MECHANICAL PROPERTIES OF JUTE FABRIC LAMINATED FOR PIPE SHAPE STRUCTURE REINFORCED UNSURATED POLYESTER RESIN MATRIX COMPOSITES

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ABSTRACT: Natural fibre in composite material is one of the most researched areas today. An experimental investigation was conducted to explore mechanical properties of jute fabric laminated for pipe shape structure composite. In this study, the composite was made using jute fabric that acted as a reinforcement and polyester resin as its matrix. The jute pipe composite was fabricated using hand lay-up technique and followed by vacuum bagging technique. The jute pipe shape structure was fabricated with 1 ply fabric (S/N1) until 5 ply jute fabric (S/N5). The improvement of tensile strength was found at S/N3 and S/N4 with approximately 54.80 % increment compared to S/N1. Hence, improvement of the composite strength was noted when the fibers were gradually added into the composites and homogeneously distributed throughout the composites. However, the mechanical properties were lessened as the number of jute mat layers increased from 1 to five layers of jute fabric (S/N 5). The results of this study indicated that the mechanical properties of jute laminated pipe shape structure composite with four layer of jute mat (S/N 4) at 56.47% appeared as the most potentially improved properties compared to S/N 1. The findings may facilitate improvements in utilizing the natural fibre for structure materials.

KEYWORDS: *Jute Fabric; Pipe Structure; Mechanical Behaviour*

1.0 INTRODUCTION

Composite consists of two or more materials made from matrixes that are reinforced by fibres, combining high mechanical and physical performance of the fibres and matrix [1-2]. In recent years, there has been an increasing interest in composite products due to their performance; good strength, high corrosion resistance, lightweight, toughness and stiffness. Due to the advantages of composite materials, there have been a rapid development of composite in many applications such as automotive, sports, construction, marine, aerospace and other commercial products [2-3]. Meanwhile, fibre reinforced polymer is a multi-phase composite produced by combining polymer resins such as polyester, vinyl ester and epoxy, with fillers and reinforcing fibres to produce a bulk material with properties, better than those of the individual base materials. According to Aly [4], a major potential advantage claimed for fibrous composite materials in structural applications is that the material can be tailored by proper orientation of the fibres in various layers to optimize the desired properties.

Besides, the use of natural plant fibres as the reinforcement in fibre reinforced composites has become popular and widely used in the industry nowadays because of its beneficial properties in cost saving and minimized weight. In fact, according to the outstanding mechanical properties, natural fibres for composites such as jute, kenaf, flax, ramie and hemp are widely accepted in composite development. Recently, car manufacturers such as Mercedes Benz, Toyota and Daimler Chrysler have been interested in incorporating natural fibre composites into both interior and exterior parts of their cars [5-6].

Moreover, among these natural fibre, jute fibre has the potential to be used as a replacement for synthetic fibre reinforcement materials in composite for application which requires high strength to weight ratio, high corrosion and further weight reduction. Raval and Kansagra [7] analyzed the effects of jute fibre on fibre-reinforced concrete. They concluded that by adding jute fibres, the compressive strength and split tensile strength increases to 33 % and 10 % respectively due to the increase in fibre proportion. Hence, the water absorption increases which leads to increase in porosity thereby decreasing the strength characteristics. Bajpai et al. [8] utilized the jute fibre reinforced epoxy composite for industrial safety helmet. Five different composites were fabricated using hand lay-up technique. The results showed one layer of glass and three layers of jute fibre composite succeeded maximum flexural strength of 100.78 MPa. For impact strength, three layers of glass and one layer of jute fibre were able to reach higher impact strength of

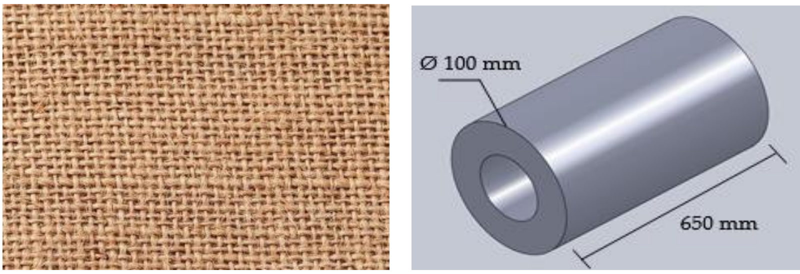
72.24 J/m. They suggested that three layers of glass and one layer of jute fibre can be used to replace the existing materials used to make industrial grade safety helmet. Sen and Paul [9] discovered an experimental study on the confinement strength and modulus parameters of fully confined concrete cylinders and 50 % confined concrete cylinders using natural fibre that are jute and sisal, and also the one using artificial fabric, that are carbon and glass fibre composites-wrapped concrete cylinders subjected to axial compressive load. The diameter of the cylinder was 103 mm and 200 mm in heights. They found that sisal FRP as well as jute FRP confined cylinders, have superior performance compared to unconfined cylinders. Sisal FRP-wrapped cylinders displayed ultimate axial load of comparable magnitude to CFRP confinement. However, if the confinement was partially done, sparse or inadequate, the axial load carrying capacity and ductility characteristics will degrade. Full wrapping displayed a higher axial load carrying capacity than partial wrapping configurations.

