EFFECT OF THREAD MATERIAL AND STITCH ORIENTATION ON TENSILE MECHANICAL PROPERTY OF STITCHED OIL PALM EMPTY FRUIT BUNCH FIBER REINFORCED EPOXY COMPOSITES

Ahmad Luqman b. Ahmad Ghazilan
Department of Mechanical, Faculty of Engineering,
International Islamic University Malaysia,
Jalan Gombak, 53100, Kuala Lumpur, Malaysia
Email: ahmadluqman141@gmail.com, Tel: 018- 216 0141

Hanan Mokhtar
Department of Mechanical, Faculty of Engineering,
International Islamic University Malaysia,
Jalan Gombak, 53100, Kuala Lumpur, Malaysia
Email: hananm@iium.edu.my, Tel: 019- 216 6127

Mohd Sultan Ibrahim Shaik Dawood
Department of Mechanical, Faculty of Engineering,
International Islamic University Malaysia,
Jalan Gombak, 53100, Kuala Lumpur, Malaysia
Email: sultan@iium.edu.my, Tel: 012- 252 4502

ABSTRACT

Short random fibers do not have the desired mechanical performance as continuous fibers, but this weakness may be overcome by applying methods that make up for their deficiency. Stitching is one of the methods that have been proven to be an effective reinforcement for through-thickness (out-of-plane) mechanical properties by incorporating z-direction reinforcements of synthetic fiber. There are not many studies on stitch thread effect on the mechanical performance of bio composites, thus the effect of thread material and stitch row orientations on the tensile strength and modulus of elasticity are investigated. Tensile tests were performed in accordance to ASTM D 638 specifications using Universal Testing Machine INSTRON 5582. The data indicates that incorporating thread material of Nylon 210D improves the tensile performance due to the additional load bearing capability and better surface interfacial adhesion on the outer ply of stitched thread with epoxy resin. The results also indicate that by incorporating parallel stitch row orientation, the oil palm empty fruit bunch fiber reinforced epoxy composite's tensile performance improves due to the increase in fiber volumetric content for load bearing conditions from additional stitched threads. Therefore, it was found that the material thread and stitch row orientation affect the tensile performance, and that using Nylon 210D and parallel stitch row orientation optimizes the tensile performance of stitched palm oil empty fruit bunch fiber reinforced epoxy composites.

Keywords: Stitched empty fruit bunch composite, vacuum bagging, threads material, stitch orientation, tensile properties

Introduction

Through a remarkable development locally and globally, natural fibers are becoming a preferred choice due to its advantageous properties such as low cost, low density, biodegradability, and better insulating and thermal resistance. Natural fibers are being used in several applications, such as the use of flax-sisal fiber mat reinforced epoxy matrix in the door panels of Mercedes Benz E-Class, flax fiber reinforced polypropylene composites for rear shelf trim panels of the year 2000 model Chevrolet Impala, and natural fiber reinforced composites in structural applications such as ceiling and partition boards (John & Thomas, 2008). The performances of natural fiber reinforced composites depend on the composition of natural fiber and polymer synthetic matrix material (Jawaid, Abdul Khalil, Hassan, Dungani, & Hadiyane, 2013). The strength and stiffness of the composite is determined by the fiber whereas the shape, surface and environmental resistance are dependent on the matrix. Thermoplastic and thermosets are the two types of dominating matrix material that offer various potential in natural fiber reinforced composite applications. Epoxy resin is suitably coupled with natural fiber due to its good adhesion capability, good heat and chemical resistance, exemplified electrical insulating properties and superior mechanical performance (Shinoj, Visvanathan, Panigrahi, & Kochubabu, 2011). Vacuum bagging technique was chosen to provide good physical and mechanical performance as compared to the wet lay-up process due to its process control, improve equipment and cost effective method (SPSystems).

