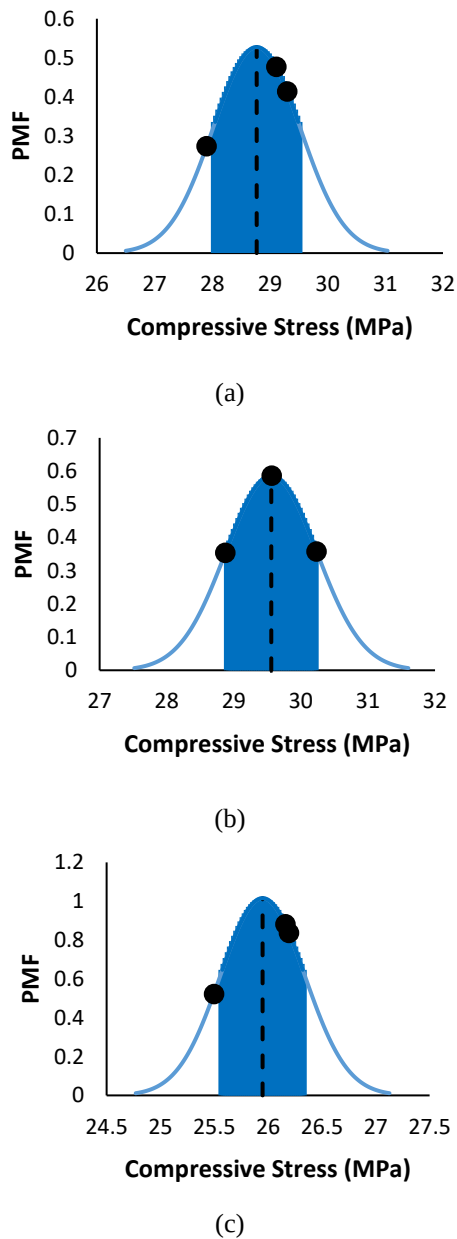


Figure 6. Graph of NDD on variations of (a) GGJ, (b) JGJ, and (c) JJG

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. These results support the study done by Khorramian and Sadeghian (2021). The results of this study indicate that the use of a hybrid system can increase the axial load capacity and increase the lateral stiffness of cylindrical concrete columns (Khorramian and Sadeghian, 2021). Furthermore, the results of this study also support the results of the investigation carried out by Aslam *et al.* (2020). The results showed that the hybrid system reinforcement significantly increased the axial compression behavior of damaged concrete columns (Aslam *et al.*, 2021).

The pattern of damage to the laminated jute and HLC composite wrap is shown in Figure 7. Based on the damage that occurs in 1 jute layer shown in Figure 6a, the jute fabric does not have a strong effect on CCC. It is visually evident that CCC damage occurs very easily and tears the casing at any location on the surface of the casing. Thus, the application of a jute fabric of as much as 1 layer was not effective in increasing the CCC strength. However, an increase in strength was seen in the number of jute fabrics of 2 and 3 layers. Based on visual observation of the pattern of damage in Figures 6b and c, the damage was concentrated in only one location. This shows that the strength of the jute fabric is fairly even on the CCC surface and the damage only occurs at one of the weakest locations. This pattern of damage was similar to the HLC-coated specimens as shown in Figures 6d, e, and f. In other words, the strength of the CCC can be increased even more by the application of an HLC coating and possibly by other materials.

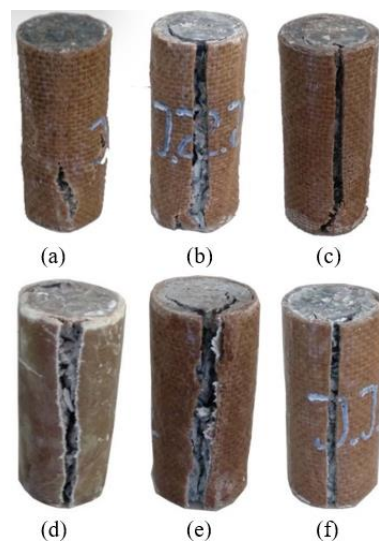


Figure 7. Damage to the surface of the jute layer in variations of (a) J1, (b) J2, (c) J3, (d) GGJ, (e) JGJ, and (f) JJG

