

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 analisis 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 °C 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 ° 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 180°C before being crushed into small pellets for the hot press moulding. Hot pressing the pellets in a designated mould for 5 minutes at 180 ° 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 pellets, 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

DECLARATION	
TITLE PAGE	
ACKNOWLEDGEMENTS	iii
ABSTRAK	iv
ABSTRACT	v
TABLE OF CONTENT	vi
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF SYMBOLS	xiv
LIST OF ABBREVIATIONS	xv
CHAPTER 1 INTRODUCTION	1
1.1 General Background	1
1.2 Problem statement	2
1.3 Objectives	2
1.4 Scope of study	3
1.5 Thesis layout	4
CHAPTER 2 LITERATURE REVIEW	5
2.1 Introduction	5
2.2 Natural Fibre Composite Materials	5
2.3 Fabrication of Natural Fibre Composite	9
2.4 Design and Manufacturing of Honeycomb Core	13

2.5	Mechanical Performance of Sandwich Honeycomb Structure	20
2.6	Scaling of Honeycomb Structure	21
2.7	Modelling of Honeycomb Core	22
2.8	Summary	23
CHAPTER 3 METHODOLOGY		24
3.1	Introduction	24
3.2	Sample Preparation	26
3.3	Composite Fabrication	27
3.4	Tensile test	31
3.5	Fabrication of Sandwich Square Honeycomb Structure	34
	3.5.1 Single slots	34
	3.5.2 Double slots	38
3.6	Compression Test	40
3.7	Finite Element	42
CHAPTER 4 RESULTS AND DISCUSSION		44
4.1	Introduction	44
4.2	Mechanical Properties of Material	44
	4.2.1 Tensile test on new and recycled kenaf/PLA composite	44
	4.2.2 Tensile test on new and recycled pineapple/PLA composite	46
	4.2.3 Tensile test on new and recycled sugar palm/PLA composite.	47
	4.2.4 Compressive behaviour of sandwich square honeycomb structure – scaling factor	53
	4.2.5 Stress-strain curve analysis.	56
	4.2.6 Crushing behaviour and failure mechanism.	61

4.2.7	Compressive behaviour of sandwich square honeycomb structure – recycling.	63
4.3	Finite Element Modelling	70
4.3.1	Experimental results	70
4.3.2	Mesh refinement	72
4.3.3	Comparison between analytical and experiment results - energy absorption.	73
CHAPTER 5 CONCLUSIONS & RECOMMENDATIONS		76
5.1	Conclusions	76
5.2	Recommendations for future work	77
REFERENCES		78
APPENDIX A FINITE ELEMENT		81
APPENDIX B YIELD STRESS		99
APPENDIX C CONFERENCE		100
APPENDIX D JOURNAL		101
APPENDIX E EXHIBITION		102

LIST OF TABLES

Table 2.1	The summary of mechanical properties of natural fibres	6
Table 3.1	The summary of mass ratio used for all types of fibre.	28
Table 3.2	The summary of sandwich square honeycomb structure for all specimens investigated during the compression study.	40
Table 4.1	The tensile test data summary.	48
Table 4.2	The Poisson's ratio values.	49
Table 4.3	The maximum stress along the critical.	72

LIST OF FIGURES

Figure 2.1	Schematic diagram of the corrugated mould	12
Figure 2.2	The laser cutting and slotting technique for triangular honeycomb core	15
Figure 2.3	The slots were assemble with the aid of a grid steel sheet fixture.	16
Figure 2.4	Square honeycomb core sandwich panel design with L-shaped flange	17
Figure 2.5	(a) The fixed insert mould (b) The lateral compression mould	18
Figure 2.6	(a) Aluminium honeycomb structure (b) Aluminium grid ortho panel (c) Honeycomb filled orthogrid core sandwich	19
Figure 3.1	The summary of overall methodology used.	25
Figure 3.2	UTS sieve used with meshing size of 85 μ m.	27
Figure 3.3	Bra-bender machine (batch mixer) with arrow pointing at the heat chamber where the mixing occurred.	27
Figure 3.4	(a) Pre-melting of PLA at 180 $^{\circ}$ C (b) Both fibres (i.e. sugar palm) and PLA were mixed homogeneously inside the heat chamber.	28
Figure 3.5	(a) Pineapple/PLA, (b) kenaf/PLA, (c) sugar palm/PLA mixture after being cooled down.	29
Figure 3.6	The mould with transparency film (a) before hot pressing (b) after hot pressing	30
Figure 3.7	CARVER Monarch Hydraulic Hot Press machine	30
Figure 3.8	The tensile test geometry with dimension following ASTM 638.	32
Figure 3.9	(a)The INSTRON Universal Testing Machine used for tensile test, (b) the sample of dumbbell shape Type V after tensile test and (c) tensile specimens with attached strain gauge .	32
Figure 3.10	Single slot design with dimensions.	35
Figure 3.11	Multiple pieces assembled core for single slots	35
Figure 3.12	The top/bottom sandwich plate for the single slots core design.	36