Previous studies reported that the tensile strength of oil palm fiber-epoxy resin decrease from 47.78 MPa to 46.10 MPa with an increase in oil palm fiber from 35% to 55% respectively (Kalam, Sahari, Khalid, & Wong, 2005). Another study on oil palm fiber epoxy composite showed the capability of the composite to support a 200kg load with a maximum deflection of 0.2 mm, thus presenting the potential usage of oil palm fiber-epoxy resin composite for intermediate load bearing bridge applications (Bakar, Natarajan, Kalam, & Kudiran, 2007). An increase in natural fibers in composites show a deterioration in its tensile strength, thus methods such as weaving, braiding, knitting, and stitching have been explored to improve the performance of fiber reinforced composites (Vallons, Adolphs, Lucas, Lomov, & Verpoest, 2014) (Koziol, 2013). The driving factors of 3D fiber structure development in undergoing technological improvement are the demand of reducing fabrication cost, increasing through thickness mechanical properties of laminate composites and improving the impact resistance of a fiber reinforced composites. These technological innovation have caused a great impact within the aircraft, marine and automotive industry since weight-reduction became a major factor in composite structural components ("Vacuum Infusion Processing (VIP), RTM Light (LRTM, Resin Infusion, VARTM, SCRIMP) "). Despite the advantage of weight reduction and cost effective fabrication, the main drawback is the poor through thickness mechanical property or poor inter laminar strength which led to the initial investigation of the stitching method in the 1980s by the aircraft industry and was found to have advantageous improved properties i.e. the cost effective method for joining stacked plies compared to other 3D fiber structure material (Tong, Mouritz, & Bannister, 2002).

Stitching not only improves through-the-thickness mechanical properties but also reduces damage area and enhances its energy absorption capability despite adding extra production steps in fabrication. With stitching, there is localized damage of in-plane fiber resulting from the needle penetration of layers of fibers thus causing lower flexural strength of stitched composites as compared to unstitched composites. Material discontinuity can also occur at the stitching point where it can lead to high stress concentration during load bearing conditions thus reducing performance of the composite mechanical properties (Tan, Yoshimura, Watanabe, Iwahori, & Ishikawa, 2013). Another major drawback of stitching is the detrimental factor of the in-plane properties such as compressive or tensile properties which show significant drops in performance due to the misalignment of fiber distribution which create resin rich pockets surrounding the stitch point (Ravandi, Teo, Tran, Yong, & Tay, 2016). These resin rich pockets reduce fiber content percentage and become high stress concentration points thus reducing in-plane mechanical properties (Yudhanto et al., 2015) (Mouritz, Leong, & Herszberg, 1997) (Dransfield, Baillie, & Mai, 1994). Empty fruit bunch oil palm fiber in the category of natural fiber polymeric reinforced composite generally will correspond to great benefits such as, environmental advantages in terms of economical production from biodegradable waste and also low specific weight that correspond to high specific strength and stiffness. They have a lower mechanical strength when compared to inorganic synthetic composite fiber during loading applications and are considered as inadequate, or limited, in handling loading conditions. Therefore, it is essential to enhance the mechanical performance of natural fiber composite. This paper aims to investigate and analyze the effect of stitching on tensile strength of an EFB oil palm fiber reinforced epoxy composite by using vacuum bagging fabrication technique. The effects of different thread material and stitch orientation on tensile strength were investigated. Tensile properties were studied and analyzed using Universal Testing Machine INSTRON 5582. The assessment of this research would expand the current knowledge and thus will be expected to recognize specific design, fabrication and pattern of stitched palm fiber composite which will offer a dependent solution on the usage of bio waste from local oil palm industry towards better innovation and development.

Material And Method

Untreated oil palm empty fruit bunch fiber obtained from Malaysia Palm Oil Board in Selangor, Malaysia. Zeepoxy HL002 TA/B epoxy resin, epoxy hardener, vacuum bagging consumables and materials supplied by Sky Tech Enterprise. Nylon thread of linear density 210 denier-15 ply and Polyester thread of 380 denier-15 ply supplied by HLF FISHING SUPPLIES Sdn. Bhd.

Tangled and intermixed oil palm empty fruit bunch fiber was carded and combed by using an electrical motor carding machine to produce untangled and organized fiber layer. Individual layers of dry palm fibers are stitched manually with Nylon 210 denier-15 ply by using a modified lock stitch method with 10 mm stitching length or pitch as shown in Figure 1: a. The stitches were done in straight rows and evenly spaced as shown in Figure 1: b. Stitch pattern variation is varied with 0^0,45^0, and 90^0 stitching angle. A sample of stitch pattern variation is shown in Figure 2. Fabrication process of stitch EFB oil palm fiber composite will undergo certain steps which are started by mixing both epoxy resin and hardener according to specific fiber-matrix volume fraction ratio. Then it will impregnate thoroughly of stitch fibers layers. Wet fiber layers will be stacked in between upper and bottom stainless steel mold plate. Lastly, vacuum bagging film and vacuum pump will enclose and draw out the air within the lay-up to provide airtight confine space during curing phase of the stitch EFB composites.