The results of observations on the form of damage to the fiber using an optical microscope magnification up to 75 times are shown in Figure 8. The shape of fiber damage in the J1 variation is shown in Figure 8a. In this condition, the epoxy matrix is not able to bind the jute fiber properly so it is unable to withstand the external load given and is damaged first. Furthermore, the jute fiber provides a sufficiently large response to the load so that it appears to emerge from the embedded matrix. On the other hand, a fairly good bond between the epoxy matrix and jute fibers was seen in the J2 and J3 variations as shown in Figures 8b and c. The direction and shape of the fibers appear to be more regular and the fracture between the matrix and the fibers occurs in almost the same location. The matrix can distribute the load that is applied to all parts of the composite so that the fiber increases its strength. Thus, the strength of the laminated composite can increase the overall CCC strength.

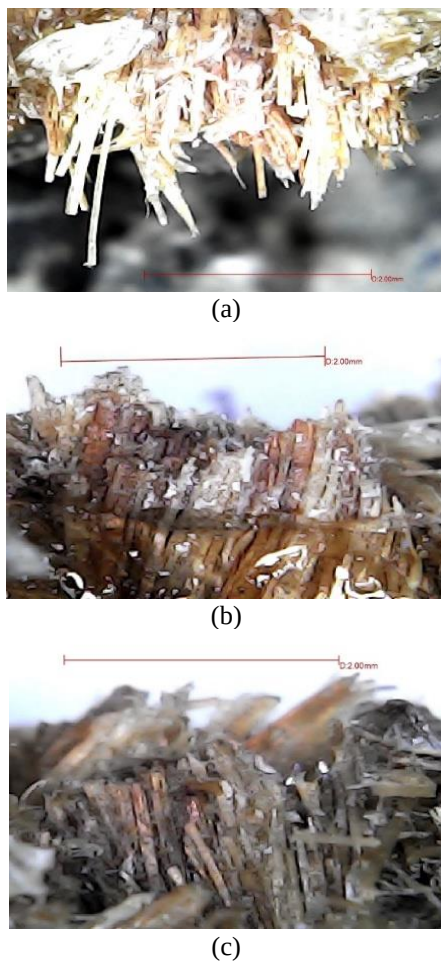


Figure 8. Optical observations at 75 times magnification of the composite structure at variations of (a) J1, (b) J2, and (c) J3

The results of the same observation on the shape of the fiber damage in the HLC specimen are shown in Figure 9. The shape of the fiber damage in the GGJ variation is shown in Figure 8a. In this condition, jute fiber gives a fairly 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 9b and c. In this condition, the fiber and matrix provide a fairly good response also 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.

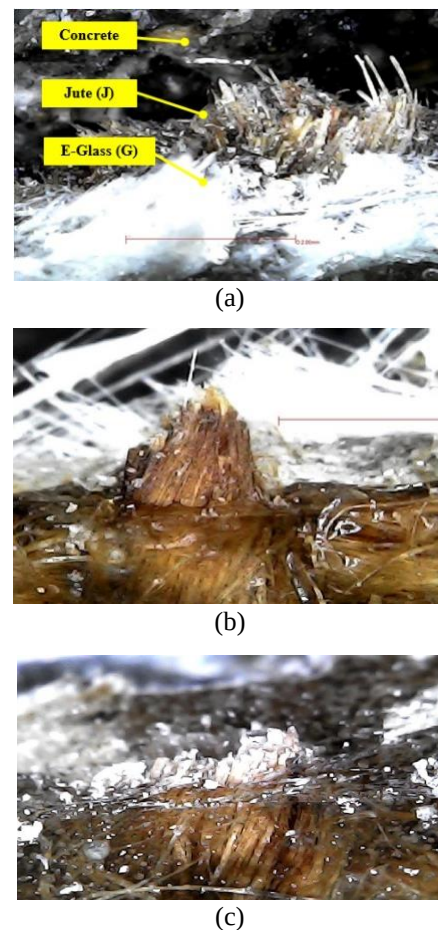


Figure 8. Optical observations of 75 times magnification of the jute fiber structure in HCL composites at variations of (a) GGJ, (b) JGJ, and (c) JJG

