UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF PHYSICAL, MECHANICAL AND MORPHOLOGICAL PROPERTIES OF UNSTITCHED AND SILK FIBRE-STITCHED WOVEN KENAF REINFORCED EPOXY COMPOSITES

YASIR KHALEEL IBRAHIM KERMASHA

CHARACTERIZATION OF PHYSICAL, MECHANICAL AND MORPHOLOGICAL PROPERTIES OF UNSTITCHED AND SILK FIBRE-STITCHED WOVEN KENAF REINFORCED EPOXY COMPOSITES

By

YASIR KHALEEL IBRAHIM KERMASHA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

November 2020

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

CHARACTERIZATION OF PHYSICAL, MECHANICAL AND MORPHOLOGICAL PROPERTIES OF UNSTITCHED AND SILK FIBRE-STITCHED WOVEN KENAF REINFORCED EPOXY COMPOSITES

By

YASIR KHALEEL IBRAHIM KERMASHA

November 2020

Chairman : Associate Professor Zulkiflle bin Leman, PhD
Faculty : Engineering

Over the past decade, natural fibers (NFs) have attracted great attention to replace synthetic fibers in fiber-reinforced polymer composites owing to their acceptable mechanical properties, light weight, low cost, and biodegradability. In transportation sections, NFs are used to fabricate various car components, such as door panels, car roofs, dashboard components, mats, and wheels. In sports goods, several types of equipment such as surfboards, windsurfing boards, tennis rackets, badminton rackets, and golf clubs are fabricated using NFs. In general, fiber composites have poor through-thickness mechanical properties due to the absence of a z-direction binder. This problem becomes more critical with the use of NFs due to their lower strength compared to synthetic fibers. Stitching is a through-thickness toughening method, which is used to introduce fibers in the z-direction and achieve better through-thickness mechanical properties. The present study aimed to determine the mechanical properties of unstitched and silk fibre-stitched woven Kenaf-reinforced epoxy composites. The woven Kenaf mat was stitched with silk fibre using a commercial sewing machine. The stitching length (S_L) and stitching row (S_R) spacing were five millimeters. The five-millimeter stitching parameters were selected to make the stitching process easier by a commercial sewing machine and to minimize the damage to the stitched fiber. The specimens were fabricated using a hand lay-up method. In total, three specimens were fabricated (one unstitched and two silk-stitched) with different stitching orientations. Following that, the specimens were cut in accordance with the standards of the American Society for Testing and Materials (ASTM), including ASTM D3039, ASTM D790, and ASTM D256 for tensile test, flexural test, and the Izod impact test, respectively. The tensile and flexural tests were conducted using an Instron 3365 universal testing machine, and the Izod impact test was performed

using an Instron CEAST 9050 testing machine. The results indicated that the stitched specimens had comparable in-plane mechanical properties to the unstitched specimens. In the tensile mechanical test, the stitched specimens showed similar and 17.1% higher tensile strength compared to the unstitched specimens. The flexural mechanical test also demonstrated a 9% decrease in the flexural strength of the stitched specimens compared to the unstitched specimens. On the other hand, the Izod impact mechanical test showed a significant improvement by 33% in the stitched specimens compared to the unstitched specimens, which confirmed that stitching could successfully enhance out-of-plane mechanical properties. Overall, the findings of this research indicated that the stitched specimens had better mechanical performance compared to the unstitched specimens, and the reduction of the flexural strength was not significant as opposed to the considerable improvement of the impact strength.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENCIRIAN SIFAT FIZIKAL, MEKANIKAL DAN MORFOLOGI KOMPOSIT EPOKSI TETULANG KENAF TANPA JAHITAN DAN DENGAN JAHITAN ANYAMAN SUTERA