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

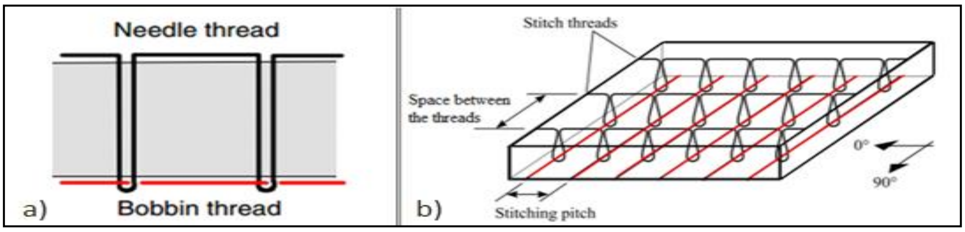
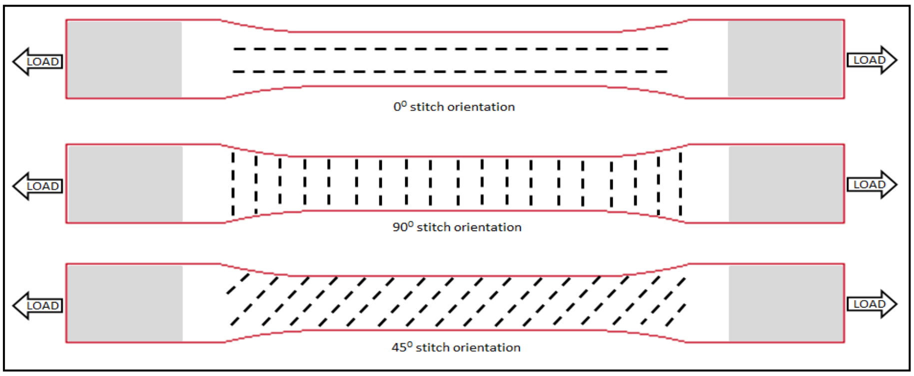


Figure 2: Stitch orientation variation sample specimen



Tensile Characterization Of Composites

Thread characterization

Tensile mechanical characterization of different stitch thread material and thickness were conducted as per ASTM D 2256 (International, 2015) specifications using Universal Testing Machine Shimadzu AGS-X 5kN. Specimen of single strand thread material was tested with 260 mm gage length at 300 mm/min test speed. Five specimens were tested for each case and averaged accordingly.

Composite tensile characterization

The tensile test specimen were prepared according to the standard size and specification of ASTM D 638 (International, 2014) by CNC milling. Tensile strength and modulus of elasticity for EFB fiber reinforced epoxy composite as well as for stitched EFB fiber reinforced epoxy composite were tested using INSTRON 5582 Universal testing machine, quarter bridge BX 120-3AA strain gages 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 averaged accordingly.

Results And Discussion

Stitch threads characterization and tensile properties

The results of stitch thread characterization and tensile properties for different thread material are shown in Table 1. Tensile strength and modulus of elasticity from a single strand tensile test of Nylon 210D thread correspond to 4.395 MPa and 43.603 MPa respectively, while the results show a value of 2.710 MPa and 20.885 MPa for Polyester 380D thread. This clarifies that Nylon 210D has a higher tensile strength and modulus of elasticity when compared to Polyester 380D.

Table 1: Characterization of Stitch Thread

Thread material	Thread Tensile Strength (MPa)	Thread Tensile Modulus (MPa)
Nylon 210D/15ply	4.395	43.603
Polyester 380D/15ply	2.710	20.885

EFB composite tensile properties

The measurement of load and strain data were made simultaneously during tensile testing. Tensile strength is calculated by dividing maximum load by the average cross-sectional gage length area of the specimen. Modulus of elasticity is calculated by extending the initial linear portion of stress-strain curve by dividing the difference in stress corresponding to the section on the straight line by the corresponding difference in strain value. Graphs of stress versus strain of EFB palm fiber composite and stitched EFB palm fiber composite specimen from tensile testing for thread material and stitch orientation variation were plotted as in Figure 3 and Figure 4 respectively. Results of tensile properties testing of unstitched EFB and stitched EFB fiber reinforced epoxy composite at 20% fiber by volume under different thread material and stitch pattern parameters are shown in Table 2 and Table 3 respectively.