Conclusions

The average compressive strength of CCC specimens without wrap is 11.72 MPa. Furthermore, the average compressive strength of CCC specimens with variations of J1, J2, and J3 was 11.07 MPa, 23.83 MPa, and 23.84 MPa, respectively. Furthermore, the average compressive strength of CCC specimens with the application of HCL Jute E-glass on variations of GGJ, JGJ, and JJG was 28.77 MPa, 29.56 MPa, and 25.95 MPa, respectively. Based on the results of checking the validity of the test data using the PMF method, it was found that the data obtained were data in an NDD state. This is evidenced from the NDD graph that the data are close to the average value or within the range of $\mu - \sigma < X < \mu + \sigma$. Based on the results of the compressive strength test, the strength of the CCC specimen with the application of jute wrap increased by more than 100% in variations J2 and J3. However, the jute wrap only slightly increased the compressive strength in only one layer variation (J1). Furthermore, the application of HLC jute e-glass showed a significant increase in the compressive strength of CCC specimens, reaching up to 150%. Based on the pattern of damage, it can be seen that in variations J2 and J3 the wrap strength is quite evenly distributed to withstand the given load. The application of HLC jute e-glass with variations GGJ, JGJ, and JJG has a damage pattern similar to the jute fabric J2 and J3. Microscopically, the direction and shape of the fiber look more regular and the fracture between the matrix and the fiber occurs at almost the same location. This proves that the matrix can distribute the given load evenly throughout the fiber so that there is a significant increase in compressive strength.

Acknowledgement

The author would like to thank Fakulti Kejuruteraan Pembuatan (FKP), Universiti Teknikal Malaysia Melaka (UTeM) and Universitas Medan Area (UMA), Sumatera Utara, Indonesia who has supported this study.