Oleh

YASIR KHALEEL IBRAHIM KERMASHA

November 2020

Pengerusi : Profesor Madya Zulkiflle bin Leman, PhD
Fakulti : Kejuruteraan

Sedekad yang lalu, gentian semula jadi mendapat perhatian yang besar dalam menggantikan gentian sintetik dalam komposit polimer tetulang serat kerana sifat mekanikalnya yang cukup baik, ringan, kos yang rendah dan yang paling penting, keterbiodegradasikannya. Dalam bahagian pengangkutan, gentian semula jadi digunakan untuk membuat pelbagai komponen kereta seperti panel pintu, bumbung kereta, komponen papan pemuka, pelapik dan roda. Dalam barangan sukan pula, pelbagai peralatan seperti papan luncur, peluncur angin, raket tenis, raket badminton dan kelab golf kini dibuat menggunakan gentian semula jadi. Secara amnya, komposit gentian mempunyai sifat mekanikal ketebalan telus yang lemah kerana ketiadaan pengikat arah z. Masalah ini lebih kritikal dengan penggunaan gentian semula jadi kerana kekuatannya yang rendah berbanding gentian sintetik. Jahitan adalah kaedah pengerasan ketebalan telus yang digunakan bagi memperkenalkan gentian pada arah-z yang akan menghasilkan sifat mekanikal ketebalan telus yang lebih baik. Kajian ini dilakukan bagi mengenal pasti sifat mekanikal komposit epoksi tetulang gentian kenaf yang terhasil dengan tenunan tanpa jahitan dan dengan jahitan gentian sutera. Pelapik kenaf yang ditenun dijahit dengan gentian sutera menggunakan mesin jahit komersial. Panjang jahitan (SL) dan jarak mentah jahitan (SR) yang dipilih dalam kajian ini adalah 5 mm. Parameter jahitan 5 mm dipilih bagi mempermudah proses jahitan menggunakan mesin jahit komersial selain meminimumkan kerosakan pada gentian yang dijahit. Spesimen direka menggunakan kaedah pengacuan sentuh (hand lay-up). Tiga spesimen direka; satu tidak dijahit manakala dua laginya dijahit sutera dengan orientasi jahitan yang berbeza. Spesimen dipotong mengikut piawaian American Society for Testing and Materials (ASTM). Piawaian ASTM digunakan di mana ASTM D 3039, ASTM D 790 dan ASTM D 256 untuk ujian tegangan, ujian lenturan dan ujian impak Izod dilakukan. Ujian tegangan dan lenturan dijalankan menggunakan mesin ujian universal Instron 3365 sementara ujian impak Izod dilakukan menggunakan mesin ujian Instron CEAST 9050. Hasil menunjukkan bahawa spesimen yang dijahit mempunyai sifat mekanikal dalam pesawat yang berbeza dengan spesimen yang tidak dijahit. Bagi ujian mekanikal tegangan, spesimen yang dijahit menunjukkan kekuatan tengangan yang serupa dan 17.1% lebih tinggi berbanding spesimen yang tidak dijahit. Hasil ujian mekanikal lenturan menunjukkan penurunan sekitar 9% dalam kekuatan lenturan bagi spesimen yang dijahit berbanding dengan spesimen yang tidak dijahit. Sebaliknya, keputusan ujian mekanikal impak Izod menunjukkan peningkatan yang ketara sebanyak 33% untuk spesimen yang dijahit berbanding spesimen yang tidak dijahit yang memberikan maksud bahawa jahitan berjaya meningkatkan sifat mekanikal luar pesawat. Hasil kajian ini menunjukkan bahawa spesimen yang dijahit mempunyai prestasi mekanikal yang lebih baik berbanding dengan spesimen yang tidak dijahit dan bahawa penurunan kekuatan lenturan agak tidak signifikan berbanding peningkatan kekuatan hentaman yang besar.

ACKNOWLEDGEMENTS

In the name of Allah, Most gracious, Most merciful. Alhamdulillah, with his blessing, I have completed this research and the preparation of this thesis.

I would like to express my deepest gratitude to my supervisor Associate Professor Dr. Zulkiflle b. Leman for his continuous support, guidance and encouragement throughout my study and the preparation of this thesis. Sincere appreciation is also extended to my co-supervisors, Dr. Mohaiman J. Sharba and Prof. Ir. Ts. Dr. Mohamed Thariq bin Haji Hameed Sultan.

Deepest thanks and apparition to my parents and siblings for their support, prayers and encouragement. Special thanks to my friends for their great efforts, support and cooperation.

Special thanks to the faculty of engineering and the staff and technicians of the Department of Mechanical and manufacturing engineering for their technical support and assistance.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Zulkiflle bin Leman, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohaiman Jaffar Sharba, PhD
Associate Professor
Faculty of Engineering
Middle Technical University
(Member)

Mohamed Thariq bin Haji Hameed sultan, PhD
Professor, Ir., Ts.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 08 April 2021

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee: Associate Professor Dr. Zulkiflle b. Leman.

Signature: ______________________________
Name of Member of Supervisory Committee: Dr. Mohaiman J. Sharba

Signature: ______________________________
Name of Member of Supervisory Committee: Professor Ir. Ts. Dr. Mohamed Thariq bin Haji Hameed Sultan

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

NFs	Natural Fibres
3D	Three Dimensions
ASTM	American Society for Testing and Materials
FRP	FiberReinforced Plastic
NKTP	National Kenaf and Tobacco Board
2D	Two Dimension
PES	polyester
CF	Carbon Fibre
CFRB	Carbon FiberReinforced polymer
GFRP	Glass FiberReinforced Polymer
FIDEC	Fiberand Biocomposite Center
MTIB	Malaysia Timber Industry Board
FS	Flexural Strength
FM	Flexural Modulus
IS	Impact Strength
TS	Tensile Strength
TM	Tensile Modulus
WKS/X	Woven kenaf silk X
WKS/XY	Woven kenaf silk XY

LIST OF NOMENCLATTURE

$\sigma\, max$	Maximum tensile strength (MPa)
$P\, max$	Maximum applied load or load at break (N)
ε	Strain (mm/mm)
A	Cross-sectional area (mm^2)
L	Length (mm)
d	Thickness (mm)
W	Weight (g)
b	Width (mm)
SD	Stitching Density (mm^{-2})
S_R	Stitching Row (mm)
S_L	Stitching Length (mm)
E	Young's modulus (MPa)
Wt%	weight fraction

CHAPTER 1

INTRODUCTION

1.1 Background

Over the past decade, natural fibers (NFs) have been more commonly used as composite resin enforcement in fiber-reinforced polymer composites owing to their favorable mechanical properties, cost-efficiency, high specific strength, eco-friendliness, and biodegradability (Dicker et al., 2014; Shah, 2014). NFs are increasingly used as reinforcement for polymer composites instead of glass fibre and other synthetic fibre and numerous applications in sports goods and transportation sections (Yan et al., 2014). Among natural fibers, Kenaf fiber (*Hibiscus cannabinus*) has been widely used as reinforcement in composites and is considered a proper alternative with its rapid growth in different climatic conditions and ensured cost-efficiency (Asim et al., 2018). While NFs have several advantages, they also have major limitations such as high moisture absorption and poor wettability, which lead to the poor bonding between the natural fibre and polymer matrix (Adekunle, 2015), thereby affecting the use of NFs for structural applications and in aerospace and automotive sectors (T. Khan et al., 2018).

In general, laminated fiber-reinforced polymer composites have poor mechanical properties in the out-of-plane direction, which are mainly resulted from missing z-direction fibers. The out-of-plane properties of the composite (e.g., impact properties) play a key role in design considerations as laminate composites are known to have insignificant impact properties, which is more crucial when NFs are used as reinforcing fibers in composites (Ravandi et al., 2017). Therefore, several three-dimensional (3D) methods have been developed (e.g., 3D braiding, weaving, knitting, and stitching) to introduce the throw thickness fibre (z-direction fiber) and increase the delamination resistance of the laminate system. Among 3D toughening methods, stitching is rather prominent as it is easy to use, cost-efficient, and highly effective. However, this method causes degradation in the in-plane mechanical properties such as local fibre damage, resin pockets, and crimps (Tong et al., 2002).

1.2 Problem Statement

The use of NFs has increased dramatically within the past decade, while many aspects of their behavior remain to be further investigated. One of these aspects is the effects of through-thickness stitching on the in-plane and through-thickness mechanical properties of composites, which are involved in numerous composite applications. Two-dimensional (2D) textile composites often have poor impact resistance and low delamination strength due to crimp and the lack of a binder in the thickness direction (z-direction), respectively (Chou, 2005). To overcome these disadvantages, we applied a 3D stitching technique in the current research. A 3D-stitched fiber-reinforced polymer composite could fundamentally overcome the fatal shortcomings of the low inter-laminar strength and low delamination resistance of conventional laminated composites. To date, the effects of stitching on the delamination and impact properties of natural fibre composites have not been adequately investigated, and data are also scarce regarding the effects of stitching on Kenaf fibre-reinforced epoxy composite. Kenaf fibre have compelling mechanical properties in terms of flexural and tensile strength. Recently, Kenaf fibers have been extensively accepted in automotive industries for the fabrication of interior and engine parts, such as the headliner, dashboard, air cleaner, and door trim (Ishak et al., 2010). Therefore, a guideline is required in this regarding to define the essential mechanisms and simplify the conclusions.

1.3 Research Objectives

The present study aimed to experimentally determine the in-plane and through-thickness mechanical performance of unstitched and silk fiber-stitched woven Kenaf-reinforced epoxy composites. The specific objectives of the research are as follows:

I. To investigate the physical and chemical properties of kenaf fibre material.
II. To analyze the effects of stitching parameters on the mechanical properties of unstitched and 3D stitched woven Kenaf-reinforced epoxy composites;
III. To assess the morphology of unstitched and 3D stitched woven Kenaf-reinforced epoxy composites

1.4 Scope of Study

Our study is focused on determining the mechanical properties and behavior of unstitched and 3D stitched woven Kenaf-reinforced epoxy composites using three layers of woven Kenaf stitched with silk fibre with different stitching densities and patterns. The composites were fabricated using the hand lay-up method. The stitching length (S_L) and stitching raw spacing (S_R) were determined to be five millimeters, and the five-millimeter stitching parameters were selected to facilitate the stitching process using a commercial sewing machine and minimize the damage to the stitched fiber. Composite specimens were prepared, cut in accordance with the ASTM standards, and examined in terms of tensile, flexural, and impact properties. The observation of their surface fracture was carried out using a microscope, and the effects of stitching on the mechanical properties of the silk fiber-stitched woven Kenaf-reinforced epoxy composites were also evaluated as the main objective of the current research.

1.5 Thesis Structure

This thesis has been prepared in five chapters. Chapter 1 is introductory and provides the study background, shows the problem statement of the study, and introduces the scope and objectives of the research. Chapter 2 presents a literature review on the previous studies that are relevant to the research subject and area, and a review of NFs and the importance of using NFs to replace syntactic fibre have also been provided. In addition, 3D toughening methods have been introduced in this chapter, particularly stitching. Previous studies have indicated the effects of stitching on the mechanical properties of natural and syntactic fibers, which has also been presented in this chapter. Chapter 3 describes the methodology of the study, starting from raw material preparations to show the used materials in our study. The methods used to fabricate the composite have also been introduced in this chapter. This chapter also describes specimen cutting and the applied mechanical tests (tensile, flexural, and impact tests). Chapter 4 introduces the results and discussion of the study. Furthermore, an analysis of the tensile, flexural, and impact properties of the unstitched and silk fiber-stitched woven Kenaf-reinforced epoxy composites has been conducted to demonstrate the effects of stitching on the mechanical properties of the composites. Finally, Chapter 5 presents the conclusion regarding the research objectives and provides recommendations and suggestions for further investigations.

REFERENCES

Adekunle, K. F. (2015). Surface treatments of natural fibres—a review: Part 1. *Open Journal of Polymer Chemistry*, *5*(03), 41.

Akil, Hm., Omar, M. F., Mazuki, A. A. M., Safiee, S., Ishak, Z. A. M., & Bakar, A. A. (2011). Kenaf fiberreinforced composites: A review. *Materials & Design*, *32*(8–9), 4107–4121.

Ali, M. E., Yong, C. K., Ching, Y. C., Chuah, C. H., & Liou, N.-S. (2015). Effect of single and double stage chemically treated kenaf fibres on mechanical properties of polyvinyl alcohol film. *BioResources*, *10*(1), 822–838.

Amirhafizan, M. H., Yuhazri, M. Y., Kamarul, A. M., & Sihombing, H. (2020). 3D HEMISPHERE PRESSURE CLAMPED TEST ON STITCHING PLAIN WOVEN KENAF FABRIC.

Ashori, A., Harun, J., Raverty, W. D., & Yusoff, M. N. M. (2006). Chemical and morphological characteristics of Malaysian cultivated kenaf (Hibiscus cannabinus) fibre. *Polymer-Plastics Technology and Engineering*, *45*(1), 131–134.

Asim, M., Paridah, M. T., Jawaid, M., Nasir, M., & Saba, N. (2018). Physical and flammability properties of kenaf and pineapple leaf fiberhybrid composites. In *IOP Conference Series: Materials Science and Engineering* (Vol. 368, p. 12018). IOP Publishing.

Ataollahi, S., Taher, S. T., Eshkoor, R. A., Ariffin, A. K., & Azhari, C. H. (2012). Energy absorption and failure response of silk/epoxy composite square tubes: Experimental. *Composites Part B: Engineering*, *43*(2), 542–548.

Badawi, M. S. S. S. (2007). Development of the weaving machine and 3D woven spacer fabric structures for lightweight composites materials.

Beckwith, S. W. (2008). Natural fibres: nature providing technology for composites. *SAMPE JOURNAL*, *44*(3), 64–65.

Bilisik, K., Erdogan, G., & Sapanci, E. (2019). In-plane response of para-aramid/phenolic nanostitched and nanoprepreg 3D composites under tensile loading. *Polymer Composites*, *40*(4), 1275–1286.

Bilisik, K., Karaduman, N. S., & Sapanci, E. (2019). Flexural characterization of 3D prepreg/stitched carbon/epoxy/multiwalled carbon nanotube preforms and composites. *Journal of Composite Materials*, *53*(5), 563–577.

Biron, M. (2007). Chapter 4-Detaield Accounts of Thermoplastic Resins. *Thermoplastics and thermoplastic composites, technical information for plastics users, Elsevier Ltd*, 217-714.

Bongarde, U. S., & Shinde, V. D. (2014). Review on natural fiberreinforcement polymer composites. *International Journal of Engineering Science and Innovative Technology*, *3*(2), 431–436.

Chen, S., Cheng, L., Huang, H., Zou, F., & Zhao, H.-P. (2017). Fabrication and properties of poly (butylene succinate) biocomposites reinforced by waste silkworm silk fabric. *Composites Part A: Applied Science and Manufacturing*, *95*, 125–131.

Chou, T.-W. (2005). *Microstructural design of fibercomposites*. Cambridge University Press.

Chung, W. C., Jang, B. Z., Chang, T. C., Hwang, L. R., & Wilcox, R. C. (1989). Fracture behavior in stitched multidirectional composites. *Materials Science and Engineering: A*, *112*, 157–173.

Cuppoletti, J. (2011). *Metal, ceramic and polymeric composites for various uses*. BoD–Books on Demand.

Dai, S., Cunningham, P. R., Marshall, S., & Silva, C. (2015). Influence of fiberarchitecture on the tensile, compressive and flexural behaviour of 3D woven composites. *Composites Part A: Applied Science and Manufacturing*, *69*, 195–207.

Dicker, M. P. M., Duckworth, P. F., Baker, A. B., Francois, G., Hazzard, M. K., & Weaver, P. M. (2014). Green composites: A review of material attributes and complementary applications. *Composites Part A: Applied Science and Manufacturing*, *56*, 280–289.

Dransfield, K., Baillie, C., & Mai, Y.-W. (1993). *On stitching as a method for improving the delamination resistance of CFRPs*. Minerals, Metals and Materials Society, Warrendale, PA (United States).

Elanthikkal, S., Gopalakrishnapanicker, U., Varghese, S., & Guthrie, J. T. (2010). Cellulose microfibres produced from banana plant wastes: Isolation and characterization. *Carbohydrate Polymers*, *80*(3), 852–859.

Fisher, G. L. (1994). Availability of kenaf fibres for the US paper industry. In *TAPPI PULPING CONFERENCE* (p. 91). Tappi Press.

Furrow, K. W., Loos, A. C., & Cano, R. J. (1996). Environmental effects on stitched RTM textile composites. *Journal of Reinforced Plastics and Composites*, *15*(4), 378–419.

Gohil, P. P., & Shaikh, A. A. (2010). Experimental investigation and micro mechanics assessment for longitudinal elastic modulus in unidirectional cotton-polyester composites. *International Journal of Engineering and Technology*, *2*(2), 111–118.

Gosline, J. M., Guerette, P. A., Ortlepp, C. S., & Savage, K. N. (1999). The mechanical design of spider silks: from fibroin sequence to mechanical function. *Journal of Experimental Biology*, *202*(23), 3295–3303.

Guénon, V. A., Chou, T.-W., & Gillespie, J. W. (1989). Toughness properties of a three-dimensional carbon-epoxy composite. *Journal of Materials Science*, *24*(11), 4168–4175.

Hamidi, Y. K., Yalcinkaya, M. A., Guloglu, G. E., Pishvar, M., Amirkhosravi, M., & Altan, M. C. (2018). Silk as a natural reinforcement: processing and properties of silk/epoxy composite laminates. *Materials*, *11*(11), 2135.

Hardy, J. G., & Scheibel, T. R. (2010). Composite materials based on silk proteins. *Progress in Polymer Science*, *35*(9), 1093–1115.

He, Y., Mei, M., Yang, X., Wei, K., Qu, Z., & Fang, D. (2020). Experimental characterization of the compaction behavior in preforming process for 3D stitched carbon fabric. *Composites Communications*.

Herszberg, I., & Bannister, M. K. (1993). Tensile properties of thin stitched carbon/epoxy composites. In *5th Australian Aeronautical Conference: Preprints of Papers* (p. 213). Institution of Engineers, Australia.

Ishak, M. R., Leman, Z., Sapuan, S. M., Edeerozey, A. M. M., & Othman, I. S. (2010). Mechanical properties of kenaf bast and core fiberreinforced unsaturated polyester composites. In *IOP Conference Series: Materials Science and Engineering* (Vol. 11, p. 12006). IOP Publishing.

Jain, L. K., Dransfleld, K., Mai, Y. W., & Baillie, C. (1994). Improvement of interlaminar properties in advanced fibercomposites with through-thickness reinforcement. *Cooperative Research Centre for Aerospace Structures Ltd., CRC-AS TM94012*.

Jang BZ, S. W. (1989). Mechanical properties of multidirectional fibercomposites. J Reinf Plast Compos 1989;8:538–64.

Jucienė, M., & Vobolis, J. (2009). Dependence of Stitch Length along the Seam on External Friction Force Theoretical Anglysis. *Materials Science (Medžiagotyra)*, *15*(3), 273–276.

Kaldor, A. F., Karlgren, C., & Verwest, H. (1990). Kenaf-a fast growing fibersource for papermaking. *Tappi Journal*, *73*(11), 205–208.

Kang, T. J., & Lee, S. H. (1994). Effect of stitching on the mechanical and impact properties of woven laminate composite. *Journal of Composite Materials*, *28*(16), 1574–1587.

Kaya, G., Soutis, C., & Potluri, P. (2018). Tensile Properties of a Novel Graphene Pattern Stitched Carbon/Epoxy 3D Composite. In *IOP Conference Series: Materials Science and Engineering* (Vol. 460, p. 12015). IOP Publishing.

Khan, M. A., Ashraf, S. M., & Malhotra, V. P. (2004). Development and characterization of a wood adhesive using bagasse lignin. *International Journal of Adhesion and Adhesives*, *24*(6), 485–493.

Khan, T., Hameed Sultan, M. T. Bin, & Ariffin, A. H. (2018). The challenges of natural fiberin manufacturing, material selection, and technology application: A review. *Journal of Reinforced Plastics and Composites*, *37*(11), 770–779.

Klinke, H. B., Lilholt, H., Toftegaard, H., Andersen, T. L., Schmidt, A. S., & Thomsen, A. B. (2001). Wood and plant fiberreinforced polypropylene composites. In *1st World Conference and Exhibition on Biomass for Energy and Industry*. James and James.

Komuraiah, A., Kumar, N. S., & Prasad, B. D. (2014). Chemical composition of natural fibres and its influence on their mechanical properties. *Mechanics of Composite Materials*, *50*(3), 359–376.

Larsson, F. (1997). Damage tolerance of a stitched carbon/epoxy laminate. *Composites Part A: Applied Science and Manufacturing*, *28*(11), 923–934.

Liu, A. (2002). World Production and Utilization of Jute, Kenaf, and Allied Fibres.

Malkapuram, R., Kumar, V., & Negi, Y. S. (2009). Recent development in natural fiberreinforced polypropylene composites. *Journal of Reinforced Plastics and Composites*, *28*(10), 1169–1189.

Mallick, P. K. (1993). Fibre-reinforced composites. *Materials, Manufacturing, and Design. 2nd Ed. CRC*.

Mao, C., & Zhang, C. (2020). Numerical analysis of influence factors on low-velocity impact damage of stitched composite laminates. *Mechanics of Advanced Materials and Structures*, *27*(12), 1019–1028.

Mazumdar, S. (2001). *Composites manufacturing: materials, product, and process engineering*. CrC press.

Mouritz, A P. (1996). Flexural properties of stitched GRP laminates. *Composites Part A: Applied Science and Manufacturing*, *27*(7), 525–530.

Mouritz, A P. (2004). Fracture and tensile fatigue properties of stitched fibreglass composites. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, *218*(2), 87–93.

Mouritz, A P, Gallagher, J., & Goodwin, A. A. (1997). Flexural strength and interlaminar shear strength of stitched GRP laminates following repeated impacts. *Composites Science and Technology*, *57*(5), 509–522.

Mouritz, A P卌, & Cox, B. N. (2000). A mechanistic approach to the properties of stitched laminates. *Composites Part A: Applied Science and Manufacturing*, *31*(1), 1–27.

Nishimura, A., & Aotani, H. (1986). New fabric structures for composites. *Composites'86: Recent Advances in Japan and the United States*, 29–36.

Paridah, M. T., Basher, A. B., SaifulAzry, S., & Ahmed, Z. (2011). Retting process of some bast plant fibres and its effect on fiberquality: A review. *BioResources*, *6*(4), 5260–5281.

Pereira, R. F. P., Silva, M. M., & de Zea Bermudez, V. (2015). Bombyx mori silk fibres: An outstanding family of materials. *Macromolecular Materials and Engineering*, *300*(12), 1171–1198.

Pickering, K. L., Efendy, M. G. A., & Le, T. M. (2016). A review of recent developments in natural fibercomposites and their mechanical performance. *Composites Part A: Applied Science and Manufacturing*, *83*, 98–112.

Priya, S. P., Ramakrishna, H. V, Rai, S. K., & Rajulu, A. V. (2005). Tensile, flexural, and chemical resistance properties of waste silk fabric-reinforced epoxy laminates. *Journal of Reinforced Plastics and Composites*, *24*(6), 643–648.

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.

Ravandi, M., Teo, W. S., Tran, L. Q. N., Yong, M. S., & Tay, T. E. (2017). Low velocity impact performance of stitched flax/epoxy composite laminates. *Composites Part B: Engineering*, *117*, 89–100.

Reeder, J. R. (1995). Stitching vs. a toughened matrix: compression strength effects. *Journal of Composite Materials*, *29*(18), 2464–2487.

Rong, M. Z., Zhang, M. Q., Liu, Y., Zhang, Z. W., Yang, G. C., & Zeng, H. M. (2002). Effect of stitching on in-plane and interlaminar properties of sisal/epoxy laminates. *Journal of Composite Materials*, *36*(12), 1505–1526.

Rouison, D., Sain, M., & Couturier, M. (2004). Resin transfer molding of natural fiberreinforced composites: cure simulation. *Composites Science and Technology*, *64*(5), 629–644.

Saba, N, Paridah, M. T., Abdan, K., & Ibrahim, N. A. (2016). Effect of oil palm nano filler on mechanical and morphological properties of kenaf reinforced epoxy composites. *Construction and Building Materials*, *123*, 15–26.

Saba, Naheed, Jawaid, M., Alothman, O. Y., Paridah, M. T., & Hassan, A. (2016). Recent advances in epoxy resin, natural fibre-reinforced epoxy composites and their applications. *Journal of Reinforced Plastics and Composites*, *35*(6), 447–470.

Saboktakin, A. (2019). 3D TEXTILE PREFORMS AND COMPOSITES FOR AIRCRAFT STRCUTURES: A REVIEW. *International Journal of Aviation, Aeronautics, and Aerospace*, *6*(1), 2.

Saheb, D. N., & Jog, J. P. (1999). Natural fiberpolymer composites: a review. *Advances in Polymer Technology: Journal of the Polymer Processing Institute*, *18*(4), 351–363.

Satapathy, A., Jha, A. K., Mantry, S., Singh, S. K., & Patnaik, A. (2010). Processing and characterization of jute-epoxy composites reinforced with SiC derived from rice husk. *Journal of Reinforced Plastics and Composites*, *29*(18), 2869–2878.

Shah, D. U. (2014). Natural fibercomposites: Comprehensive Ashby-type materials selection charts. *Materials & Design (1980-2015)*, *62*, 21–31.

Shah, D. U., Porter, D., & Vollrath, F. (2014). Can silk become an effective reinforcing fibre? A property comparison with flax and glass reinforced composites. *Composites Science and Technology*, *101*, 173–183.

Sirichaisit, J., Brookes, V. L., Young, R. J., & Vollrath, F. (2003). Analysis of structure/property relationships in silkworm (Bombyx mori) and spider dragline (Nephila edulis) silks using Raman spectroscopy. *Biomacromolecules*, *4*(2), 387–394.

Takatoya, T., & Susuki, I. (2005). In-plane and out-of-plane characteristics of three-dimensional textile composites. *Journal of Composite Materials*, *39*(6), 543–556.

Tong, L., Mouritz, A. P., & Bannister, M. K. (2002). *3D fiberreinforced polymer composites*. Elsevier.

Ude, A. U., Ariffin, A. K., & Azhari, C. H. (2013). Impact damage characteristics in reinforced woven natural silk/epoxy composite face-sheet and sandwich foam, coremat and honeycomb materials. *International Journal of Impact Engineering*, *58*, 31–38.

Vepari, C., & Kaplan, D. L. (2007). Silk as a biomaterial. *Progress in Polymer Science*, *32*(8–9), 991–1007.

Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: can they replace glass in fiberreinforced plastics? *Composites Science and Technology*, *63*(9), 1259–1264.

Wei, K., Liang, D., Mei, M., Wang, D., Yang, X., & Qu, Z. (2019). Preforming behaviors of carbon fiberfabrics with different contents of binder and under various process parameters. *Composites Part B: Engineering*, *166*, 221–232.

Wei, K., Liang, D., Mei, M., Yang, X., & Chen, L. (2019). A viscoelastic model of compression and relaxation behaviors in preforming process for carbon fiberfabrics with binder. *Composites Part B: Engineering*, *158*, 1–9.

Wu, E., & Wang, J. (1995). Behavior of stitched laminates under in-plane tensile and transverse impact loading. *Journal of Composite Materials*, *29*(17), 2254–2279.

Xuan, J., Li, D., & Jiang, L. (2019). Fabrication, properties and failure of 3D stitched carbon/epoxy composites with no stitching fibres damage. *Composite Structures*, *220*, 602–607.

Yaakob, M. Y., Husin, M. A., Abdullah, A., Mohamed, K. A., Khim, A. S., Fang, M. L. C., & Sihombing, H. (2019). Effect of Stitching Patterns on Tensile Strength of Kenaf Woven Fabric Composites. *International Journal of Integrated Engineering*, *11*(6), 70–79.

Yan, L., Chouw, N., & Jayaraman, K. (2014). Flax fiberand its composites–A review. *Composites Part B: Engineering*, *56*, 296–317.

Yang, K., Ritchie, R. O., Gu, Y., Wu, S. J., & Guan, J. (2016). High volume-fraction silk fabric reinforcements can improve the key mechanical properties of epoxy resin composites. *Materials & Design*, *108*, 470–478.

Yen Lian Tan, Check Yoon Yong, E. Ulysses Dorotheo, M. A. (. (2017). Unfairtobacco exposes how tobacco industry harms farmers, consumers and the environment., https://unfairtobacco.org/wp-content/uploads/2018/.

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, D., Dong, Y., Xu, J., Yang, Y., Fujiwara, K., Suzuki, E., … Hamada, H. (2016). Flexural and hydrothermal aging behavior of silk fabric/glass mat reinforced hybrid composites. *Fibres and Polymers*, *17*(12), 2131–2142.

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.

PUBLICATION

Journal

Kirmasha, Y. K., Sharba, M. J., Leman, Z., & Sultan, M. T. H. (2020). Mechanical Performance of Unstitched and Silk Fibre-Stitched Woven Kenaf Fibre-Reinforced Epoxy Composites. *Materials*, *13*(21), 4801.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : ____________________________

TITLE OF THESIS / PROJECT REPORT :

CHARACTERIZATION OF PHYSICAL, MECHANICAL AND MORPHOLOGICAL PROPERTIES OF UNSTITCHED AND SILK FIBRE-STITCHED WOVEN KENAF REINFORCED EPOXY COMPOSITES

NAME OF STUDENT: YASIR KHALEEL IBRAHIM KERMASHA

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.

2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.

3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from_____________ until _______________ (date) (date)

Approved by:

_____________________ (Signature of Student) New IC No/ Passport No.:	_____________________ (Signature of Chairman of Supervisory Committee) Name:
Date :	Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]