Figure 3: Tensile Stress vs Strain Curves of Stitch Thread Material Variation

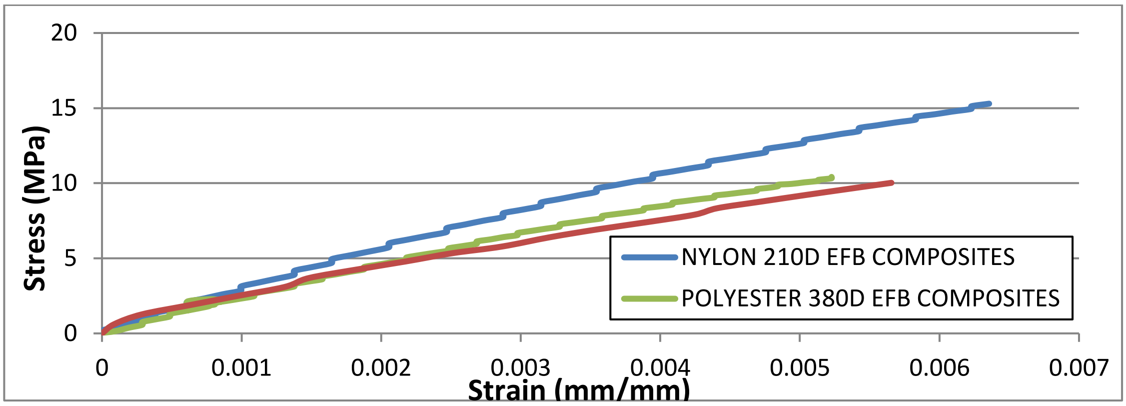


Table 2: Tensile Properties of Stitch EFB Composites under Different Thread Material

Composites	Tensile Strength (MPa)	Tensile Modulus (GPa)
EFB Composite	10.064	1712.13
Nylon 210D/15ply	16.717	2504.18
Polyester 380D/15ply	9.161	1915.10

Table 2 shows that both tensile strength and tensile modulus of elasticity for Nylon 210D/15ply stitched EFB fiber reinforced epoxy composite have greater tensile performance when compared to Polyester 380D stitched and unstitched EFB fiber reinforced epoxy composites. Tensile strength of Nylon 210D stitched EFB composite is 66.1% higher than unstitched EFB composite but Polyester 380D stitched EFB composite is 8.9% lower than the unstitched composite. On the other hand, the modulus of elasticity of both Nylon and Polyester stitched thread EFB composites exhibit better performance when compared to unstitched EFB composites, showing an increment of 31.6% and 11.8% respectively. However, most studies conclude that in-plane strength for stitched composite will induce a degradation in performance due to the decrement laminate integrity caused by resin pockets created around the stitches, fiber misalignment, fiber crimping and fiber breakage during the stitching process. Only one study reported an inconsistent result to the other cases, 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 (Kang & lee, 1994).

Composite crack damage such as delamination and fiber-matrix surface de-bonding occur during tensile loading applications. Incorporating z-direction stitching into this composite structure will suppress these cracks or delamination progress. Moreover, from extra tensional resistance and additional fiber volume fractions of stitch thread in parallel to load direction have compensated the loss from the drawback effect of stitching process or might have increased the tensile strength performance of this stitched composite. The next sets of experiments investigate the effect of stitched thread material on tensile strength and modulus of elasticity for stitched composite. Thread tensile properties of both Nylon 210D and Polyester 380D are shown in Table 1, which show the trend of higher tensile strength and modulus of elasticity for Nylon 210D when compared to Polyester 380D. Table 2 shows that when Polyester is replaced with Nylon, an improved performance in tensile strength and modulus of elasticity of 45% and 23.5% can be observed respectively. Generally, stitching in thickness direction will create resin rich pockets surrounding the stitched thread material. It is believed that Nylon 210D offer better surface interfacial adhesion on the outer ply of stitched thread with matrix resin. Greater tensional properties from thread material correspond to better tensional resistance that is able to compensate the reduction of strength due to stress concentration at rich resin regional areas. Furthermore, the growth of crack propagation during failure progress will be arrested at the nearest stitched threads by carrying most of the load from the crack tip, thus reducing the stress intensity surrounding the matrix phase (Bibo & Hogg, 1996). Hence, better tensile properties of stitched thread material induce a better ability to uphold this bridging effect during failure progress.