References

- Abu Shaid Sujon, M., Habib, M.A., and Abedin, M.Z. (2020). Experimental investigation of the mechanical and water absorption properties on fiber stacking sequence and orientation of jute/carbon epoxy hybrid composites. *Journal of Materials Research and Technology*, 9(5): 10,970-10,981. Doi:https://doi.org/10.1016/j.jmrt.2020.07.079
- ACI Committee 308. (2016). ACI 308R-2016 Guide to external curing of concrete. In *Aci*, 108
- Ali, M., Ray, B., Rokeya, B., Aleya, M., and Ahmed, Z. (2019). Potential Healing Powers with Jute Plant- A Review. *International Journal of Sciences: Basic and Applied Research*, 48(5):10-23.
- Aslam, H.M.U., Khan, Q. uz Z., Sami, A., and Raza, A. (2021). Axial compressive behavior of damaged steel and GFRP bars reinforced concrete columns retrofitted with CFRP laminates. *Composite Structures*, 258(3):113206.
- Blitzstein, J.K., and Hwang, J. (2015). Introduction to Probability. CRC Press. *Journal of the American Statistical Association*, 92(439):1,226. Doi:https://doi.org/10.2307/2965608
- Bye, G. (2011). Portland Cement (3rd ed.). ICE Publishing. Doi:https://doi.org/10.1680/pc.36116
- Chethan, N., Nagesh, S.N., and Sunith Babu, L. (2019). Mechanical behaviour of Kenaf-Jute-E-glass reinforced hybrid polymer composites. *Materials Today: Proceedings*, 46(11), 4454-4459. Doi: https://doi.org/10.1016/j.matpr.2020.09.679
- Committee, A. (2014). ASTM C 39/C 39M - 01. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM International. Doi: https://doi.org/10.1520/C0039
- Devore, J. (2012). Probability and Statistics for Engineering and the Sciences (8th ed.). Brooks/Cole.
- Ganesan, K., Kailasanathan, C., Rajini, N., Ismail, S.O., Ayrlmis, N., Mohammad, F., Al-Lohedan, H.A., Tawfeek, A M., Issa, Z.A., and Aldhayan, D.M. (2021). Assessment on hybrid jute/coir fibers reinforced polyester composite with hybrid fillers under different environmental conditions. *Construction and Building Materials*, 301(July), 108-117. Doi: https://doi.org/10.1016/j.conbuildmat.2021.124117
- Gere, J.M. (2017). *Mechanics of Materials* (6th ed.). Thomson Learning, Inc.
- Gribniak, V., Sultani, H.A., Rimkus, A., Sokolov, A., and Torres, L. (2021). Standardised quantification of structural efficiency of hybrid reinforcement systems for developing concrete composites. *Composite Structures*, 274(1): 114357.
- Himmelbauer, F., Winter, G., Grün, F., and Kiesling, C. (2022). VHCF properties and assessment of specimens and thin-walled component-like structures made of high-strength steel X5CrNiCuNb16-4, *International Journal of Fatigue*, 156(1):106645.
- Huang, S., Yan, L., Bachtar, E.V., Gao, C., and Kasal, B. (2022). Bond behaviour between flax-glass hybrid fibre reinforced epoxy composite and laminated veneer lumber joints. *Journal of Building Engineering*, 50(1):104207.
- Islam, M.H., Islam, M.R., Dulal, M., Afroj, S., and Karim, N. (2022). The effect of surface treatments and graphene-based modifications on mechanical properties of natural jute fiber composites: A review. *IScience*, 25(1):103597.
- Joseph, L., Kumar, P.S., Jayanarayanan, K., and Mini, K.M. (2022). Strengthening of plain concrete cylinders with hybrid composites based on basalt and sisal fiber systems. *Materials Today: Proceedings*, 2,444-2,448.
- Kastratović, G., Grbović, A., Sedmak, A., Božić, Ž., and Sedmak, S. (2021). Composite material selection for aircraft structures based on experimental and numerical evaluation of mechanical properties. *Procedia Structural Integrity*, 31(1):127-133.
- Khorramian, K., and Sadeghian, P. (2021). Hybrid system of longitudinal CFRP laminates and GFRP wraps for strengthening of existing circular concrete columns. *Engineering Structures*, 235(2020):112028. Doi: https://doi.org/10.1016/j.engstruct.2021.112028
- Kilimtzidis, S., Kotzakolios, A., and Kostopoulos, V. (2023). Efficient structural optimisation of composite materials aircraft wings. *Composite Structures*, 303(1):116268.

