The tensile strength of mechanical joint prototype of lontar fiber composite

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Abstract. In the present study, an experimental activity has been programmed to investigate the effect of joint prototype configuration on tensile strength of lontar (Borassus Flabellifer) fiber composite. To do so, a series of tests were conducted to establish the tensile strength of different joint prototype configuration specimen of lontar fiber composite. In addition, post observation of macroscope was used to map damage behavior. The analysis of lontar fiber composite is a challenge since the material has limited information than others natural fiber composites materials. The results shown that, under static tensile loading, the tensile strength of 13 MPa produced by single lap joint of lontar fiber composite is highest compare to 11 MPa of tensile strength generated by step lap joint and double lap joint where produced the lowest tensile strength of 6 MPa. It is concluded that the differences of tensile strength depend on the geometric dimensions of the cross-sectional area and stress distribution of each joint prototype configuration.

1. Introduction
In a climate with increasing focus and need for environmentally sustainable material for automotive and aeronautics industry, also the economic impact of natural material and its benefits are recognized as a key driver for growth in the agricultural industry, especially for developing countries [1]. Researcher will be expected to wonder wheather mechanical company can do more to support automotive and aeronautic industry or other transportation industry in going green while also opening new market and sales channels for themselves. In this regard, there are six main issues that are driving the automotive and aeronautic industry to seek new materials are cost effectiveness, biodegradability and the capability of material.
Figure 1. Driving product development of composite material

From the point of view of materials engineering, natural fiber is considered one of the new era environmentally friendly materials which have good properties to replace the conventional synthetic fiber as a reinforcement of composite materials in all industries in coming centuries [2]. Natural fibers are used in various applications as explained by previous work [3]. Table 1 shows the comparison between natural and synthetic fibers.

| Aspect         | Property       | Natural Fibers | Synthetic Fibers |
|----------------|----------------|----------------|------------------|
| Technical      | Mechanical Properties | Moderate       | High             |
|                | Moisture Sensitivity | High           | Low              |
|                | Thermal Sensitivity  | High           | Low              |
| Environmental  | Resource        | Infinite       | Limited          |
|                | Production      | Low            | High             |
|                | Recyclability   | Good           | Moderate         |

Apart from their biodegradability, natural fiber are becoming increasingly popular due to their abundance in tropical country, low cost, and recyclable nature in the field of composites for automotive and aeronautic application. The benefits of using natural fiber composites increase result from the fact that they are made from a renewable and sustainable plant fiber source, they release no net carbon dioxide, are 40% lighter than fiberglass and have a better energy management characteristics than glass fiber in their respective composite structures. For example, it takes 3.1 MJ of energy to produce 1 kilogram of kenaf, whereas it takes almost four times the same energy (~12 MJ) to produce 1 kilogram of glass fiber [5].

Previous works [6-8] in the field of lontar fiber composite investigated on the characteristics of the physical properties of lontar fiber, lontar fiber composite mechanical strength and influence of chemical treatment. Generally, their results shown that the tensile strength of lontar fiber composite with NaOH treatment had greater tensile strength than obtained from non treatment specimens. Their works also concluded that 30 % of lontar fiber volume fraction resulting optimal tensile and bending strength compared with others volume fraction.

The presence of geometrical discontinuities like cutouts and holes are an important machining operations to facilitate the assembly of composite component such as joining of riveted and bolted joints because composites cannot be welded directly like metal materials to ascertain the structural integrity or connections of complex composite products. Mechanical connections remain the key means for the transfer of loads between structural elements made of composite materials [9]. Several
important factors such as structural and architectural requirements, technological process, nature of materials, application speed, environment advantages and disadvantages, as well as the total cost, need to be considered when the type of connection is chosen [10]. An experimental study of bolt-hole clearance effects in double-lap, multi bolt composite joints indicated that variable clearances in multi-bolt joints significantly influence the load distribution. At the higher loads the distribution tends to even out, but this process may be interrupted by failure [11].

A comparative study on different drill points geometries and feed rate for composite laminates drillings concluded that low feed rate seemed appropriate for laminate drilling and the most adequate tool for higher feed rates is the twist drill with a 120° point angle for minimal delamination [12]. Early results about the effect of hole fabrication and hole diameter on the tensile strength of lontar fiber composite have been generated as preliminary study of the author [13]. The results shown that tensile strength of moulded hole lontar fiber composite specimens is higher compared to the drilled hole specimens in all diameter and width (d/w) ratio. It has been noted that tensile strength of drilled hole specimen has been mostly affected by the presence of initial defect due to drilling operations.