Figure 4: Tensile Stress vs Strain Curves of Stitch Orientation Variation

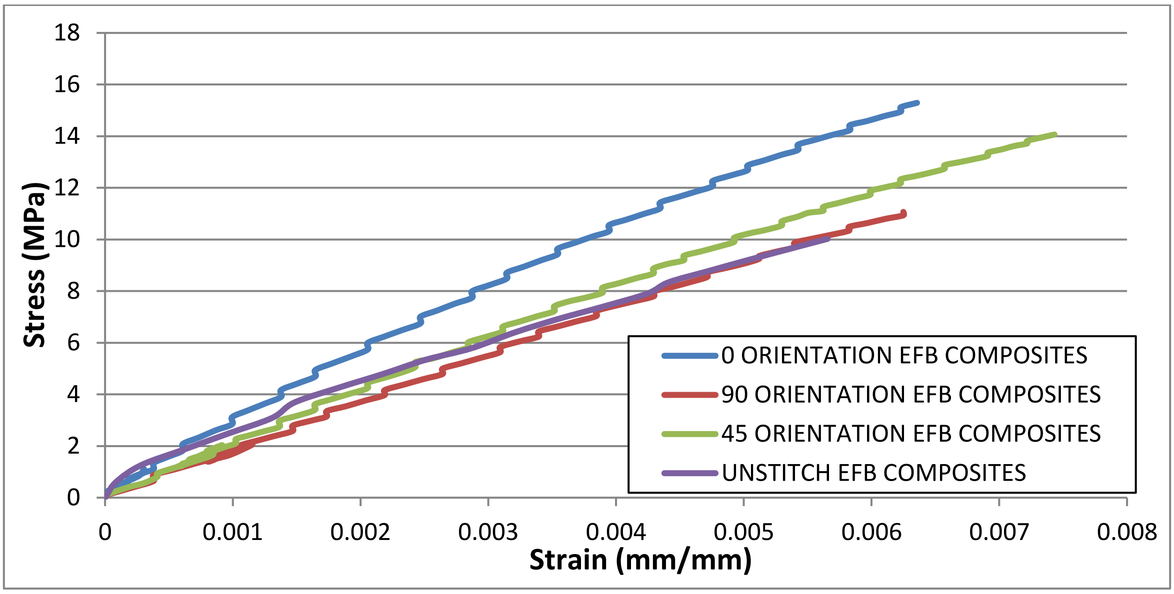


Table 3: Tensile Properties of Stitch EFB Composites under Different Stitch Orientation

Composites	Tensile Strength (MPa)	Tensile Modulus (GPa)
EFB Composite	10.064	1712.13
0^0 Orientation	16.717	2504.18
45^0 Orientation	14.694	1965.55
90^0 Orientation	11.978	1785.42

In Table 3, all tensile strength and tensile modulus of elasticity for three different stitch orientation of Nylon 210D/15ply EFB fiber reinforced epoxy composite correspond to a greater tensile performance when compared to unstitched EFB fiber reinforced epoxy composite. Tensile strength of 45^0 stitch orientation EFB composite is 12.1% smaller than the 0^0 stitch orientation EFB composite, whereas the tensile strength of 90^0 stitch orientation EFB composite is 28.3% smaller than the 0^0 stitch orientation EFB composite. Modulus of elasticity of both 45^0 and 90^0 stitch orientation EFB composite also exhibit a reduced performance when compared to 0^0 stitch orientation EFB composites which decrease by 21.5% and 28.7% respectively. The performance clearly shows that stitched rows aligned parallel to load direction of an EFB composite brings out the best performance of tensile properties when compared to other stitching patterns.

Figure 2 shows the stitching row orientation on EFB reinforced epoxy composite tensile specimens and Table 3 shows the effect of stitch pattern on tensile mechanical performance. As demonstrated, the properties of both strength and modulus of elastitcy of stitch row orientation that is parallel to the load direction is superior when compared to diagonal and transverse row stitch orientation EFB composites. Stitching introduces resin rich pockets and voids that lead to poor fiber-matrix surface adhesion and greater local stress intensity. As such, 0^0 stitch orientation row direction, fiber volumetric content and fraction for load bearing condition increases with additional stitching threads, thus slightly improving the strength. In contradiction to previous investigations, when incorporating 90^0 orientation, voids or resin rich regional areas may be created without any additional fiber volumetric content, thus, the load bearing capability will ultimately be held upon matrix and fiber-matrix surface adhesion capability alone (Zhao, Rödel, Herzberg, Gao, & Krzywinski, 2009). This finding can be supported with the investigation of diagonally oriented stitch row direction that shows the performance of strength and modulus falling in between the parallel and transverse stitch row direction. Similar results of better tensile, compressive, flexural and impact strength for 0^0 orientation in comparison to 90^0 orientation stitch row direction stitch composites (Mouritz et al., 1997).

Conclusion

The tensile performance of z-directional stitching for empty fruit bunch oil palm fiber reinforced composite was evaluated to accommodate an improvement in conventional natural fiber reinforced composite. Several sets of investigations were carried out to determine the effect of stitch thread material and stitch row direction on the tensile performance of EFB reinforced composites. There are drawbacks to the incorporation of stitches for tensile performance due to focal stress concentration, fiber misalignment and breakage. However, by introducing through thickness reinforcement into preform natural fiber, there is a possibility of improving the tensile performance of natural fiber reinforced matrix composites. In this study, the tensile properties of Nylon 210D as the thread material for stitched EFB oil palm reinforced composite show better performance as compared to Polyester 380D stitched and unstitched EFB oil palm fiber reinforced composite. This study also concludes that tensile properties of parallel oriented stitch row direction for stitched EFB oil palm reinforced composite correspond to the best performance in comparison to diagonal, transverse oriented stitch row direction and unstitched EFB oil palm fiber reinforced composite. In fact, additional load bearing capability of a thread material, better interfacial surface adhesion capability of a thread material and increase in fiber volumetric fraction of stitching process induce better ability to suppress fiber-matrix surface of delamination crack during failure progress. This clearly indicates that by introducing stitches in through thickness direction of natural, short, untreated and random EFB oil palm fiber reinforced composite, it compensates the loss from the drawback effect of stitching and improves the tensile strength and modulus of elasticity of stitched EFB oil palm fiber reinforced epoxy composites. This z-directional reinforcement of a stitched EFB oil palm fiber reinforced epoxy composites exhibits unique mechanical properties when compared to EFB oil palm fiber reinforced epoxy composites. Nowadays, automobile, construction and aerospace sectors have been identified as the future industries for natural fiber based composite structures. Most of them try to replicate the performance of natural fiber composites with inorganic synthetic fiber composite, but still it is not comparable due to their inadequate strength. Although with the usage of short, untreated and random oriented EFB oil palm fiber as a means of reinforcement has corresponded to a weak tensile performance when compared to inorganic synthetic fiber composite, it is believed that EFB oil palm fiber reinforced epoxy composite will thrive in impact strength due to its high fracture toughness (Jawaid, Abdul Khalil, & Abu Bakar, 2010). There are still various challenges in the development of natural fiber composite structure and cost-effective fabrication technique as to provide superior composite mechanical properties. However, with proper design of chemical treatment and the use of unidirectional or woven configuration of stitched EFB oil palm fiber, many advantages and applications of natural fiber based composites within automobile, aerospace and construction industries can be made possible.

Acknowledgement

The authors would like to acknowledge the Department of Mechanical Engineering of International Islamic University Malaysia for the support to carry out this work as well as the Ministry of Higher Education (MOHE) kindly provided funding for the research through the “Fundamental Research Grant Scheme” (FRGS) projects no. FRGS13-082-0323.

References

Bakar, M., Natarajan, V., Kalam, A., & Kudiran, N. (2007). Mechanical Properties of Oil Palm Fibre Reinforced Epoxy for Building Short Span Bridge. In E. E. Gdoutos (Ed.), *Experimental Analysis of Nano and Engineering Materials and Structures* (pp. 97-98): Springer Netherlands.

Bibo, G. A., & Hogg, P. J. (1996). The role of reinforcement architecture on impact damage mechanisms and post-impact compression behaviour. *Journal of Materials Science, 31*(5), 1115-1137. doi: 10.1007/BF00353091

Dransfield, K., Baillie, C., & Mai, Y.-W. (1994). Improving the delamination resistance of CFRP by stitching—a review. *Composites Science and Technology, 50*(3), 305-317.

International, A. (2014). Standard Test Method for Tensile Properties of Plastics *ASTM D638-14*. West Conshohocken, PA.

International, A. (2015). Standard Test Method for Tensile Properties of Yarns by the Single-Strand Method *ASTM D2256 / D2256M-10(2015)*. West Conshohocken, PA.

Jawaid, M., Abdul Khalil, H. P. S., & Abu Bakar, A. (2010). Mechanical performance of oil palm empty fruit bunches/jute fibres reinforced epoxy hybrid composites. *Materials Science and Engineering: A, 527*(29–30), 7944-7949.

Jawaid, M., Abdul Khalil, H. P. S., Hassan, A., Dungani, R., & Hadiyane, A. (2013). Effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites. *Composites Part B: Engineering, 45*(1), 619-624.

John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. *Carbohydrate Polymers, 71*(3), 343-364.

Kalam, A., Sahari, B. B., Khalid, Y. A., & Wong, S. V. (2005). Fatigue behaviour of oil palm fruit bunch fibre/epoxy and carbon fibre/epoxy composites. *Composite Structures, 71*(1), 34-44.

Kang, T. J., & lee, S. H. (1994). Effect of stitching on the mechanical and impact properties of woven laminate composite. *Journal Composite Material, 28*, 1574-1587.

Koziol, M. (2013). Effect of thread tension on mechanical performance of stitched glass fibre-reinforced polymer laminates – experimental study. *Journal of Composite Materials, 47*(16), 1919-1930.

Mouritz, A. P., Leong, K. H., & Herszberg, I. (1997). A review of the effect of stitching on the in-plane mechanical properties of fibre-reinforced polymer composites. *Composites Part A: Applied Science and Manufacturing, 28*(12), 979-991.

Ravandi, M., Teo, W. S., Tran, L. Q. N., Yong, M. S., & Tay, T. E. (2016). The effects of through-the-thickness stitching on the Mode I interlaminar fracture toughness of flax/epoxy composite laminates. *Materials & Design, 109*, 659-669.

Shinoj, S., Visvanathan, R., Panigrahi, S., & Kochubabu, M. (2011). Oil palm fiber (OPF) and its composites: A review. *Industrial Crops and Products, 33*(1), 7-22.

SPSystems. *Composite Engineering Materials-Product Information Handbook-Guide to Composites*. St Cross Business Park, Newport, Isle of Wight.

Tan, K. T., Yoshimura, A., Watanabe, N., Iwahori, Y., & Ishikawa, T. (2013). Effect of stitch density and stitch thread thickness on damage progression and failure characteristics of stitched composites under out-of-plane loading. *Composites Science and Technology, 74*(0), 194-204.

Tong, L., Mouritz, A. P., & Bannister, M. (2002). *3D fibre reinforced polymer composites*: Elsevier.

Vacuum Infusion Processing (VIP), RTM Light (LRTM, Resin Infusion, VARTM, SCRIMP) http://www.moldedfiberglass.com/processes/vacuum-infusion-molding

Vallons, K., Adolphs, G., Lucas, P., Lomov, S. V., & Verpoest, I. (2014). The influence of the stitching pattern on the internal geometry, quasi-static and fatigue mechanical properties of glass fibre non-crimp fabric composites. *Composites Part A: Applied Science and Manufacturing, 56*, 272-279.

Yudhanto, A., Lubineau, G., Ventura, I. A., Watanabe, N., Iwahori, Y., & Hoshi, H. (2015). Damage characteristics in 3D stitched composites with various stitch parameters under in-plane tension. *Composites Part A: Applied Science and Manufacturing, 71*, 17-31.

Zhao, N., Rödel, H., Herzberg, C., Gao, S.-L., & Krzywinski, S. (2009). Stitched glass/PP composite. Part I: Tensile and impact properties. *Composites Part A: Applied Science and Manufacturing, 40*(5), 635-643.