- Kovler, K., and Chernov, V. (2009). Types of damage in concrete structures. In *Failure, distress and repair of concrete structures*. Woodhead Publishing Limited, 32-56. Doi: <https://doi.org/10.1533/9781845697037.1.32>
- Mahjoub, R., Yatim, J.M., A, M.S., Zulkarnain, N.A., and Raftari, M. (2016). The use of Kenaf fiber reinforced polymer to confine the concrete cylinder. 3(2015):459–463. Doi: <https://doi.org/10.1016/j.matpr.2016.01.130>
- Majumder, A., Stochino, F., Farina, I., Valdes, M., Fraternali, F., and Martinelli, E. (2022). Physical and mechanical characteristics of raw jute fibers, threads and diatoms. *Construction and Building Materials*, 326(1):126903.
- Martini, Fadiah, I., and Biru, B. (2023). Kajian Perilaku Kuat Geser Tanah Terhadap Penambahan Serat Karung Goni. *Civil Engineering Journal on Research and Development*, 4(1):9-16.
- Mohammed, A.A., Manalo, A.C., Maranan, G.B., Muttashar, M., Zhuge, Y., Vijay, P.V., and Pettigrew, J. (2019). Effectiveness of a novel composite jacket in repairing damaged reinforced concrete structures subject to flexural loads. *Composite Structures*, 111634. Doi: <https://doi.org/10.1016/j.compstruct.2019.111634>
- Montgomery, D.C., and Runger, G.C. (2011). *Applied Statistics and Probability for Engineers* (5th ed.) John Wiley & Sons Inc.
- Nagaraj, C., Mishra, D., and Reddy, J.D.P. (2020). Estimation of tensile properties of fabricated multi layered natural jute fiber reinforced e-glass composite material. *Materials Today: Proceedings*, 27(8):1,443-1,448. Doi: <https://doi.org/10.1016/j.matpr.2020.02.864>
- Ouarhim, W., Essabir, H., Bensalah, M. O., Rodrigue, D., Bouhfid, R., and Qaiss, A. el kacem. (2020). Hybrid composites and intra-ply hybrid composites based on jute and glass fibers: A comparative study on moisture absorption and mechanical properties. *Materials Today Communications*, 22(2019):48-57. Doi: <https://doi.org/10.1016/j.mtcomm.2019.100861>
- Ross, S.M. (2014). *Introduction to Probability Models*. In *Introduction to Probability Models* (11th ed.). Elsevier. Doi: <https://doi.org/10.1016/c2013-0-11417-1>
- Saleem, M.H., Ali, S., Rehman, M., Hasanuzzaman, M., Rizwan, M., Irshad, S., and Shafiq, F. (2020). Jute : A Potential Candidate for Phytoremediation of Metals - A Review. *Journal of Plants MDPI*, 9(258):1-14.
- Senthilrajan, S., Venkateshwaran, N., Naresh, K., Velmurugan, R., and Gupta, N.K. (2022). Effects of jute fiber length and weight percentage on quasi-static flexural and dynamic mechanical properties of jute/polyester composites for thin-walled structure applications. *Thin-Walled Structures*, 179(1):109719.
- Shekar, S., and Ramachandra, M. (2018). Green Composites : A Review. *Materials Today: Proceedings*, 5(1):2,518-2,526. Doi: <https://doi.org/10.1016/j.matpr.2017.11.034>
- Song, H., Liu, J., He, K., and Ahmad, W. (2021). A comprehensive overview of jute fiber reinforced cementitious composites. *Case Studies in Construction Materials*, 15(1):e00724.
- Talikoti, R.S., and Kandekar, S.B. (2019). Strength and Durability Study of Concrete Structures Using Aramid-Fiber-Reinforced Polymer. *Journal of Fibers MDPI*, 7(11): 1-11. Doi: <https://doi.org/10.3390/fib7020011>
- Townsend, T. (2020). World natural fibre production and employment. In *Handbook of Natural Fibres*. Elsevier Ltd. 15-36. Doi: <https://doi.org/10.1016/B978-0-12-818398-4.00002-5>
- Wang, D., Zhang, C., Zulfikar, A.J., Mehrez, S., Huynen, I., Mahariq, I., and Elbadawy, I. (2023). Tuning layer thickness and layer arrangement in a GdMnO₃ and GdMnO₃-MoSe₂ bi-layer absorber to cover the S , C , and X band frequency range. *Surfaces and Interfaces*, 36(2022):1-9. Doi: <https://doi.org/10.1016/j.surfin.2022.102507>
- Wayadande, U., and Pol, C.B. (2018). CFRP Application in Retrofitting of RCC Column. *International Research Journal of Engineering and Technology (IRJET)*, 5(6): 1,304-1,309.
- Wei, Z., and Xu, X. (2022). Numerical study on impact resistance of novel multilevel bionic thin-walled structures. *Journal of Materials Research and Technology*, 16(1):1,770-1,780.
- Ye, J. (2003). *Laminated Composite Plates and Shells*. In *Laminated Composite Plates and Shells*. <https://doi.org/10.1007/978-1-4471-0095-9>
- Yu, Q., Li, X., and Gu, X. (2018). Durability of concrete with CFRP wrapping. *MATEC Web Conferences*, 199, 1-5.
- Zimmermann, N., and Wang, P.H. (2020). A review of failure modes and fracture analysis of aircraft composite materials. *Engineering Failure Analysis*, 115(1):104692.