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Effect of Stitching on the Tensile Mechanical Property of Empty Fruit Bunch Oil Palm Fiber Reinforced Epoxy Composites

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Abstract. Stitching has proven to be an effective reinforcement for improving through-thickness (out-of-plane) mechanical properties with the incorporation of z-direction reinforcements of synthestic fiber. There are drawbacks to stitching as it may cause focal stress concentration, and fiber misalignment and breakage, but at the same time, it can also improve the tensile performance of the composite. Tensile properties, such as tensile strength and modulus of elasticity, were obtained from tensile tests performed on both stitched and unstitched oil palm fiber composites as per ASTM D638 specifications using Universal Testing Machine INSTRON 5582. The test results indicated that stitching natural, short, untreated and random empty fruit bunch oil palm fiber reinforced epoxy composites improve the tensile strength and elastic modulus due to the increase in matrix volume percentage and additional tensional resistance .

1. Introduction

The interest in synthetic fibers have moved on to natural fibers as environment is one of the key concerns. Natural fibers are not only environmentally friendly, but also offer potential improvement in reinforcing materials when compared to synthetic fibers. The advantages of natural fibers are mainly the low cost, low density, biodegradability, and better insulating and thermal resistance. Synthetic fibers are becoming unpopular due to it being non-renewable, non-degradable and expensive whereas natural fibers are becoming more accepted due to its properties of stiffness, flexibility, impact resistance and modulus of elasticity. Natural fiber reinforcements being used in the industry are the use of flax-sisal fiber mat reinforced epoxy matrix to produce door panels for Mercedes Benz E-Class, flax fiber reinforced polypropylene composite for rear shelf trim panels for the year 2000 model Chevrolet Impala, and natural fiber reinforced composites in structural applications such as ceiling and partition boards [1].

The performance of natural fiber reinforced composite depends on the composition properties of natural fiber and polymer synthetic matrix material. Mostly, the strength and stiffness of the structural load is carried by its fiber whereas the shape, surface and environmental resistance is carried out by its matrix. Thermoplastic and thermosets are the two type of dominating matrix materials that offer various potential in natural fiber reinforced composite applications. Epoxy resin as matrix material is suitable for natural fiber reinforced composite due to its good adhesion capability, good heat and chemical resistance, exemplified electrical insulator properties and superior mechanical performance [2]. Vacuum bagging techniques for fabricating natural fiber reinforced composite provide good physical and mechanical performance compared to wet lay-up process due to its process control, improve equipment and cost effective method [3]. It has been reported that tensile strength for oil palm fiber-epoxy resin decreases from 47.78 MPa to 46.10 MPa with increasing value of oil palm fiber content from 35% to 55% respectively [4]. Another study on the mechanical properties of 10% oil palm fiber content composite with epoxy resin polymer matrix for a 7m T-Beam configuration is reported to be able to support 200kg of load with a maximum deflection of 0.2mm, thus suggesting the potential usage of oil palm fiber-epoxy resin composite for intermediate load bearing bridge application [5].

Weaving, braiding, knitting and stitching have become major methods of 3D fiber structure to improve the performance of fiber reinforced composites. The driving factors of 3D fiber structural development to undergo such technological improvement are the demand in reducing fabrication cost, increasing through thickness mechanical properties of laminate composites, and improving the impact resistance of fiber reinforced composites. This technological innovation have undergone major transformation within the aircraft, marine and automotive industry since the urge of weight-reduction factor upon manufacturing better physical as well as mechanical properties of composite structural components [6]. Despite having various advantages of weight reduction factor and cost effective fabrication factor, the primary drawback of fiber reinforced composites as structural components are the poor through thickness mechanical properties or poor interlaminar strength. The stitched fiber reinforced composite was initially investigated in the 1980s by the aircraft industry for an improvement towards through thickness mechanical properties, and it was found to have advantageous improved properties which are the cost effective method for joining stacked plies compared to other 3D fiber structure material [7].

Stitched fiber reinforced composite as an advanced fiber reinforced composite structure offer various advantages such as improved through-thickness mechanical properties, reduction of damage area and enhanced energy absorption capability despite adding extra steps in its composite fabrication process. On the other hand, the major drawbacks and limitations exerted for stitched fiber reinforced composites are the localized damage of in-plane fiber resulting from needle penetration of the prepreg layers of fibers which then cause lower flexural strength of stitched composites compared to unstitched composites. Material discontinuity can also occur at the stitching point where it can lead to high stress concentration during load bearing condition thus reducing the performance of the composite mechanical properties. In addition, one of the major drawbacks of stitched or other through thickness reinforcing methods is the detrition of the in-plane properties such as compressive or tensile properties. Apparently, these significant drops are due to the misalignment of fiber distribution which creates resin rich pockets surrounding the stitch point. These resin rich pockets reduce fiber content percentage becoming a high stress concentration point thus reducing in-plane mechanical properties [8] [9].

2. Material and Method

2.1 Material

Untreated oil palm empty fruit bunch fiber is obtained from Malaysia Palm Oil Board in Bangi, Selangor, Malaysia. Zeepoxy HL002 TA/B epoxy resin, epoxy hardener, vacuum bagging consumables and materials was supplied by Sky Tech Enterprise. Nylon thread of linear density of 210 denier-15 ply was supplied by HLF FISHING SUPPLIES Sdn. Bhd.

2.2 Stitch Preparation of Oil Palm Composites
Tangled and intermixed oil palm empty fruit bunch fiber was carded and combed using an electrical motor carding machine to produce untangled and organized fiber layer. Individual layers of dry palm fibers are stitched manually with 210 denier 15 ply thread (0.0158 mm^2 cross sectional area, 4.395 MPa tensile strength, and 43.603 MPa tensile modulus) using modified lock stitch method with 10 mm stitching length or pitch as shown in Figure 1.a. The stitches are straight rows and evenly spaced as shown in Figure 1.b. For the fabrication of stitched empty fruit bunch oil palm fiber composite, a 400 mm x 400 mm bottom stainless steel plate and 300 mm x 300 mm upper stainless steel plate, and four 200 mm x 5 mm flexible resin stopper were used as a mold. A layer of mylar sheet was placed on each side of the plate as a releasing agent. Epoxy resin and epoxy hardener were mixed thoroughly according to its specific fiber-matrix volume fraction ratio. A layer of stitched empty fruit bunch oil palm fiber is stacked accordingly on the bottom plate. The stirred epoxy resin and hardener were impregnated through the layer of stitched fibers. Vacuum bagging materials were then placed on top of the wet fibers and covered by the upper plate mold. Vacuum bagging film enclosed the lay-up to provide a confined space which is sealed around the edges of the mold by using sealant tape. The vacuum pump draws out the air inside the confined space to produce airtight vacuum bag until curing process is complete.

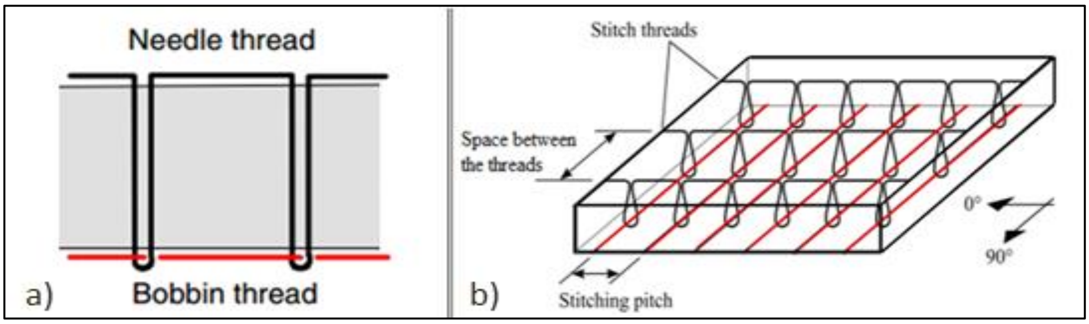

Figure 1. a) Modified lock stitch method and b) Schematic view of stitching.

2.3 Tensile Characterization of Composites
Tensile test specimen was prepared according to the standard size and specification of ASTM D 638 [10] using CNC milling. Tensile strength and modulus of elasticity for stitched and unstitched empty fruit bunch epoxy composite were tested by using INSTRON 5582 Ultimate Testing Machine, quarter bridge BX 120-3AA strain gauges and D4 Data Acquisition conditioner. This measurement was conducted according to ASTM D 638 procedures at a test speed of 5mm/min. Five specimens were tested for each case and its average value is tabulated accordingly.

3. Results and discussion
Measurement of load and strain data were made simultaneously during tensile testing process. Tensile strength is calculated by dividing the maximum load by the average cross-sectional gauge length area of the specimen. Modulus of elasticity is calculated by extending the initial linear portion of stress-strain curve then by dividing the difference in stress corresponding to the section on this straight line by the corresponding difference in strain value. Cross-plot graphs of stress and strain data of plain epoxy and EFB palm fiber composite specimen from tensile testing are plotted on Figure 1. Results of tensile tests of stitched and unstitched empty fruit bunch fiber reinforced composite at 20% fiber volume are shown in Table 1.

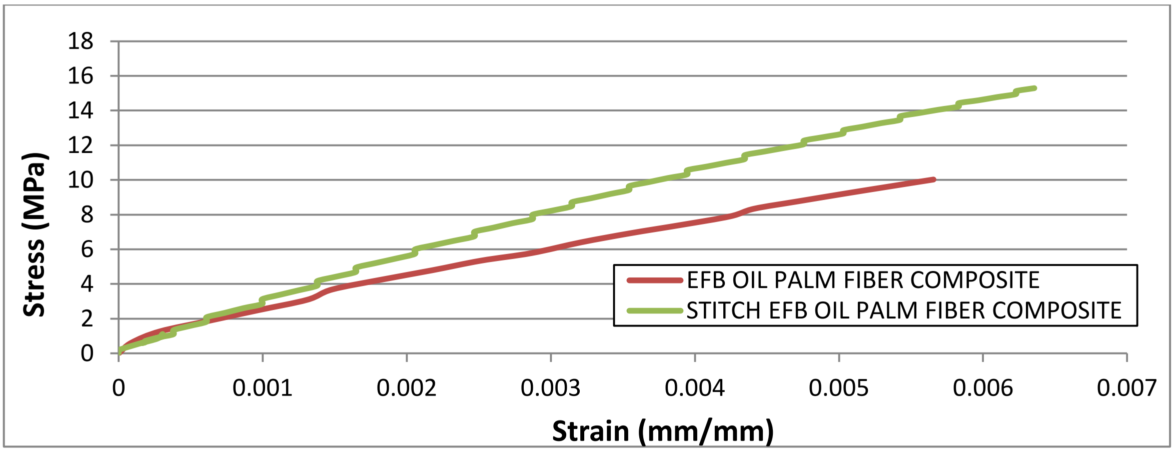

Figure 2. Tensile Stress vs Strain Curve.

Table 1. Tensile test results.

Composites	Tensile Strength (MPa)	Tensile Modulus (MPa)
Unstitched EFB Composite	10.064	1712.13
Stitched EFB Composite	16.717	2504.18

Based on Table 1, both tensile strength and tensile modulus of elasticity for the stitched composite correspond to a greater tensile performance when compared to the unstitched composite; i.e. 16.717 MPa and 2504.18 MPa respectively. Most reported studies have concluded that in-plane strength for stitched composite will induce a degradational performance due to decremental laminate integrity caused by undulation or resin pockets created around the stitches, as well as fiber misalignment, fiber crimping and fiber breakage during stitching process. Only one study reported an inconsistent result, in which both tensile strength and tensile modulus of elasticity for stitched composite have better performance compared to unstitched composite, and for this study it was believed that fiber breakage after stitching was neglected since the stitching process was done on dry preform fiber layers [11].

Importantly, empty fruit bunch fiber in this study was considered as short and randomly oriented fiber. The axial load applied to the composite structure is not exerted directly on the fiber material, but first, applied to the matrix material and later transferred to the fiber throughout the fibers end and cylindrical surface. This condition induces the fact that for short and randomly oriented fiber composites, the load carrying capability and capacity is mainly being carried out by the matrix, which is completely different to the load carrying capability of synthetic or conventional long and unidirectional fiber composites. Stitching introduces extra resin rich pockets surrounding the thread which increases the percentage value of resin to fiber material volume which then reduces the tensile performance under axial or in-plane load.

However, with natural, short and randomly oriented fiber composite, the load carrying capability mainly falls upon the matrix, thus by introducing Z-direction stitches, it increases the resin rich pockets surrounding the thread areas which will then increase the matrix volume percentage. The connected, continuous and axially aligned stitched thread will also serve as an additional tension resistance for axial load. Combining both factors of increased volume percentage of matrix material and extra tensional resistance from continuous axially aligned thread, the tensile performance, i.e., tensile strength and modulus of elasticity of stitched palm fiber composite was improved by 40% and 32% when compared to unstitched composite. It has been reported in one study that the slight increment of stitched composite tensile strength is due to the increased fiber volume fraction from the additional stitching thread. The benefit from increased fiber volume fraction have compensated the drawback factor of a fiber breakage and stress concentration at resin pocket around stitches [12].

4. Conclusion

The tensile performance of z-directional stitching for empty fruit bunch oil palm reinforced epoxy composite is evaluated to accommodate an improvement to conventional natural fiber reinforced composite. There are drawbacks with the incorporation of stitches for tensile performance due to focal stress concentration, fiber misalignment and fiber breakage. However, introducing through thickness reinforcement into preform natural fiber by stitching provides a possibility of improving the tensile performance of natural fiber reinforced matrix composites. In this study the tensile properties of stitched empty fruit bunch oil palm reinforced epoxy composite have shown better performance in both tensile strength and tensile modulus compared to unstitched empty fruit bunch oil palm fiber reinforced composite. This clearly indicates that by introducing stitches in through thickness direction of natural, short, untreated and randomly oriented empty fruit bunch oil palm fiber reinforced epoxy composite improves the tensile strength and modulus of elasticity due to the increased matrix volume percentage and additional tensional resistance from the stitched thread. Although stitched empty fruit bunch oil palm fiber as a means of reinforcement has corresponded to a weak tensile performance when compared to inorganic synthetic fiber composites, it is believed that empty fruit bunch oil palm fiber reinforced composite thrives in impact strength due to its high fracture toughness [13].

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References

[1] John M J and Thomas S Biofibres and biocomposites 2008 *Carbohydrate Polymers* **71** 343-364
[2] Shinoj S, Visvanathan R, Panigrahi S and Kochubabu M Oil palm fiber (OPF) and its composites: a review 2011 *Industrial Crops and Products* **33** 7-22
[3] *SP Systems Guide to Composites*.
[4] Kalam A, Sahari B B, Khalid Y A and Wong S V Fatigue behaviour of oil palm fruit bunch fibre/epoxy and carbon fibre/epoxy composites 2005 *Composite Structures* **71** 34-44
[5] Bakar M, Natarajan V, Kalam A and Kudiran N Mechanical properties of oil palm fibre reinforced epoxy for building short span bridge 2007 *Experimental Analysis of Nano and Engineering Materials and Structures* 97-98
[6] Vacuum Infusion Processing (VIP), RTM Light (LRTM, Resin Infusion, VARTM, SCRIMP) [Online]. Available: http://www.moldedfiberglass.com/processes/vacuum-infusion-molding
[7] L. Tong, A. P. Mouritz, and M. Bannister, 3D fibre reinforced polymer composites: Elsevier, 2002. L. Tong, A. P. Mouritz, and M. Bannister, 3D fibre reinforced polymer composites: Elsevier, 2002.
[8] Mouritz A P, Leong K H and Herszberg I A review of the effect of stitching on the in-plane mechanical properties of fibre-reinforced polymer composites 1997 *Composites Part A: Applied Science and Manufacturing* **28** 979-991
[9] Dransfield K, Baillie C and Mai Y-W Improving the delamination resistance of CFRP by stitching—a review 1994 *Composites Science and Technology* **50** 305-317
[10] International A Standard test method for tensile properties of plastics 2014 *ASTM D638-14*
[11] Kang T J and Lee S H Effect of stitching on the mechanical and impact properties of woven laminate composite 1994 *Journal Composite Material* **28** 1574-1587
[12] Mouritz A P Fracture and tensile fatigue properties of stitched fiberglass composites 2004 *Journal of Material: Design and Application* **218** 87-93

[13] Jawaid M, Abdul Khalil H P S and Abu Bakar A Mechanical performance of oil palm empty fruit bunches/jute fibres reinforced epoxy hybrid composites 2010 *Materials Science and Engineering: A* **527** 7944-7949