Figure 3.13	The 1x1 sandwich square honeycomb structure from (a) kenaf/PLA (b) pineapple/PLA (c) sugar palm/PLA composite.	37
Figure 3.14	Double slots drawing using Abaqus with dimensions.	38
Figure 3.15	Multiple pieces assemble core for double slots.	38
Figure 3.16	The top/bottom sandwich plate for the double slots core.	39
Figure 3.17	A sample under compression test using INSTRON Universal Testing Machine model 3369.	41
Figure 4.1	Tensile stress-strain curve for new and recycled kenaf/PLA composite.	45
Figure 4.2	Tensile failure (a) new kenaf/PLA (b) recycled kenaf/PLA composites.	45
Figure 4.3	Tensile stress-strain curve for new and recycled pineapple/PLA composite	46
Figure 4.4	Tensile failure on (a) new pineapple/PLA (b) recycled pineapple/PLA composites.	46
Figure 4.5	Tensile stress-strain curve for new and recycled sugar palm/PLA composite	47
Figure 4.6	The fracture characteristic of both (a) new and (b) recycled pineapple/PLA specimens.	47
Figure 4.7	Transverse and longitudinal plot for kenaf/PLA new tensile specimen.	50
Figure 4.8	Transverse and longitudinal plot for kenaf/PLA recycled tensile specimen.	50
Figure 4.9	Transverse and longitudinal plot for sugar palm/PLA new tensile specimen	51
Figure 4.10	Transverse and longitudinal plot for sugar palm/PLA recycled tensile specimen	51
Figure 4.11	Transverse and longitudinal plot for pineapple/PLA new tensile specimen.	52
Figure 4.12	Transverse and longitudinal plot for pineapple/PLA recycled tensile specimen	52
Figure 4.13	Load-displacement graph for single and double slots of kenaf/PLA sandwich square honeycomb composite.	54
Figure 4.14	Load-displacement graph for single and double slots of pineapple/PLA sandwich square honeycomb composite.	54

Figure 4.15	Load-displacement graph for single and double slots of sugar palm/PLA sandwich square honeycomb composite	55
Figure 4.16	The stress-strain curve for both single and double slots square honeycomb structure for kenaf/PLA composite.	57
Figure 4.17	The stress-strain curve for both single and double slots sandwich square honeycomb structure for pineapple/PLA composite	58
Figure 4.18	The stress-strain curve for both single and double slots sandwich square honeycomb structure for sugar palm/PLA composite	58
Figure 4.19	The summary of maximum compression load for all fibres, single and double slots design.	60
Figure 4.20	The summary of absorption energy for all fibres.	60
Figure 4.21	The stress-strain curve for pineapple/PLA double slots sandwich square honeycomb structure with four distinct regions.	61
Figure 4.22	The compression behaviour of double slots sandwich square honeycomb structure with four distinct regions.	62
Figure 4.23	Load-displacement curve for new and recycled kenaf/PLA composite.	63
Figure 4.24	Stress-strain curve for the new and recycled kenaf/PLA composite.	64
Figure 4.25	Load-displacement graph for new and recycled pineapple/PLA composites.	65
Figure 4.26	Stress-strain curve for the new and recycled pineapple/PLA composite.	65
Figure 4.27	Load-displacement graph for new and recycled sugar palm/PLA composites.	66
Figure 4.28	Stress-strain graph for new and recycled sugar palm/PLA composites.	67
Figure 4.29	The summary of maximum compression load for all fibres, new and recycled composites.	69
Figure 4.30	The summary of energy absorption for all fibres, new and recycled composites.	69
Figure 4.31	Eigenvalues, mode 1 = 0.03619, mode 2 = 0.04173, mode 3 = 0.04183	70
Figure 4.32	Stress-strain curve for Pineapple/PLA double slots sandwich square honeycomb composite.	71

Figure 4.33	Maximum stress located at the specific location of node in the sandwich square honeycomb structure.	71
Figure 4.34	Maximum stress located at the specific location of node in the sandwich square honeycomb structure.	72
Figure 4.35	The compression behaviour of sandwich square honeycomb in four different region.	74
Figure 4.36	Total energy absorption value for both experiment and FE model	75

LIST OF SYMBOLS

σ	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](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](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 fiber reinforced PLA composites. *Journal of Cleaner Production*, 142, 1609–1618. <https://doi.org/10.1016/j.jclepro.2016.11.139>

- Walentyński, R., Cybulski, R., & Koziel, 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>