Although all off the above studies were related to jute fibre composite with various applications, no study particularly addresses the mechanical properties of jute pipe shape structure was found. Thus, the focus in this study was to investigate mechanical properties of jute pipe shape structure composite. The jute pipe shape structure was prepared using jute, resin, and mould. The testing samples were prepared according to ASTM standards. Then, the samples were tested for tensile and flexural property.

2.0 MATERIALS AND METHOD

In this study, Norsodyne 3110W brand polyester was used. It was supplied by CCP Composites Resins (M) Sdn. Bhd. The price of this unsaturated polyester was RM 20.00 per liter. For the material preparation, the resin was measured using a digital scale at 60 percent of total weight fraction of the composite, and then mixed by 1 percent of MEKP Catalyst or methyl ethyl ketone peroxide. The example of jute fibre is shown in Figure 1 (a) and was purchased from Feel Purple Services in Sungai Buloh Malaysia with an estimated price of RM 4.00 per square meter. The jute fibre was cut into 314 mm X 350 mm dimension for the first layer. Then, the cut dimension increased for the next layer as the outer diameter increased.

The size proposed for this research is shown in Figure 1 (b) with an inner diameter of 100 mm and a length pipe of 500 mm. Meanwhile, the thickness of the product depended on the number of layers used in the sample. The thickness for lamination was contributed by the number of jute fibre and polyester resin used in the process. In this case, the sample with five plies of jute fibre was expected as the thickest laminate and the sequences of jute ply as shown in Table 1.



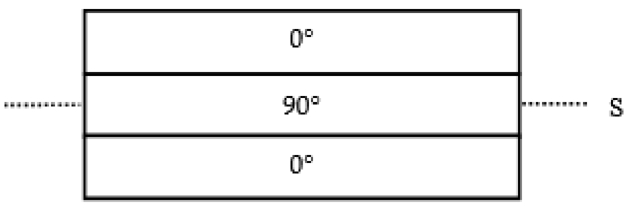
(a) (b)

Figure 1: Example of (a) jute fibre and pipe size (b)

Table 1: Design of composite pipe shape structure

Serial Number	Layers design
S/N1	Sample pipe with 1 ply of Jute
S/N2	Sample pipe with 2 ply of Jute
S/N3	Sample pipe with 3 ply of Jute
S/N4	Sample pipe with 4 ply of Jute
S/N5	Sample pipe with 5 ply of Jute

The orientation of layers used will significantly contributes to the properties of the composite. For this study, the orientation of 0°/90° of fibre was used. As the orientation changed, the properties of the composite would also change especially in mechanical properties. Therefore, it is proven that the orientation of laminate would significantly affect mechanical properties of the natural composite. Based on previous studies, the proposed laminate orientation used for this present study was [0/90] as shown in Figure 2.



Note: S is a plane of geometry, 00 is a jute orientation in zero degree and 900 is a jute orientation in ninety degree.

Figure 2: Laminate orientation code based on ASTM 6507 in S/N 3

Next, lay-up process was constructed according to laminate sequence shown in Figure 3, where the jute plies were lay-up with the polyester resin as the matrix and followed by the process of adding jute fibres one by one, until it reached the maximum layers of five. The vacuum bag was stacked onto the mould using the sealant tape to achieve the maximum air suction. Then, the product would be left to cure at ambient room temperature for 24 hours followed by a minimum of 16 hours at a temperature of 40˚C. The final sample of jute pipe structure is shown in Figure 4.

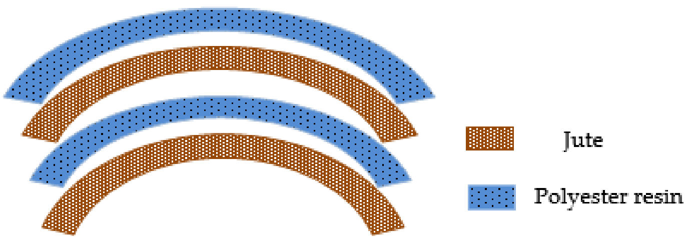


Figure 3: Example of laminate sequence in S/N 2

Figure 4: Jute pipe structure

3.0 RESULTS AND DISCUSSION

3.1 Tensile Test

As stated by Irawan et al. [10], the adhesion at interface between the resin and fibre and their mechanical properties can greatly affect the composite performance. Based on other research dealing with natural fibre, the fibres were often treated in order to obtain better adhesion between the fibre and the matrix [11-12]. However, in this case, the jute mat fibre was not treated as it stayed in its original form as it came straight from the supplier.

The result of each serial number was concluded in this section, and each of the serial numbers was discussed in details. The graph provides information on tensile modulus, tensile strength and maximum load obtained, hence identifying the ductile or brittle behavior of the samples.

Generally, the patent of the graph produced were similar for all the samples. The result of tensile from the graph signified an increasing manner up to S/N 4; however, the result of S/N 5 indicated a descending patent of tensile result. Hence, fibre content in the composite directly affected the product's strength. Based on Figure 5, the behavior of the tensile graph for each sample of jute pipe where the graphs illustrated the elastic deformation of the sample until point A where yielding process occurred due to first matrix crack or interface failure. After that, the samples continued to deform plastically until it reached its maximum load and catastrophically failed. After that point, the sample experienced post failure where brittle fracture, fibre pull out and delamination took place.

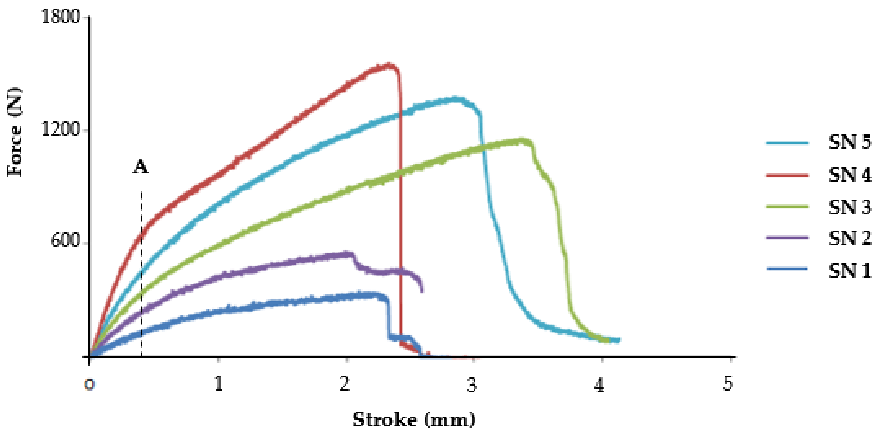


Figure 5: Tensile test graphs

Basically, the strength of a composite depended on the strength of the matrix and fibre. Once the matrix was fractured, all the loads would be transferred to the fibre and if the resulting stress in the matrix shot above the ultimate tensile strength of the matrix, the composite would fracture or the composite would continue to support the loads until it exceeded its ultimate tensile strength in Figure 5. The values of maximum force, tensile strength and tensile modulus for all the design in the composite were compiled in Table 2.

Table 2: Overall average result of tensile test

S/N	Average		
	Maximum Force, F_{max}(N)	**Tensile Strength, (MPa)**	**Tensile Modulus, E (GPa)**
1	393.75	18.86	0.82
2	598.45	18.41	1.00
3	1123.43	28.88	1.02
4	1486.98	29.51	1.05
5	1394.79	20.52	0.83

Apparently, as the number of fibre increased, the tensile strength of the composite would also increase as shown in Figure 6. However, in this tensile test, the tensile strength in S/N 5 with five jute mat indicated a descending trend. Similarly, the results also applied for tensile modulus and maximum force for each sample as illustrated in Figures 7 and 8, respectively.

This situation may be caused by the high content of jute fibre in the sample which tends to promote formation of micro voids during the fabrication process; hence leading to lower tensile modulus and tensile strength. In fact, this void could be the initiator of failure and also stress concentrator in the jute pipe resulted in lower tensile properties of jute pipe. The presence of voids in the composite might initiate the crack propagation along the interface of matrix-fibre, and then there would be a large amount of new crack created perpendicularly to the stress direction. Hence, if the fibres did not break at this moment, these cracks would bridge the gap on the interface to pull the fibre out of the matrix. Thus, the result of fibre pull out occurred.

