DEVELOPMENT AND EVALUATION OF LINERBOARD MADE FROM SODA-ANTHRAQUINONE TREATED COCONUT COIR FIBER FOR PROTECTIVE PACKAGING

By

NOR MAZLANA BINTI MAIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement of the Degree of Doctor of Philosophy

February 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT AND EVALUATION OF LINERBOARD MADE FROM SODA-ANTHRAQUINONE TREATED COCONUT COIR FIBER FOR PROTECTIVE PACKAGING

By

NOR MAZLANA BINTI MAIN

February 2018

Chair: Assoc. Prof. Rosnita binti A. Talib, PhD
Faculty: Engineering

This research aimed to develop a linerboard made from coconut coir fiber (acts as a reinforcing fiber) blended with old corrugated container (OCC)/ dry strength agent (DSA) with high burst and ring crush strength properties. This newly developed linerboard would be an alternative source of commercial Malaysian packaging material containing DSA, OCC and industrial long fiber (ILF). Fiber characterization, soda-AQ pulping optimization, mechanical treatment (beating) and blending process of the coir fiber were investigated to optimize the characteristics of this linerboard.

The coir fibers were characterized using chemical and morphological analyses, to assess the fiber's potential for the production of pulp and paper. Chemical analysis was performed according to Technical Association of the Pulp and Paper Industry (TAPPI) Standards, while the morphological properties were measured using a Quantimeter image analyzer. From the fiber characterization, it was found that; the chemical composition of fiber was suitable for a pulping process; the fiber was short fiber with an average length of 0.84 ± 0.17 mm; and the fiber had a thin wall dimension, offering better fiber bonding during the papermaking process.

Soda-AQ pulping was optimized from nine (9) runs of the experiment. The condition of 18% active alkali (AA) and 1.5 hrs cooking time was chosen for mechanical treatment (beating). This condition had provided the highest screened yield (48.99%), a low reject yield (0.27%), high viscosity (11.73 cP), and the preferred Kappa number (41), which were acceptable for unbleached linerboard production. Since beating treatment could strengthen the coir pulp, evaluation at various revolutions (1000, 2000, 4000 and 8000) was carried out. The optimum beating revolution was obtained from the intersection between freeness and burst index; which was at 2000 revolutions. By using this revolution, the burst index of 4.57 kPa.m^2/g and ring crush index of 1.76 Nm^2/g was obtained.

The optimum beating revolution was further used in the blending process. Before linerboard production, the preferred DSA was determined, which was amphoteric polyacrylamide (aPAM) with 1.5% dosage. Series of blends containing coir, aPAM, ILF and OCC were formulated. It was observed that the blending ratio of 10/90/1.5 (coir/OCC/aPAM) was the ideal ratio and chosen as selected formulation. This selection was made based on the values of burst index (3.37 $kPa.m^2/g$) and ring crush index (1.90 Nm^2/g), which fulfilled the minimum requirement by the Malaysian industrial linerboard.

After the fabrication of the corrugated board using 10/90/1.5 (coir/OCC/aPAM) linerboard and commercial flute, the cushioning performance was assessed using a stress-energy method. The effectiveness of this new corrugated board was attained from the minimum G values (fragility product) and dynamic cushion curves. The results showed that this new corrugated board was comparable with the commercial corrugated board.

As for the conclusion, with the fiber characterization, soda-AQ pulping and mechanical treatment (beating) optimization, with the consideration of the blending process effects, it was recommended that the used of 10/90/1.5 (Coir/OCC/DSA) linerboard be suitable for the additional component of corrugated board. This alternative linerboard has high potential to be used in container production for protective packaging application. In addition, the used of coir fiber as short fiber in the blending process may replace the using of imported long fiber as commonly used in Malaysian industrial linerboard.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN DAN PENILAIAN BODPELAPIK YANG DIPERBUAT DARIPADA GENTIAN SABUT KELAPA TERAWAT OLEH *SODA-ANTHRAQUINONE* BAGI PELINDUNG PEMBUNGKUSAN

Oleh

NOR MAZLANA BINTI MAIN

Februari 2018

Pengerusi: Prof. Madya Rosnita binti A. Talib, PhD
Fakulti: Kejuruteraan

Matlamat kajian ini adalah untuk membangunkan bodpelapik diperbuat dari gentian sabut kelapa (bertindak sebagai pengukuhan gentian) yang dicampur dengan bekas beralun lama (OCC)/ agen penguat kering (DSA) serta mempunyai sifat kekuatan pecah dan gelang musnah yang tinggi. Bodpelapik yang baru dibangunkan ini merupakan sumber alternatif kepada bahan pembungkusan komersial Malaysia yang mengandungi DSA, OCC dan gentian panjang industri (ILF). Pencirian gentian, pengoptimuman pemulpaan soda-AQ, rawatan mekanikal (pemukulan) dan proses pencampuran ke atas gentian sabut kelapa telah diselidik untuk mengoptimumkan ciri-ciri bodpelapik ini.

Gentian sabut kelapa telah dicirikan menggunakan analisis kimia dan morfologi, untuk menilai potensi gentian untuk pengeluaran pulpa dan kertas. Analisis kimia telah dilakukan mengikut Piawaian Persatuan Teknikal Industri Pulpa dan Kertas (TAPPI), manakala sifat morfologi telah diukur dengan menggunakan satu penganalisis imej Quantimeter. Daripada pencirian gentian, didapati bahawa; komposisi kimia gentian sesuai untuk proses pemulpaan; gentian adalah gentian pendek dengan panjang purata 0.84 ± 0.17 mm; dan gentian mempunyai dimensi dinding nipis, yang menawarkan ikatan gentian yang lebih baik semasa proses pembuatan kertas.

Pempulpaan soda-AQ telah dioptimumkan daripada sembilan (9) eksperimen yang telah dijalankan. Keadaan pada 18% alkali aktif (AA) dan 1.5 jam masa memasak telah dipilih untuk rawatan mekanikal (pemukulan). Keadaan ini telah memberikan hasil pengskrinan tertinggi (48.99%), hasil sisa yang rendah (0.27%), kelikatan tinggi (11.73 cP), dan nombor Kappa yang diingini (41), yang mana boleh diterima untuk pengeluaran bodpelapik yang tak diluntur. Oleh kerana rawatan pemukulan boleh menguatkan pulpa sabut kelapa, penilaian kepada pelbagai revolusi (1000, 2000, 4000 dan 8000) telah dilaksanakan. Revolusi pemukulan yang optimum telah diperolehi daripada persilangan di antara indeks kebebasan dan pecah; iaitu pada 2000 revolusi.

Dengan menggunakan revolusi ini, indeks pecah sebanyak 4.57 kPa.m^2/g dan indeks gelang musnah sebanyak 1.76 Nm^2/g telah diperolehi.

Revolusi pemukulan yang optimum seterusnya telah digunakan dalam proses pencampuran. Sebelum penghasilan bodpelapik, DSA yang boleh diterima telah ditentukan, iaitu *amphoteric polyacrylamide* (aPAM) dengan dos 1.5%. Siri campuran yang mengandungi sabut kelapa, aPAM, ILF dan OCC telah diformulasikan. Telah diperhatikan bahawa nisbah pencampuran 10/90/1.5 (coir/OCC/aPAM) adalah nisbah yang ideal dan telah dipilih sebagai formulasi terpilih. Pemilihan ini dibuat berdasarkan nilai indeks pecah (3.37 kPa.m^2/g) dan indeks gelang musnah (1.90 Nm^2/g), yang memenuhi keperluan minimum oleh perindustrian bodpelapik Malaysia. Selepas pembuatan bod beralun menggunakan bodpelapik 10/90/1.5 (coir/OCC/aPAM) dan *flute* komersial, prestasi kusyen dinilai menggunakan satu kaedah tekanan-tenaga. Keberkesanan bagi bod beralun yang baru ini telah diperolehi daripada nilai minimum G (kerapuhan produk) dan lengkung kusyen dinamik. Keputusan telah menunjukkan bahawa bod beralun yang baru ini adalah setanding dengan bod beralun komersial.

Sebagai kesimpulan, dengan pencirian gentian, pengoptimuman soda-AQ dan rawatan mekanikal (pemukulan), dengan pertimbangan kesan proses pencampuran, telah disyorkan bahawa penggunaan bodpelapik 10/90/1.5 (Coir/OCC/DSA) adalah sesuai sebagai komponen tambahan bagi bod beralun. Bodpelapik alternatif ini mempunyai potensi yang tinggi untuk digunakan dalam pengeluaran bekas bagi aplikasi pelindung pembungkusan. Di samping itu, penggunaan gentian sabut kelapa sebagai serat pendek dalam proses pencampuran boleh menggantikan penggunaan serat panjang yang diimport seperti yang biasa digunakan dalam perindustrian bodpelapik di Malaysia.

ACKNOWLEDGEMENTS

First and foremost, all praise is for Allah SWT, the most gracious and merciful, Who has given me the patience, strength, determination and capability to complete what I have started.

I would like to express heartiest gratitude, appreciation and deep thanks to my supervisor, Assoc. Prof. Dr. Rosnita A. Talib and my co-supervisors, Prof. Dr. Russly Abd. Rahman, Dr. Rushdan Ibrahim and Dr. Ainun Zuriyati Mohamed for their guidance, helpful advise, generous encouragement, never-ending patience, critical comments, kind attention and willingness to assist me throughout this research. Without their valuable advice and support, it would not be possible for me to complete this research.

I am most thankful to the staffs of the Pulp and Paper Program of Forest Research Institute of Malaysia (FRIM), Institute of Tropical Forestry and Forest Products (INTROP, UPM), and the Mineral Research Centre, Minerals and Geoscience Department of Malaysia (JMG) for their assistance, service, and experience shared during my research work at the laboratories and workplaces. My special thanks are due to Dr. Rohaya and Dr Sharmiza for their excellent technical assistance and performing several analyses included in this thesis. My sincere appreciation also goes to my fellow friends for their support, inspirations, advices and ideas during the implementation of this work.

My special appreciation is dedicated to the Ministry of Education of Malaysia, and Universiti Tun Hussein Onn Malaysia (UTHM) for providing the scholarship under the SLAB financial scheme. I am also grateful to GS Paper and Packaging Sdn. Bhd., and Malayan Adhesive Chemical (MAC) Sdn. Bhd. for supplying me the raw materials in this research.

Last but not least, I would like to express my gratefulness and indebtedness to my beloved family members for their support and understanding throughout the journey. To my beloved husband and kids, from the bottom of my heart, thank you for your amazing endless love and support. Their patience and sacrifice throughout this entire process may never be completely appreciated.

Thanks again to all of you. I could not have completed this thesis without each of you.

I certify that a Thesis Examination Committee has met on 5 February 2018 to conduct the final examination of Nor Mazlana Main on her thesis entitled "Development and evaluation of linerboard made from Soda-Anthraquinone Treated Coconut Coir Fiber for Protective Packaging" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

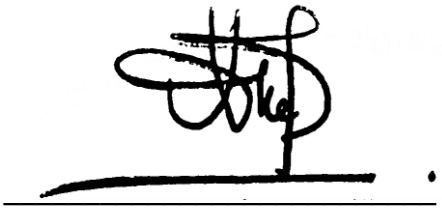
Members of the Thesis Examination Committee were as follows:

Rosnah binti Shamsudin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Mazlina binti Mustapa Kamal, PhD
Associate Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Edi Syams bin Zainudin, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Lerpong Jarupan, PhD
Assistant Professor
Faculty of Agro-Industry
Kasetsart University
Thailand
(External Examiner)



NOR AINI AB. SHUKOR, PhD
Proffesor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 28 March 2018

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

Rosnita binti A. Talib, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Russly bin Abdul Rahman, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ainun Zuriyati binti Mohamed, PhD
Senior Research Officer
Institute of Tropical Forestry and Forest Products
Universiti Putra Malaysia
(Member)

Rushdan bin Ibrahim, PhD
Senior Research Officer
Pulp and Paper Program
Forest Research Institute Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: Nor Mazlana binti Main (GS36627)

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) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Associate Professor Dr. Rosnita binti A. Talib

Signature: _____
Name of Member of Supervisory Committee: Professor Dr. Russly bin Abdul Rahman

Signature: _____
Name of Member of Supervisory Committee: Dr. Ainun Zuriyati binti Mohamed

Signature: _____
Name of Member of Supervisory Committee: Dr. Rushdan bin Ibrahim

TABLE OF CONTENTS

		Page
ABSTRACT		i
ABSTRAK		iii
ACKNOWLEDGEMENTS		v
APPROVAL		vi
DECLARATION		viii
LIST OF TABLES		xiv
LIST OF FIGURES		xvi
LIST OF ABBREVIATIONS		xx
CHAPTER		
1	**INTRODUCTION**	
	1.1 Research Background	1
	1.2 Problem Statement	3
	1.3 Research Hypothesis	4
	1.4 Research Aim and Objectives	4
	1.5 Scope and Significance of Research	4
	1.6 Organization of Thesis	5
2	**LITERATURE REVIEW**	
	2.1 Production and Demand of Packaging Paper	8
	2.2 Natural Fibers for Pulp and Paper	9
	2.2.1 General Structure of Plant Fibers	10
	2.2.2 Coir Fiber	12
	2.2.3 Potential of Coir Fiber in Papermaking	13
	2.3 Fiber Characterization	13
	2.3.1 Fiber Dimension on Pulp and Paper Properties	13
	2.3.2 Chemical Composition on the Pulping Process	15
	2.4 Pulping	20
	2.4.1 Chemical Pulping	20
	2.4.2 Pulping with Anthraquinone	21
	2.4.3 Regulatory Issues Associated with AQ	23
	2.5 Active Alkali on the Pulp and Paper Properties	24
	2.6 Cooking Time and Temperature on the Pulp and Paper Properties	25
	2.7 Beating on Pulp and Paper Properties	26
	2.8 DSA on the Pulp and Paper Properties	28
	2.9 Pulp Blending on Paper Properties	29
	2.9.1 Pulp Blends with Long Fiber	30
	2.9.2 Pulp Blends with Recycled Fiber	30
	2.10 Zeta Potential	31
	2.11 Linerboard	35
	2.12 Corrugated Board	36
	2.12.1 Corrugated Board Construction	36
	2.12.2 Flutes Structure	37
	2.12.3 Cushioning Material Classification	38
	2.12.4 Mechanical Shock and Fragility Product	38

2.12.5 Description of Dynamic Shock Cushioning Property 40
2.12.6 Procedure of ASTM D1596 42
2.12.7 Procedure of Stress-Energy Method 43

3 MATERIALS AND METHODS
3.1 Introduction 45
3.2 Materials 45
3.3 Characterization of Coir Fiber 46
3.3.1 Determination of Chemical Composition 46
3.3.1.1 Determination of Extractive 46
3.3.1.2 Determination of Ash Content 47
3.3.2.3 Determination of Acid Insoluble Lignin 48
3.3.2.4 Determination of Holocellulose, Alpha-cellulose and Hemicellulose 48
3.3.2 Determination of Fiber Morphology 49
3.4 Methods of Soda-AQ Pulping 50
3.4.1 Determination of Pulp Properties 52
3.4.1.1 Determination of Pulp Yield and Reject Yield 52
3.4.1.2 Determination of Pulp Kappa Number 53
3.4.1.3 Determination of Pulp Viscosity 53
3.4.1.4 Determination of Pulp Freeness 54
3.4.2 Formation of Paper Handsheet 54
3.4.3 Determination of Paper Properties 55
3.4.3.1 Determination of Paper Grammage 55
3.4.3.2 Determination of Paper Thickness and Apparent Density 55
3.4.3.3 Determination of Paper Brighness and Opacity 56
3.4.3.4 Determination of Paper Bursting Strength 56
3.4.3.5 Determination of Paper Tensile Strength 56
3.4.3.6 Determination of Paper Tearing Strength 57
3.4.3.7 Determination of Paper Ring Crush Strength (RCT) 57
3.4.3.8 Determination of Paper Morphology 58
3.5 Process of Coir Pulp Beating 58
3.5.1 Determination of Beaten Pulp Properties 58
3.5.2 Determination of Beaten Paper Properties 58
3.6 Approach of Coir Pulp Blending 58
3.6.1 Blending Method of Coir Pulp with aPAM and cPAM 59
3.6.2 Blending Method of Coir Pulp with ILF, OCC and aPAM 59
3.6.3 Measurement of Zeta Potential 60

3.7 Method of Statistical Analysis 61
3.8 Fabrication of Corrugated Board using 10/90/1.5 (Coir/OCC/aPAM) 61
3.8.1 Determination of Basis Weight for Commercial Sample 61
3.8.2 Determination of Structural and Strength Properties for Commercial Samples 61
3.8.3 Preparation of Linerboard and Corrugated Cushion Sample 62
3.9 Evaluation of Cushioning Performances using Stress-Energy Method 64
3.9.1 Experimental Procedure of Cushion Testing 64
3.9.2 Dynamic Stress-Energy Equation to Generate Cuhion Curve 68

4 COIR FIBER CHARACTERIZATION, PULP PROCESSING FROM SODA-AQ, MECHANICAL AND BLENDING TREATMENT FOR LINERBOARD PRODUCTION
4.1 Coir Fiber Characterization 69
4.1.1 Fiber Morphology of Coir Fiber 69
4.1.2 Chemical Composition of Coir Fiber 70
4.2 Pulp Properties 72
4.3 Paper Properties 75
4.3.1 Structural and Strength Properties 75
4.3.2 Optical Properties 79
4.4 Mechanical Treatment (Coir Pulp Beating) 80
4.4.1 Beating Analysis 80
4.4.2 Morphology Analysis 83
4.5 Coir Pulp Blending 86
4.5.1 Blending Coir Pulp with aPAM and cPAM 87
4.5.2 Blending Coir Pulp with aPAM and ILF 96
4.5.3 Blending Coir Pulp with aPAM and OCC 103
4.6 Zeta Potential 110
4.7 Summary 112

5 FABRICATION OF CORRUGATED BOARD USING 10/90/1.5 (COIR/OCC/APAM) LINERBOARD AND EVALUATION OF CUSHIONING PERFORMANCES
5.1 Structural and Strength Properties of 10/90/1.5 (coir/OCC/aPAM) and Commercial Linerboard 114
5.2 Dynamic Stress Vs Dynamic Energy for Singlle Wall and Duble Wall Samples 116
5.3 Comparisons between Coir and Commercial Samples using Dynamic Cushion Curves 119
5.4 Comparisons between Coir and Commercial Samples at Different Drop Heights 124
5.5 Comparison between Single and Double Wall Samples 127
5.6 Summary 130

6 CONCLUSIONS AND RECOMMENDATIONS
6.1 Introduction 132
6.1.1 Coir Fiber Characterization and Soda-AQ Pulping Process on the Pulp and Paper Properties 132
6.1.2 Effect of Mechanical Treatment (Beating) on the Pulp and Paper Properties 132
6.1.3 Effect of Coir Pulp Blending with DSA, ILF and OCC on the Linerboard Properties 133
6.1.4 Evaluation of Cushioning Performances on Corrugated Board 133
6.2 Recommendations for Further Studies 133

REFERENCES 135
APPENDICES 151
BIODATA OF STUDENT 169
LIST OF PUBLICATIONS 170

LIST OF TABLES

Table		Page
2.1	Fiber dimensions and their derived values of some natural fibers, hardwood and softwood	15
2.2	Chemical compositions of some natural fibers, hardwood and softwood	19
2.3	Standards flute structures and application	37
2.4	Approximately fragility level classes	39
3.1	Specifications of dry strength agents supplied by MAC Sdn. Bhd.	45
3.2	Soda-AQ pulping condition for coir fibers	51
3.3	Full factorial DOE coir pulping settings	52
3.4	Percentage of coir pulp, ILF and aPAM blending	59
3.5	Percentage of coir pulp, OCC and aPAM blending	60
3.6	Percentages of the materials used in zeta potential analyzing	60
3.7	Selected DE range for single wall corrugated sample in cushioning test	66
3.8	Selected DE range for double wall corrugated board sample in cushioning test	66
3.9	Example of static loading, drop height and thickness combination to determine the first indicator of dynamic energy setting for single wall	67
3.10	Example of static loading, drop height and thickness combination to determine the first first indicator of dynamic energy setting for double wall	67
4.1	Fiber characteristics of coir fiber	69
4.2	Chemical analysis of coir fiber	70
4.3	Pulp properties results of coir fiber	72

4.4	Structural and strength properties of coir paper from soda-AQ pulping	75
4.5	Optical properties of coir paper	80
4.6	Pulp evaluation and paper properties as a function of beating process	81
4.7	Linerboard properties properties of coir linerboard with the aPAM and cPAM addition	91
4.8	Pulp evaluation and linerboard properties of blending coir with aPAM and ILF	98
4.9	Properties of coir and commercial linerboard	99
4.10	Linerboard properties of coir pulp blended with OCC and aPAM	105
4.11	ζ potential for aPAM, alum, coir and combination of the materials used at different pHs	110
5.1	Structural and strength properties of 10/90/1.5 (coir/OCC/aPAM) and commercial linerboard	115
5.2	Data collected for a selected dynamic energy level of commercial sample (single wall)	116
5.3	Data collected for a selected dynamic energy level of coir sample (single wall)	117
5.4	Dynamic stress vs. dynamic energy equations for all samples (exponential)	119
5.5	Acceleration value from stress energy equations vs. strain for single wall commercial and coir sample	120
5.6	Acceleration value from stress energy equations vs. strain for double wall commercial and coir sample	121
5.7	Acceleration value at 3 different drop height for single wall commercial and coir sample	125
5.8	Acceleration value for single wall and double wall sample at 9 inches drop height	127
5.9	Burst strength of single and double corrugated board	130

LIST OF FIGURES

Figure		Page
1.1	Process flow of experimental design and methodology	7
2.1	Fiber classification	10
2.2	Organization of microfibrils and cellulose in the plant cell wall	11
2.3	The structure of a wood fiber	11
2.4	Cross-section of a coconut fruit	12
2.5	Idealized for fiber structure (a) thick wall fibers, and (b) thin wall fibers	14
2.6	Structure of cellulose	16
2.7	Chemical reactions of anthraquinone: (a) Anthraquinone redox reaction, (b) Aldehyde oxidation by anthraquinone	21
2.8	The local ions concentrations	32
2.9	The schematic diagram of the possible potential distribution of the counterions which based on stern layer	33
2.10	The charge distribution, the counter ions in the electrical double layer. (a) the early Helmholtz model of a molecular capacitor; (b) The Gouy- Chapman model of the diffuse double layer; (c) the Stern model	34
2.11	The total interaction energy curves (solid lines) acquired by the summation of an attractive potential curve (dotted line) with different repulsive potential curves (dashed lines)	34
2.12	Corrugated board illustration and types of combined board	36
2.13	The standard flute sizes	37
2.14	Registered shock during a drop on a packaged product	38
2.15	Object free-fall to surface	40
2.16	Idealized shock input and cushioned response	40

2.17	Test system of dynamic shock cushioning property: (1) weight; (2) drop block; (3) guide column; (4) test specimen; (5) acceleration sensor	41
2.18	Example of cushion curve with fragility of 50 G's	42
3.1	Single wall corrugated board (a) commercial (b) prepared sample	62
3.2	Double wall corrugated board (a) commercial (b) prepared sample	62
3.3	Medium sample of single wall corrugated board	63
3.4	Medium sample of double wall corrugated board	63
3.5	One layer of corrugated pad (a) single wall, (b) double wall	64
3.6	Two layers of corrugated pad (a) single wall, (b) double wall	64
4.1	Measurement of single coir fiber (a) Fiber length; (b) Fiber diameter, cell wall thickness and lumen width	70
4.2	Comparison of different percentage of AA and cooking time according to the apparent density of coir paper	76
4.3	FESEM micrographs of cross section coir paper 60 g/m^2 at 500 X: (a) condition 1 (18% AA, 1.5 h); (b) condition 9 (22% AA, 2.5 h) and at 800 X: (c) condition 1 (18% AA, 1.5 h); (d) condition 9 (22% AA, 2.5 h) (scale bar: 10 µm)	77
4.4	Comparison of different percentage of AA and cooking time according to the burst index	77
4.5	Comparison of different percentage of AA and cooking time according to the tensile index	78
4.6	Comparison of different percentages of active alkali and cooking times according to the tear index of coir paper	79
4.7	Freeness and burst index at different beating revolutions	82
4.8	Tensile and tear indices at different beating revolutions	83
4.9	FESEM micrographs of the coir paper 60 g/m^2 for surfaces viewed at 500 X: (a) unbeaten; (b) beaten at 1000 revolutions; (c) beaten at 2000 revolutions; (d) beaten at 4000 revolutions; (e) beaten at 8000 revolutions (scale bar: 10 µm)	85

4.10	FESEM micrographs of the coir paper 60 g/m^2 for cross-sectional viewed at 800 X: (f) unbeaten; (g) beaten at 1000 revolutions; (h) beaten at 2000 revolutions; (i) beaten at 4000 revolutions; and (j) beaten at 8000 revolutions (scale bar: 10 µm)	86
4.11	FESEM micrographs of the coir linerboard 120 g/m^2 treated with aPAM for surfaces viewed at 300 X: (a) untreated; (b) aPAM at 0.5%; (c) aPAM at 1.0%; (d) aPAM at 1.5%; (e) aPAM at 2.0%	88
4.12	FESEM micrographs of the coir linerboard 120 g/m^2 treated with cPAM for surfaces viewed at 300 X: (a) untreated; (b) cPAM at 0.5%; (c) cPAM at 1.0%; (d) cPAM at 1.5%; (e) cPAM at 2.0%	89
4.13	Comparison of DSA at different dosages on the burst strength	92
4.14	Comparison of DSA at different dosages to ring crush strength	92
4.15	Comparison of DSA at different dosages to the tensile strength	93
4.16	Comparison of DSA at different dosages to the tear strength	94
4.17	Tearing effects on coir liner treated with 1.5% (a) aPAM; (b) cPAM	95
4.18	FESEM micrographs of the fiber pulled out (yellow color) and fiber broken (red color) for tear samples coir liner 120 g/m^2 at cross section viewed: (a) aPAM at 0.5%; (b) cPAM at 0.5% (magnification: 200 X)	95
4.19	Fiber pulled out and fiber broken at 1.5% aPAM and cPAM	95
4.20	Freeness and burst index at different beating revolutions for ILF	96
4.21	FESEM micrographs of the coir linerboard 120 g/m^2 blended with ILF and treated with aPAM for surfaces viewed at 300 X: (a) 100% coir; (b) 100% ILF; (c) 10% ILF; (d) 10% ILF with aPAM; (e) 20% ILF; (f) 20% ILF with aPAM; (g) 30% ILF; (f) 30% ILF with aPAM	97
4.22	Apparent density of blended coir pulp with ILF and aPAM	100
4.23	Burst strength of blended coir pulp with ILF and aPAM	101
4.24	Ring crush strength of blended coir pulp with ILF and aPAM	101
4.25	Tensile strength of blended coir pulp with ILF and aPAM	102

4.26	Tear strength of blended coir pulp with ILF and aPAM	103
4.27	FESEM micrographs of the coir linerboard 120 g/m^2 blended with OCC and treated with aPAM for surfaces viewed at 300 X: (a) 100% OCC; (b) 100% coir; (c) 10% coir; (d) 10% coir with aPAM; (e) 20% coir; (f) 20% coir with aPAM; (g) 30% coir; (h) 30% coir with aPAM	104
4.28	Apparent density of OCC blended with coir and aPAM	106
4.29	Burst strength of OCC blended with coir and aPAM	107
4.30	Ring crush strength of OCC blended with coir and aPAM	108
4.31	Tensile strength of OCC blended with coir and aPAM	108
4.32	Tear strength of OCC blended with coir and aPAM	109
4.33	Zeta Potential for slurry A and slurry B in making linerboard	111
4.34	Zeta Potential for each material used and combination of them in making linerboard	112
5.1	Dynamic stress vs dynamic energy for commercial single wall corrugated board	118
5.2	Dynamic stress vs dynamic energy for coir single wall corrugated board	118
5.3	Graph of acceleration values against static load for drop height 9 inches (Single wall)	123
5.4	Graph of acceleration values against static load for drop height 9 inches (Double wall)	124
5.5	Comparison between coir and commercial sample at different drop heights for single wall	126
5.6	Comparison between single wall and double wall for commercial sample at drop height 9 inches	129

LIST OF ABBREVIATIONS

a.d.	Air-dried (weight)
AA	Active alkali
AHQ	Anthrahydroquinone
ANOVA	Analysis of variations
aPAM	Amphoteric polyacrylamide
AQ	Anthraquinone
ASTM	American Society for Testing and Materials
BfR	German Federal Institute for Risk Assessment
CEPI	Confederation of European Paper Industries
CFR	Code of Federal Regulation
CMC	Carboxymethyl cellulose
cP	Centipoise
CP	Chemical pulping
cPAM	Cationic polyacrylamide
CSF	Canadian standard freeness
DA-SP	Data acqusition and signal processing
DE	Dynamic energy
DLVO	Derjaguin, Landau, Verwey and Overbeek
DP	Degree of polymerization
DSA	Dry strength agent
DS-DE	Dynamic stress and dynamic energy
ECF	Elementary chlorine free
EFSA	European Food Safety Authority
EPS	Expanded polystyrene
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
FESEM	Field Emission Scanning Electron Microscope
FRIM	Forest Research Institute Malaysia
G	Acceleration
G's	Dynamic stress

gsm	Grammage, g/m2
hrs	Hour
IEP	Isoelectric point
ILF	Industrial long fiber
INTROP	Institute of Tropical Forestry and Forest Products
ISO	International Organization for Standardization
kPa	Kilo Pascal
MFC	Microfibrillated cellulose
min	Minute
mL	Milliliter
MP	Mechanical pulping
mPa	Mega Pascal
N	Newton
nm	Nanometer
NTP	National Toxicology Program
o.d.	Oven-dried (weight)
ºC	Degree Celcius
OCC	Old corrugated containers
OPMFS	Palm oil male flower spikes
PAM	Polyacrylamide
psi	Pounds per square inch (pressure)
RCT	Ring crush test
RH	Relative humidity, %
sec	Second
TAPPI	Technical Association of the Pulp and Paper Industry
TEA	Tensile energy absorption
TGRT	Tukey's Group Range Test

CHAPTER 1

INTRODUCTION

1.1 Research Background

In recent days, environmental and sustainability issues awareness has been increasing around the world. One of the issues is deforesting for pulp and paper production, especially in Asia-Pacific region and European countries. Therefore, new alternative raw materials, such as non-wood and residues from agricultural and forest industries are being studied and applied to replace wood-base pulp and paper (Ferrer *et al.*, 2015; Wutisatwongkul *et al.*, 2016).

The world paper industry can be broadly classified into packaging, printing and writing, newsprint and tissue paper production. Out of those, packaging paper has been the largest category worldwide, which accounted for 51.7% of the paper industry in 2009. Meanwhile, printing and writing paper were the second largest with 27.8%, followed by newsprint and tissue paper at 11.2% and 7.5%, respectively (Jukka, 2011). Malaysia's paper industry follows this pattern, with packaging paper contributes almost 50% of the total paper production. It should be noted that Malaysia is a net importer of pulp (Singh *et al.*, 2012), particularly virgin long-fiber pulp. In general, Malaysian paper and paperboard industries have been mixing the imported virgin long-fiber pulp with secondary fibers, such as the old corrugated container (OCC) and waste papers. This is to produce papers that meet the packaging specifications. Nevertheless, the imported virgin pulp is expensive, hence imposing additional cost in papermaking industry. Therefore, the Malaysian government has been encouraging the utilization of non-wood sources gathered from annual crops and agricultural residues, as an alternative source (FRIM, 2009). This reduces the dependence on imported pulp, paper, and paperboard.

There are a wide variety of non-wood fibers that can be used for papermaking purposes in Malaysia. For example, coconut coir, bamboo, bagasse, kenaf, rice straw and oil palm empty fruit bunches (EFB). Among those fibers, coir fibers from coconut fruit is an important raw material, since only 15% of the fibers are currently recovered for use, while others are left abandoned (Karthikeyan & Balamurugan, 2012; Verma *et al.*, 2013). Furthermore, Malaysia the Top 10 of world's coconut producer ranking, with total coconut production of 653 million seeds in 2015 (Ismail & Abdul Shukur, 2016). Remarkable advantages gained by using non-wood raw materials in producing pulp, such as the production of pulp with excellent quality that can be used to make specialty grades of paper (Kaur *et al.* 2010). This study aims to assess the suitability of coir fibers in making linerboard for packaging application, using chemical pulping process.

Among all known chemical based pulping processes, soda-anthraquinone (AQ) pulping used in this study is an environmentally friendly process based on the fact that it is sulfur-free, essentially requires only a modest amount of raw material (Jimenez *et al.*, 2009). Also, an addition of AQ in soda pulping process generally increases delignification rates, selectivity, and velocity. This practice also reduces alkali charges

REFERENCES

AB Newswire (2017). Worldwide paper packaging material market to exceed $362.65 billion by 2021. http://www. abnewswire.com/pressreleases/worldwide-paper-packaging- material- market- to- exceed- 36265- billion- by-2021_93629.html. Retrieved on March 2017.

Abdul Khalil, H. P. S., Ireana Yusra, A. F., Bhat, A. H., and Jawaid, M. (2010). Cell wall ultrastructure, anatomy, lignin distribution and chemical composition of Malaysian cultivated kenaf fiber. *Industrial Crops and Products.* 31(1): 113-121.

Abdul Khalil, H. P. S., Siti Alwani, M., and Mohd Omar, A. K. (2006). Chemical composition, anatomy, lignin distribution, and cell wall structure of Malaysian plant waste fibers. *BioResources.* 1(2): 220-232.

Adamopoulos, S. (2006). Identification of fibre components in packaging grade papers. *IAWA Journal.* 27(2): 153–172.

Agopyan, V., Savastano Jr., H., John, U. M., and Cincotto, M. A. (2005). Development of vegetable fibre-cement based materials in Sao Paulo, Brazil: An overview. *Cement and Concrete Composites*. 27(5): 527-536.

Ahmad Azizi, M., Jalaluddin, H., Paridah, M. T., Hossein, R., Rushdan, I., Seyed Rashid, F, S., and Ainun Zuriyati, M. (2010a). A review of literatures related of using kenaf for pulp production (beating, fractionation, and recycled fiber). *Modern Applied Science*. 4(9): 21-29.

Ahmad Azizi, M., Jalaluddin, H., Resalati, H., Rushdan, I., Faridah, T., Seyed Rashid, S., and Ainun Zuriyati, M. (2010b). Soda-anthraquinone pulp from Malaysian cultivated kenaf for linerboard production. *BioResources.* 5(3): 1542–1553.

Ajay, C., Anje, K., and Ghosh, U. K. (2013). Blending impact of softwood pulp with hardwood pulp on different paper properties. *Tappsa Journal.* 2: 16-20.

Akgul, M., and Tozluoglu, A. (2009). Some chemical and morphological properties of juvenile woods from beech (Fagus orientalis L.) and pine (Pinus nigra A.) plantations. *Trends in Applied Sciences Research*. 4(2): 116-125.

Alén, R. (2000). Basic chemistry of wood delignification. In *Papermaking Science and Technology (Vol. 3)*, ed. P. Stenius. Finland: Fapet, Helsinki.

Ali, M. (2010). *Coconut fibre- a versatile material and its applications in engineering*. Paper presented at the Second International Conference on Sustainable Construction Materials and Technologies, Ancona, Italy, June 28-30. http://www. claisse. info/2010%20papers/k13.pdf. Retrieved on May 2013.

Alince, B., and van de Ven, T.G.M. (1993). Kinetics of colloidal particle deposition on pulp fibers 2. Deposition of clay on fibers in the presence of Poly(ethylenimine). *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 71:105-114.

Ang, L. S., Leh, C. P., and Lee, C. C. (2010). Effects of alkaline pre-impregnation and pulping on Malaysia cultivated kenaf (Hibiscus cannabinus). *BioResources.* 5(3): 1446-1462.

Anupam, K., Sharma, A. K., Lal, P. S., and Bist, V. (2016). Physicochemical, morphological, and anatomical properties of plant fibers used for pulp and papermaking. In *Fiber Plants, Sustainable Environment and Biodiversity 13,* ed. K. G. Ramawat and M. R. Ahuja, pp. 235-248. Switzerland: Springer International Publishing.

APCC (2016). *Global Scenario of Coconut Sector*, Asean and Pacific Coconut Community. Paper presented at the National Coconut Workshop, August 9, Kuala Lumpur, Malaysia.

Asasutjarit, C., Charoenvai, S., Hirunlabh, J., and Khedari, J. (2009). Materials and mechanical of pretreated coir-based green composites. *Composites Part B: Engineering*. 40(7): 633-637.

Asasutjarit, C., Hirunlabh, J., Khedari, J., Charoenvai, S., Zeghmati, B., and Cheul Shin, U. (2007). Development of coconut coir-based lightweight cement board. *Construction and Building Materials*. 21(2): 277-288.

Ashori, A. (2006). Pulp and paper from kenaf bast fibers. *Fibers and Polymers.* 7(1): 26-29.

Ayrilmis, N., Jarusombuti, S., Fuengvivat, V., Bauchongkol, P., and and White, R.H. (2011). Coir fiber reinforced polypropylene composite panel for automotive interior applications. *Fibers and Polymers*. 12(7): 919-926.

Bäckström, M., Kolar, M. C., and Htun, M. (2008). Characterisation of fines from unbleached kraft pulps and their impact on sheet properties. *Holzforschung*. 62(5): 546-552.

Bahari, A. R., Fudzi, M. S. M., Ahmad, N., and Rahman, H. A. (2015). Material properties characterization of coir cardboard. *Journal of Engineering and Applied Sciences.* 10(20): 9521-9526.

Banavath, H. N., Bhardwaj, N. K., and Ray, A. K. (2011). A comparative study of the effect of refining on charge of various pulps. *Bioresource Technology.* 102 (6): 4544-4551.

Behera, S., Patel, S., and Mishra, B. K. (2015). Effect of blending of sisal on pulp properties of waste papers in handmade papermaking. *Journal of Scientific & Industrial Research.* 74: 416-422.

Berzins, V. (1966). *Chemical composition of wood*. Research Report Note No. 61, Pulp and Paper Research Institute of Canada, Pointe-Claire.

BfR (2013). BfR removes anthraquinone from its list of recommendations for food packaging. Federal Institute for Risk Assessment. http://www.bfr. bund.de/ cm/349/bfr-removes- anthraquinone- from- its- list-of-recommandations-for food- packaging.pdf. Retrieved on March 2015.

Bhardwaj, K. N., Kumar, S., and Bajpai, K. P. (2005). Effect of zeta potential on retention and drainage of secondary fibers. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 260: 245-250.

Biermann, C. J. (1996). *Handbook of pulping and papermaking (2nd ed.)*. San Diego, California, USA: Academic Press.

Bill, S. (1994). *Pira packaging guide series: Packaging design strategy*. Lincolnshire, UK: Pira International.

Bledzki, A. K., and Gassan, J. (1999). Composites reinforced with cellulose based fibers. *Progress in Polymer Science.* 24(2): 221-274.

Borkovec, M. and Papastavrou, G. (2008). Interactions between solid surface with adsorbed polyelectrolytes of opposite charge. *Current Opinion in Colloids & Interface Science.* 13:429-437.

Bowyer, J. L., Shmulsky, R., and Haygreen, J. (2007). *Forest products and wood science an introduction (5th ed.)*. State Avenue, USA: Blackwell Publishing Proffesional.

Brandenburg, R. K., and Lee, J. J. L. (1985). *Fundamentals of packaging dynamics*. United States: MTS Systems Corporation.

Brandon, C. E., (1981). Properties of Paper. In *Pulp-Chemistry and Technology (3rd ed.)*. New York: John Wiley and Sons.

Bryce, J. R. G. (1980). Alkaline pulping. In *Pulp and Paper: Chemistry and Chemical Technology*, ed. J. P. Casey (3rd ed.), pp 402-411. Canada: John Wiley & Sons, Inc.

Burgess, G. (1990). Consolidation of Cushion Curves. *Packaging Technology and Science*. 3(4): 189-194.

Burgess, G. (1994). Generation of cushion curves from one shock pulse. *Packaging Technology and Science*. 7(4): 169-173.

Butt, H. J. & Kappl, M. (2010). *Surface and Interfacial Forces*. German: Wiley-VCH Verlag GmBH & Co. KGaA, Weinheim.

Cadena, E. M., Garcia, J., Vidal, T., and Torres, A. L. (2009). Determination of zeta potential and cationic demand in ECF and TCF bleached pulp from eucalyptus and flax. Influence of measuring conditions. *Cellulose*. 16(3): 491-500.

Campbell, A. C. (2010). *The Use of A-Fute, B-Flute, AC-Flute, and BC-Flute Corrugate Paperboard as a Cushioning Material*. Published master dissertation, Clemson University, USA.

Casey, J. P. (1980). *Pulp-Chemistry and Technology (3rd ed.)*. New York, USA: John Wiley and Sons.

Clark, J. A., (1985). *Pulp Technology and Treatment for Paper*. San Fransico: Miller-Freeman.

Copur, Y., and Tozluoglu, A. (2008). A comparison of kraft, PS, kraft-AQ and kraft-NaBH 4 pulps of Brutia pine. *Bioresource Technology*. 99(5): 909-913.

Daleski, E. J. (1965). The effect of elevated temperatures on the alkaline pulping processes. *Tappi.* 48(6): 325-330.

Danny, E. A. (2010). Chemistry of Plant Fibres. In *Industrial Application of Natural Fibres: Structure, Properties and Technical Applications (1st ed.)*, ed. J. Mussig, pp.13-18. UK: John Wiley and Sons, Ltd.

Daum, M. (2007). Simplified presentation of the stress-energy method for general commercial use. *Journal of Testing and Evaluation.* 36(1): 1-3.

Davinson, R. W. (1980). Theory of dry strength development. In *Dry Strength Additives*, ed. W. F. Reynolds, pp 20-23. USA: TAPPI Press.

Defoirdt, N., Biswas, S., De Vriese, L., Tran, L.Q.N., Acker, J.V., Ahsan, Q., Gorbatikh, L., Vuure, A.V. and Verpoest, I. (2010). