SANDWICH SQUARE HONEYCOMB STRUCTURE FROM BIODEGRADABLE AND RECYCLABLE COMPOSITES

ZAHIDAH BINTI ANSARI

Master of Science

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science in Mechanical Engineering

____

(Supervisor's Signature)

Full Name : DR.MOHD RUZAIMI BIN MAT REJAB

Position : SENIOR LECTURER

Date :

____

(Co-supervisor's Signature)

Full Name : DR.DANDI BACHTIAR

Position : SENIOR LECTURER

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : ZAHIDAH BINTI ANSARI

ID Number : MMF15010

Date :

SANDWICH SQUARE HONEYCOMB STRUCTURE FROM BIODEGRADABLE AND RECYCLABLE COMPOSITES.

ZAHIDAH BINTI ANSARI

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Master of Science

Faculty of Mechanical Engineering

UNIVERSITI MALAYSIA PAHANG

MAY 2018

Dedicated to abah, ibu, angah, ude & adik

ACKNOWLEDGEMENTS

In The Name of Allah, The Most Beneficent, The Most Merciful.

I would like to convey my deepest gratitude and appreciation to my primary supervisor, Dr. Mohd Ruzaimi bin Mat Rejab for his in-depth knowledge, continuous guidance, countless encouragements and valuable lessons in this research and life. His patience and advices throughout this journey had thought me a lot on becoming a responsible individual as well as an academician. Without it, this work would not have been possible. I would like to include a special note of appreciation to Dr. Dandi Bachtiar and Dr. Januar Parlaungan for their unwavering support, feedback and guidance in realizing this research.

I am indebted to members of Faculty of Mechanical Engineering, Universiti Malaysia Pahang including friends in Structural Manufacturing and Degradation Research Group, including Dr. Zakri Ghazali, Noor Zakiah Md Zaid, Nur Khaleeda Romli and Ma Quanjin. It has been a wonderful journey to acquire knowledge with them. My appreciation also towards the staffs and friends in my university with whom I had been associating with, either directly or indirectly during my term in the Faculty of Mechanical Engineering. I am also honoured to have the experience of working with some of the best experts from both the Forest Research Institute Malaysia (FRIM), Mr. Nordin Puteh, Dr. Sufian and from the Institute of Tropical Forestry and Forest Products (INTROP), Ms. Ana Salleza, Mr.Hafizie Manap. Without their help the research would not have been completed successfully.

In addition, I am also grateful to the Ministry of Higher Education (RACE/F3/TK01/UMP/4)) and Universiti Malaysia Pahang (RDU1403109) for rewarding the financial support to support this research. Lastly, I am forever thankful to my parents, Mr. Ansari Noorudeen and Mrs. Faridah Ahmad for their support from various aspects, namely mentally, physically and financially for this memorable journey to be possible. A special dedication to my brothers whom have always keep me going forward whenever I am in doubt of myself. Finally, to my friends and colleagues, thank you for this enjoyable learning process.

ABSTRAK

Peningkatan tahap kesedaran terhadap alam sekitar menggalakkan pembangunan komposit dari serat semulajadi, terutamanya dalam struktur sarang lebah kerana sifatnya yang ringan. Struktur sarang lebah telah digunakan secara meluas di dalam pelbagai sektor industri seperti aeroangkasa, automotif dan yang terbaru di dalam sektor industri pembuatan perabot kerana ia mampu mengurangkan berat keseluruhan produk. Walaubagaimanapun, hanya sedikit sahaja kajian yang telah dilakukan terhadap struktur ini bagi memahami kekuatannya. Selain itu, prospek mengitar semula komposit serat semula jadi kepada produk baru juga belum pernah di bincangkan dalam sebarang penyelidikan sebelumnya. Tujuan utama kajian ini adalah untuk mengkaji sifat-sifat mekanik struktur segi empat sarang lebah sandwic yang diperbuat daripada tiga jenis serat semulajadi iaitu serat kenaf, serat nenas dan serat kabung bersama gentian asid polilaktik *(*PLA*)*. Dalam pada itu, kajian ini juga bertujuan untuk mengkaji tingkah laku mampatan, kesan penskalaan dan analisisa unsur terhingga terhadap struktur segi empat sarang lebah sandwic. Kajian ini turut mengkaji kesan mengitar semula komposit semulajadi terhadap kekuatan serta daya penyerapan tenaga. Kajian ini dijalankan terhadap komposit semulajadi yang diperbuat daripada campuran PLA dengan tiga jenis serat iaitu serat kenaf, serat nenas dan serat kabung. Serat yang panjang telah dihancurkan kepada serat pendek bagi memastikan keseragaman sepanjang proses penghasilan komposit termasuk bahagian mengitar semula. Serat dan PLA kemudian dicampur menggunakan mesin pencampur kelompok pada suhu 180 ºC sebelum dihancurkan kepada palet-palet kecil untuk proses acuan penekan bersuhu panas. Setiap serat komposit di mampatkan sehingga mencapai ketebalan 3 mm selama 5 minit pada suhu 180 º dan tekanan sebanyak 60 tan. Kemudian struktur segi empat sarang lebah sandwic yang dihasilkan akan melalui ujian kemampatan manakala plat serat komposit akan melalui ujian tegangan. Produk akhir akan dikitar semula tanpa sebarang penambahan bahan lain serta melalui proses yang sama dan menjalani set ujian yang sama bagi mengkaji kekuatan struktur segi empat sarang lebah sandwic serta tahap penyerapan tenaga.Kekuatan tegangan pengurangan komposit dikitar semula dengan kenaf / PLA mencatatkan 36.28 MPa untuk komposit baru dan 19.72 MPa untuk komposit yang dikitar semula. Selepas proses kitar semula, kekuatan tegangan berkurang sebanyak 5 – 45 %. Nilai Poisson’s ratio untuk kedua-dua specimen baru dan dikitar semula berada dalam nilai 0.2 – 0.3.Selain itu, dari segi faktor skala, nilai tekanan dan penyerapan tenaga meningkat apabila bilangan sel meningkat. Komposit kabung / PLA menunjukkan kenaikan tertinggi sebanyak 115.20% apabila bilangan slot dua kali ganda. Sementara itu, model FE dibangunkan dan dianalisis dengan menggunakan perisian ABAQUS 6.13 untuk mengesahkan keputusan eksperimen yang diperolehi. Walau bagaimanapun, apabila komposit serat semula jadi dikitar semula, komposit dikitar semula kenaf / PLA mencatatkan nilai ketegasan maksimum sebanyak 7.8 MPa dan nilai penyerapan tenaga sebanyak 720.12 J berbanding komposit nenas/ PLA dan kabung / PLA yang dikitar semula. Akhir sekali, perbandingan antara model FE dan data eksperimen menunjukkan peratusan ralat yang sedikit yakni sebanyak 10.97% disebabkan oleh ketidaksempurnaan geometri struktur segi empat sarang lebah sandwic. Kajian ini menunjukkan bahawa komposit yang dikitar semula mempunyai potensi yang besar untuk digunakan sebagai bahan gentian bagi aplikasi berbeban rendah terutamanya dalam industri pembuatan perabot.

ABSTRACT

Increasing environment concern has triggered the development of natural fibre composite, especially in a honeycomb structure due to its lightweight properties. A honeycomb structure is usually used in aerospace, automotive and recently in furniture industries as it is a good weight saving option. However, only a small number of natural fibre composites have been studied as a honeycomb structure. Besides that, the prospect of recycling the natural fibre composite into a new product has yet to be discussed in any previous research. This research aims to investigate the mechanical properties of the sandwich square honeycomb structure made out of three types of fibre, which are kenaf, pineapple and sugar palm fibre reinforced with polylactic acid (PLA). Apart from that, the objectives of this study are to study the compression behaviour, the scaling effect and the finite element analysis of the sandwich square honeycomb structure. Furthermore, this research also investigates the effect of recycling the natural fibre composite in term of its strength and energy absorption values. This study was conducted on natural fibre composites made from mixing PLA with three different types of natural fibres; kenaf, sugar palm and pineapple leave fibres. The long fibres were crushed and sieved into short fibres to ensure uniformity throughout the process including recycling. Then fibres and PLA were mixed using a batch mixer at 180ºC before being crushed into small pallets for the hot press moulding. Hot pressing the pallets in a designated mould for 5 minutes at 180 º C and 60 tonnes of pressure produced plates of each fibre with a thickness of 3 mm. Later on, the plate underwent tensile test and the sandwich square honeycomb structure fabricated from the plate underwent a compression test. The end products were then recycled into plates by the same process of crushing into pallets, hot pressing and fabrication into sandwich square honeycomb structure without adding any new materials. The recycled sandwich square honeycomb were also put through the same set of tensile and compression test in order to investigate the strength and energy absorption capabilities. Tensile strength of kenaf/PLA composite recorded the highest value of 36.28 MPa for new composite and 19.72 MPa for recycled composite. After the recycling process, the tensile strength exhibit a reduction between 5-45 %. The Poisson's ratio of the composite both new and recycled was also recorded between 0.2-0.3, which is the normal range for natural fibre composites. Besides that, in term of scaling factor, the value of compression stress and energy absorption increased when the number of cell increased. The sugar palm/PLA indicated the highest increment of 115.20% when the number of slots doubled. Meanwhile, FE model was developed and analysed using ABAQUS 6.13 software to verify the experimental results obtained. However, when the natural fibre composite was recycled, kenaf/PLA recycled composite recorded the highest maximum stress of 7.8 MPa and energy absorption value of 720.12 J compared to recycled pineapple/PLA and sugar palm/PLA composite. Finally, the comparison between the FE model and experimental data presented a small percentage error of 10.97 % due to the geometries' imperfections of the experimental sandwich square honeycomb structures. This showed that the recycled natural fibre composite has a good possibility to be used to replace current materials in low load bearing application especially in furniture making industry

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

σ_t	Tensile stress
E	Young’s modulus
ε	Tensile strain
ε_x	Transverse strain
ε_y	Longitudinal strain
A_t	the cross-sectional area at the smallest part (tensile)
G	original length of the specimen
L_f	final length of the specimen
P_t	external axial load(tensile)
ν	Poisson’s ratio

LIST OF ABBREVIATIONS

EDM	Electro-discharge machine
FEA	Finite element analysis
FE	Finite element
HDPE	High density polyethylene
HIPS	High impact polystyrene
LDPE	Low density polyethylene
Ni-Cr	Nickel-Chromium
Ni-Cr-P	Nickel-Chromium-Phosphorous
PALF	Pineapple leaf fibre
PET	Polyethylene terephthalate
PLA	Polylactic acid
POM	Polyoxymethylene
PP	Polypropylene
SPF	Sugar palm fibre
SPF/SPS	Sugar palm reinforced plasticized sugar palm starch
SSHS	Sandwich square honeycomb structure

REFERENCES

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*, *43*(2), 542–548. https://doi.org/10.1016/j.compositesb.2011.08.019

Bachtiar, D., Sapuan, S. M., & Hamdan, M. M. (2008). The effect of alkaline treatment on tensile properties of sugar palm fibre reinforced epoxy composites. *Materials and Design*, *29*(7), 1285–1290. https://doi.org/10.1016/j.matdes.2007.09.006

C. Jacob, G., F.Fellers, J., Simunovic, S., & Starbuck, J. M. (2001). Energy Absorption in Polymer Composites for Automotive Crashworthiness. *Journal of Composite Materials*, *36*(07). https://doi.org/10.1106/002199802023164

Cicala, G., Pergolizzi, E., Piscopo, F., Carbone, D., & Recca, G. (2018). Hybrid composites manufactured by resin infusion with a fully recyclable bioepoxy resin. *Composites Part B*, *132*, 69–76. https://doi.org/10.1016/j.compositesb.2017.08.015

Hassan, E., Wei, Y., Jiao, H., & Huo, Y. (2012). Plant Fibers Reinforced Poly (Lactic Acid)(Pla) As a Green Composites: Review. *International Journal of Engineering …*. Retrieved from http://www.ijest.info/docs/IJEST12-04-10-046.pdf

Hayes, A. M., Wang, A., Dempsey, B. M., & McDowell, D. L. (2004). Mechanics of linear cellular alloys. *Mechanics of Materials*, *36*(8), 691–713. https://doi.org/10.1016/j.mechmat.2003.06.001

Ishak, M. R., Leman, Z., Sapuan, S. M., Edeerozey, A. M. M., & Othman, I. S. (2010). Mechanical properties of kenaf bast and core fibre reinforced unsaturated polyester composites. *IOP Conference Series: Materials Science and Engineering*, *11*, 012006. https://doi.org/10.1088/1757-899X/11/1/012006

Leman, Z., Sapuan, S. M., Saifol, A. M., Maleque, M. A., & Ahmad, M. M. H. M. (2008). Moisture absorption behavior of sugar palm fiber reinforced epoxy composites. *Materials and Design*, *29*(8), 1666–1670. https://doi.org/10.1016/j.matdes.2007.11.004

López Jiménez, F., & Triantafyllidis, N. (2013). Buckling of rectangular and hexagonal honeycomb under combined axial compression and transverse shear Dedicated to Prof. S. Kyriakides on the occasion of his 60th birthday. *International Journal of Solids and Structures*, *50*(24), 3934–3946. https://doi.org/10.1016/j.ijsolstr.2013.08.001

Mellquist, E. C., & Waas, A. M. (2004). Size Effects In the Crushing of Honeycomb Structures, (April), 1–14.

Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., & Islam, M. S. (2015). A Review on Natural Fiber Reinforced Polymer Composite and Its Applications. *International Journal of Polymer Science*, *2015*, 1–15. https://doi.org/10.1155/2015/243947

Morton, J. (1988). Scaling of impact-loaded carbon-fiber composites. *AIAA Journal*, *26*(8), 989–994. https://doi.org/10.2514/3.10001

Naresh, C., Chand, A., Kumar, K., & Chowdary, P. (2013). Numerical Investigation into Effect of Cell Shape on the Behavior of Honeycomb Sandwich Panel. *Ijirset.Com*, *2*(12), 8017–8022. Retrieved from http://ijirset.com/upload/2013/december/64A_Numerical.pdf

Russell, B., Deshpande, V., & Wadley, H. (2008). Quasistatic deformation and failure modes of composite square honeycombs. *Journal of Mechanics of Materials and Structures*, *3*(7), 1315–1340. https://doi.org/10.2140/jomms.2008.3.1315

Saba, N., Paridah, M. T., & Jawaid, M. (2015). Mechanical properties of kenaf fibre reinforced polymer composite: A review. *Construction and Building Materials*, *76*, 87–96. https://doi.org/10.1016/j.conbuildmat.2014.11.043

Sahari, J., Sapuan, S. M., Zainudin, E. S., & Maleque, M. A. (2013). Mechanical and thermal properties of environmentally friendly composites derived from sugar palm tree. *Materials and Design*, *49*, 285–289. https://doi.org/10.1016/j.matdes.2013.01.048

Sapuan, S. M., & Bachtiar, D. (2012a). Mechanical Properties of Sugar Palm Fibre Reinforced High Impact Polystyrene Composites, *4*, 101–106. https://doi.org/10.1016/j.proche.2012.06.015

Sapuan, S. M., & Bachtiar, D. (2012b). Mechanical Properties of Sugar Palm Fibre Reinforced High Impact Polystyrene Composites. *Procedia Chemistry*, *4*, 101–106. https://doi.org/10.1016/j.proche.2012.06.015

Shih, Y. F., Chang, W. C., Liu, W. C., Lee, C. C., Kuan, C. S., & Yu, Y. H. (2014). Pineapple leaf/recycled disposable chopstick hybrid fiber-reinforced biodegradable composites. *Journal of the Taiwan Institute of Chemical Engineers*, *45*(4), 2039–2046. https://doi.org/10.1016/j.jtice.2014.02.015

Sutherland, L. S., & Guedes Soares, C. (1999). Impact tests on woven-roving E-glass/polyester laminates. *Composites Science and Technology*, *59*(10), 1553–1567. https://doi.org/10.1016/S0266-3538(99)00023-8

Swanson, S. R. (1993). Scaling of impact damage in fiber composites from laboratory specimens to structures. *Composite Structures*, *25*(1–4), 249–255. https://doi.org/10.1016/0263-8223(93)90171-L

Tanaka, M. (2011). Design of novel 2D and 3D biointerfaces using self-organization to control cell behavior. *Biochimica et Biophysica Acta - General Subjects*, *1810*(3), 251–258. https://doi.org/10.1016/j.bbagen.2010.10.002

Tian, X., Liu, T., Wang, Q., Dilmurat, A., Li, D., & Ziegmann, G. (2017). Recycling and remanufacturing of 3D printed continuous carbon fi ber reinforced PLA composites. *Journal of Cleaner Production*, *142*, 1609–1618. https://doi.org/10.1016/j.jclepro.2016.11.139

Walentyński, R., Cybulski, R., & Kozieł, K. (2014). Local buckling and post-buckling investigation of cold-formed self-supported elements. *Recent Advances in Computational Mechanics - Proceedings of the 20th International Conference on Computer Methods in Mechanics, CMM 2013*, 23–37. https://doi.org/10.1201/b16513-6

Yang, F. J., Hassan, M. Z., Cantwell, W. J., & Jones, N. (2013). Scaling effects in the low velocity impact response of sandwich structures. *Composite Structures*, *99*, 97–104. https://doi.org/10.1016/j.compstruct.2012.11.011

Zuhri, M. Y. M., Guan, Z. W., & Cantwell, W. J. (2014). The mechanical properties of natural fibre based honeycomb core materials. *Composites Part B: Engineering*, *58*, 1–9. https://doi.org/10.1016/j.compositesb.2013.10.016