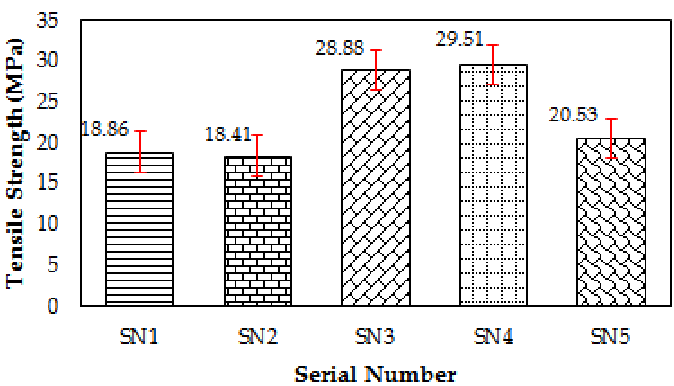


Figure 6: Graph of tensile strength

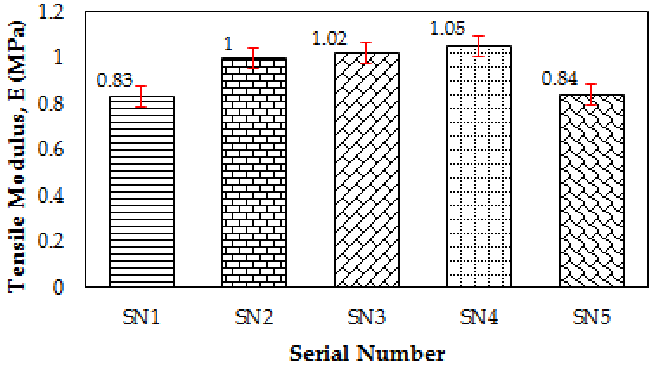


Figure 7: Graph of tensile modulus

The results of tensile were consistent with a study done by Lee et al. [13] that showed the tensile modulus and tensile strength increment were subjected to the increase of fibre loading which then lessened after it met the real fibre content. Therefore, it can be concluded that the fibre content increased up to its optimum and the result would give a repulsive effect to the tensile properties due to high volume of defects.

Most of the failures observed after the test was the brittle fractures shown in Figure 9 (a). These fracture either occurred at the gage section or tab intersection point. Basically, the fracture on the tab intersection was well restrained by the clamping blocks while failure in gage section resulted from excessive delamination as there was no through thickness restraint. Based on failure mode in ASTM D 3039, there were similar fracture trend with the samples shown in Figure 9 (b). Basically, the failure modes of the composite materials under tension loading are affected by fabrication defects such as voids, fibre waviness and poor resin wetting [14].

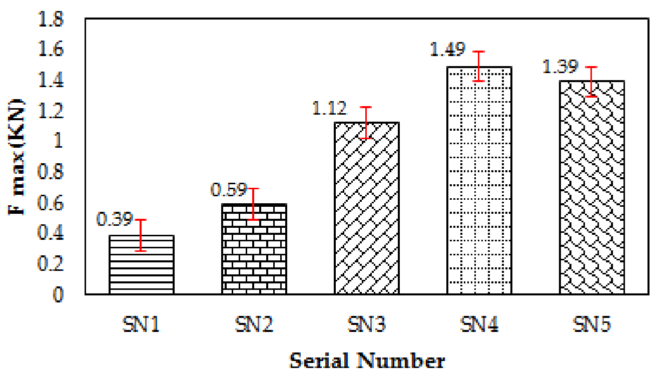


Figure 8: Graph of maximum force

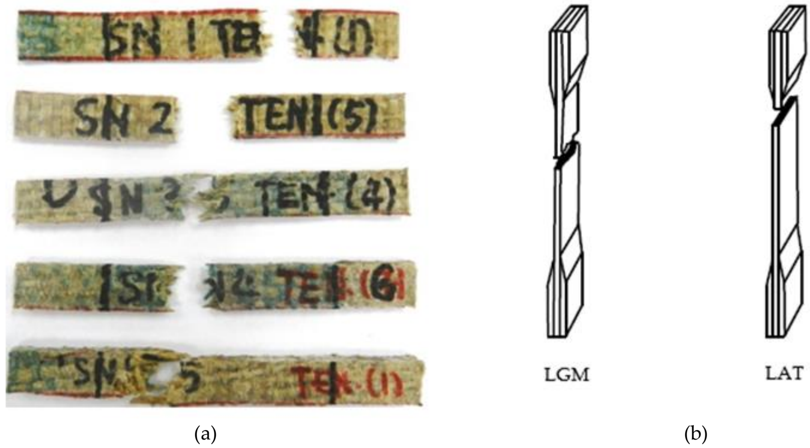


Figure 9: Figures of five samples after tested under tensile load; (a) consists of S/N1, S/N2, S/N 3, S/N 4 and S/N 5 and (b) Failure modes from ASTM D 3039 consist of Lateral-Gage-Middle and Lateral-At grip-Top failures

3.2 Flexural Test

Based on the graph in Figure 10, S/N 1 showed the lowest value of flexural strength before S/N 2. This situation was due to the poor rigidity of the sample as its small number of reinforcing materials. These samples tended to promote quick matrix crack or interface failure and failed at low stress level. Based on the graph from three point bending test on S/N 3 in Figure 10, the early deformation could be seen at the first matrix crack or occurrence of interface failure.

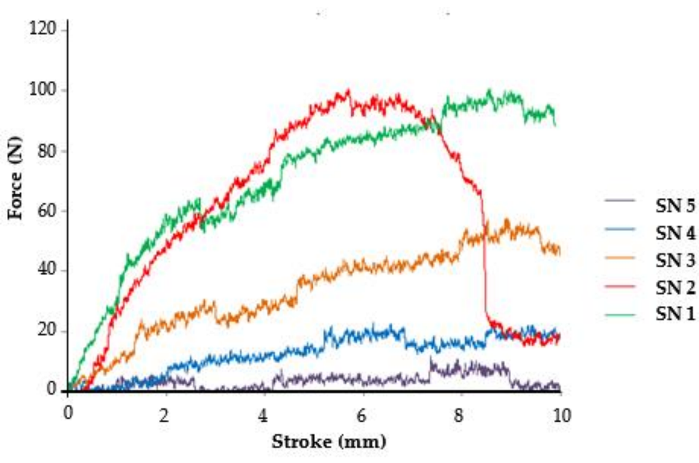


Figure 10: Flexural test graphs

The same phenomenon applied to S/N 4 with four layers of jute and S/N 5 with five layers of jute whereby the elastic deformation of the sample occurred at the beginning of the bending up, to the point it started to yield and deform plastically due to first matrix crack or interface failure until it reached the maximum point before it totally failed. After it reached the maximum stress, the sample would start to fail where at this point the wire mesh showed delamination, matrix crack and pull-out failure. Besides, when a ductile matrix was bonded to a brittle fibre, the fibres tended to snap ahead off the crack tip and left the matrix to deform in ductile manner. Thus, in this situation, the fibre would fail before the matrix due to the ductile behavior of the matrix material.

Table 3: Overall average result of flexural test

S/N	Average	
	Flexural Strain, εf (mm)	**Flexural Strength, σf (MPa)**
1	9.26±1.39	37.47±0.78
2	6.30±2.85	38.31±0.33
3	6.57±3.10	49.18±0.56
4	3.84±2.74	51.98±0.17
5	3.32±4.68	48.33±0.27

Meanwhile, the overall data is compiled into Table 3 to show the average of flexural strain and flexural strength (Figures 11 and 12). As being highlighted in Table 3, the average maximum force for each serial number for jute pipe increased as the number of jute mat increased. This phenomenon shows that as the fibre volume increased, the maximum load of the sample increased.

In terms of Figure 11, the flexural strength was based on proportional manner to the thickness of the jute pipe and the effect of fibre loading. As the number of jute mat layer increased, the flexural strength of the sample also increased. This case indicated that the flexural rigidity of the product increased as the thickness increased. However, flexural strength for S/N 5 reduced and appeared in contrary trend compared to other samples. In this situation, the reason of poor interaction of jute and the polyester matrix could be the factor contributing to poor flexural strength in S/N 5. Unlike the result in Figure 12 of flexural strain; the flexural strain of the jute pipe decreased as the number of jute mat increased. As the result, S/N 5 appeared to be the lowest flexural strain percentage amongst other samples and indicated the brittle behavior of the samples under bending force.

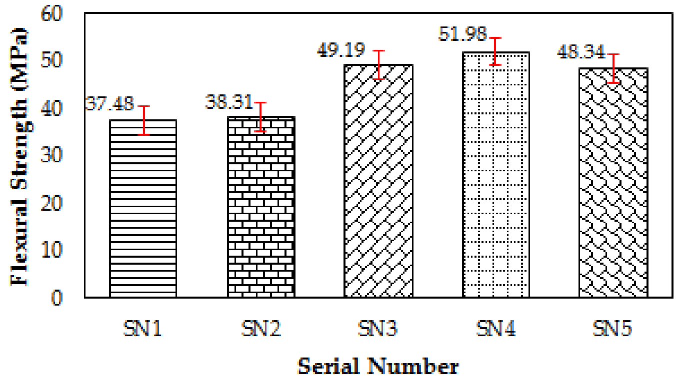


Figure 11: Graphs of flexural strength

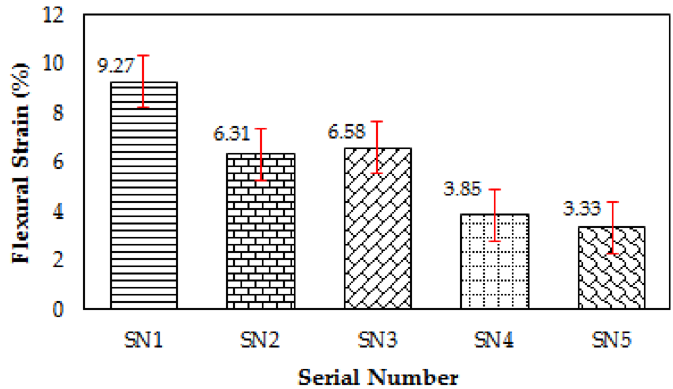


Figure 12: Graphs of flexural strain (%)

The flexural test samples are presented in Figure 13 which shows the bending behavior of each sample. As the number of the jute mat layer increased, the bending form at the samples became more visible. Flexural properties of the composites are essentially influenced by the adhesion between matrix and the fibres. At poor matrix-fibre adhesion of ligneous jute and polyester, the product may result in lower flexural strength as it tends to promote premature failure and also may lead to post failure like delamination, debonding and fibre pull out.

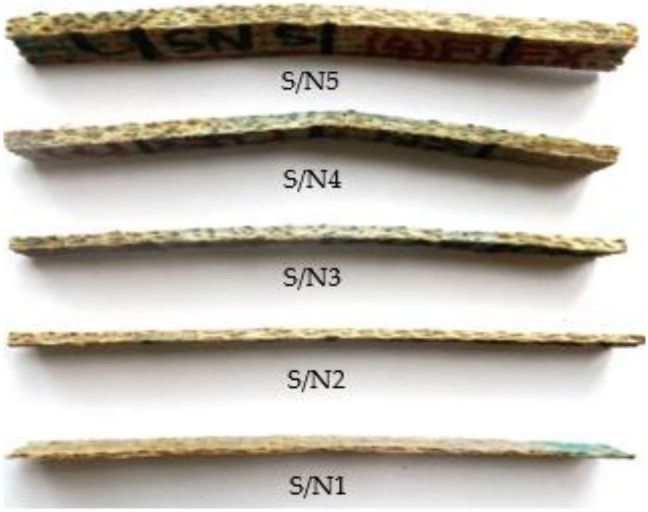


Figure 13: Five samples after tested under flexural load

4.0 CONCLUSION

The purpose of the current study is to determine the mechanical properties of jute pipe shape structure composites. This study has shown that the improvement of tensile strength is found at S/N3 and S/N4 with approximately 54.80% increased compared to S/N1. Thus, when fibers are gradually added into composites, the fibers will then be distributed homogeneously throughout the composites, thus improving the composite strength. As a result, the addition of fiber loading influences the value of tensile and flexural properties. However, as the number of jute mat layers increases to five layers of jute mat (SN 5), the mechanical properties are lessened. In this condition, the internal defects in jute laminated pipe are the main reason of the stress concentrator which can initiate crack propagation; hence decreasing the mechanical properties. Most of the results show an increment of mechanical properties up to S/N 4; however descending value is obtained at S/N 5. Therefore, the results of this study indicates that mechanical properties of jute laminated pipe shape structure composite with four layer of jute mat (S/N 4) is the most potentially improved at 56.47% compared to S/N 1. Further study might explore on the effect of hybrid jute pipe structure composite.

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