On the other hand, the use of lontar fiber composite in structure design of mechanical joint is a challenging task since very limited work has been done on the application of lontar fiber composite for mechanical fastened joint design. Against this background, the research plan has been undertaken, with an objective to investigate the variation of joint prototype and its effect on mechanical properties of lontar fiber. The present work thus aims to understand the tensile behavior of lontar fiber composites on different type of mechanical joint prototype by experimental method. This study is part of a project at Universitas Nusa Cendana as a center study of archipelagic dryland field to invent a variety of potential natural fibers in East Nusa Tenggara - Indonesia as an reinforcement for biodegradable plastic matrix composite materials for transportation industry.

2. Methodology
The composite specimen that used in this study was reinforced by lontar fiber with 5 cm of fiber length. The composite produced by pressure molding process that contains 0.32 of nominal lontar fiber volume as the reinforcement and polyester was employed as the matrix throughout 4 mm of specimen thickness. The orientation of fiber random against each other. In order to investigate mechanical joint prototype tensile strength, three types of joint prototype were studied, i.e single lap joint, double lap joint and step lap joint as seen in Figure. 2. Test was carried out with a servo-hydraulic testing machine with a capacity of 100 kN. The machine was equipped with a standard load cell and mechanical grips. Specimens were aligned and mounted first in the lower and afterwards in the upper grips of the test station. After mounting the specimens, any loading due to the gripping was minimized through controller panel. A unit of dial indicator was used to record all the test results such as load and displacement. Then, the tests were considered to begin. Static tensile tests were performed under a constant cross-head speed of 1 mm/min.
Step Lap Joint

Double Lap Joint

Single Lap Joint

Lo : 250 mm   L : 150 mm   L₁ : 100 mm   T : 4 mm
D : 8 mm      d : 125 mm    W : 50 mm

Figure 2. Specimen Geometry
The test procedure was based on standard ASTM D5961 which consisting of five specimens of each test for respectively each type of joint configuration. Figure 3 shows the test set up and all type of specimens.

3. Results and Discussion
The tensile strength of mechanical joint prototype of lontar fiber composite was analyzed. Figure 4 shows the load versus global displacement curves in static condition for the test specimens.

Each specimen exhibits a typical of brittle behavior with suddenly failure where the highest ultimate tensile load of 2900 N resulting by single lap joint specimen which is 50 % greater than load value of step lap joint which is about 1500 N. Figure 5 shows the typical stress and strain behavior of joint prototype of long random lontar fiber composite under tensile load.
Figure 5. Stress vs strain of joint prototype of lontar fiber composite

The curve gives the relationship between stress and strain where stress is calculating from given load and strain obtained from global displacement. The stress - strain curve behavior shows the brittle behavior of composite material with the sudden failure of composite material under tensile loading in static condition. It was found that the highest stress of 13 MPa produced by step lap joint specimen and followed by single lap joint specimen where generated 11 MPa of tensile stress. Furthermore, the lowest tensile stress was produced by double lap joint specimen. At the beginning of the loading, a non linear behavior corresponding to the realignment of fibers and mechanical grips movement is observed. After this first phase, a linear behavior is obtained. From Figure. 5, the different slope can be observed on some part of curves during the second phase (shown by black arrow), could be associated to the changing of damage mechanism from matrix cracking into debonding and fiber breakage. This kind of behavior also explained by Arnautov et.al, 2015 in their study about carbon/epoxy composites joint.

Locally, the variation of the cross-sectional area of joint prototype produces the stress calculation and resulting local stress level between areas with different joint configuration. Joint prototype of Step lap joint has smaller cross-sectional area compare to other joint prototype configuration. Therefore, step lap joint generates the highest stress where indicate in Figure.5. This result is certainly different from Figure.4 due to the presence of cross-sectional area which is inversely proportional to the stress and load on strength calculation. The local strain of the specimen under the tensile load also entirely depends upon the thickness of the cross sectional area. The step lap joint specimen tends to show more strain compared to single and double lap joint specimen. It is quite evident that strain increases with decrease in thickness of cross-sectional area of specimen. In other words, the joint geometry affects the strength of mechanical joint prototype of lontar fiber composite.

The highest UTS of joint prototype of lontar fiber composite specimen is around 13 MPa resulting highest modulus measurement of 2.2 GPa as seen in Figure. 6.
The stiffness of single lap joint and step lap joint was found to be around 2 times higher compared to double lap joint. The likely reason for this is that the configuration of double lap joint contains cut off in the middle part then generates less effective stiffness of the bridging mechanism. Lower stiffer bridging generates lower ability to sustain the given load. Consequently, double lap joint produces lower tensile stiffness modulus compared to step and single lap joint. The macroscopic images of final failure of joint prototype can be seen in Figure. 7.

The damage of joint prototype of lontar fiber composite in tension is fairly transverse to the loading axis. The presence of the hole increases highest stress concentration that leads to strength degradation and initiate damage during the test. It was found that damage starts in form of cracking emanating due to matrix cracking around the hole and propagated along the width. The damage area propagated by the debonding of the fiber and the matrix at the interface located around the hole. After initial damage, the specimens continued to sustain the load under increasing displacements. When the critical point was reached, damage area reaches to the end of width side of the specimen and specimen
ultimately failed mainly due to the fiber breakage. It means that, at final stage of specimen failure, fibers no longer able to carry the increasing of given load and damage has occurred completely.

4. Conclusion
This study presents experimental results of different mechanical joint prototype configuration of long random lontar fiber composite under static tensile loading. The results show that the differences of joint prototype configuration of lontar fiber composite have an effect on its tensile strength. It was found that the highest stress of 13 MPa produced by step lap joint specimen and followed by single lap joint specimen where generated 11 MPa of tensile stress. Furthermore, the lowest tensile stress of 6 MPa was produced by double lap joint specimen. The differences in tensile strength and strain possibly originated by different thickness of cross sectional area at of each joint prototype. The double lap joint experiences the lowest tensile modulus of 1.2 GPa due to less effective stiffness of the bridging mechanism on tensile strength of lontar fiber composite. The tensile damage of lontar fiber specimen with different joint prototype configurations occurs in the form of matrix cracking and ultimately failed mainly due to the fiber breakage.

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References

[1] Anandjiwala R D 2006 The Role of Research and Development in Global Competitiveness of Natural Fiber Products (Natural Fiber Vision 2020) p 1
[2] Ramesh M, Palanikumar K and Hemachandra Reddy K 2017 Plant Fibre Based Bio-Composites: Sustainable and Renewable Green Materials. Renewable and Sustainable Energy Reviews 79 558
[3] Yousif B F, Shalwan A, Chin C W and Ming K C 2012 Flexural Properties of Treated and Untreated Kenaf/Epoxy Composites. Materials and Design 40 378
[4] Saravana Bavan D and Mohan Kumar D 2010 Potential Use of Natural Fiber Composite Materials in India. Journal of Reinforced Plastics and Composites 29 3600
[5] Khan M A, Hinrichsen G, Drzal L T 2001 Influence of Novel Coupling Agents on Mechanical Properties of Jute Reinforced Polypropylene Composite. Compos Interf 20 1711
[6] Boimau K 2009 Characterization of Tension Behavior and Surface Topograph of Lontar Fiber Alkali Treatment. Proceedings of the 8th Regional Conference on Annual Mechanical Engineering, Semarang, Indonesia
[7] Boimau K and Limbong I 2010 The Effect of Volume Fraction on Tensile Strength of Composite Polyester Reinforced by Lontar Fiber. Proceedings of Regional Conference on Environment Friendly in Sustainable, Malang, Indonesia
[8] Boimau K, Bale J, Lagan M, Limbong I 2011 The Effect of Volume Fraction of Bending Strength of Composite Polyester Reinforced by Lontar Fiber. Proceedings of the 11th Regional Conference on Annual Mechanical Engineering, Yogyakarta, Indonesia
[9] Arnautov A, Nasibullins A, Gribniak V, Blumbergs I and Hauka M 2015 Experimental Characterization of The Properties of Double-Lap Needled and Hybrid Joints of Carbon/Epoxy Composites. Materials 8 7578
[10] Sergiu P, Nicolae T, Paul C, and Dragos B 2012 Experimental Program Regarding The Behaviour of Composite Materials Joints. Buletinul Institutului Politehnic Din Iaşi Secţia Construcţii. Arhitectură, Publicat de Universitatea Tehnică , Gheorghe Asachi din Iaşi Tomul LVIII (LXII), Fasc 4
[11] Lawlor V P, McCarthy M A and Stanley W F 2005 An Experimental Study of Bolt-Hole Clearance Effects in Double-Lap, Multi-Bolt Composite Joints. Comp. Struct 71 176
[12] Durão L M P, Gonçalves D J S, Tavares J M R S, de Albuquerque V H C, Aguiar Vieira A and Torres Marques A 2010 Drilling Tool Geometry Evaluation for Reinforced Composite Laminates, *Comp. Struct* 92 1545

[13] Bale J, Boimau K and Tokoh R 2016 The Effect of Fabrication Process and Hole Diameter on Tensile Strength of Lontar Fiber Composite. *Sainstek Undana* 3 B-58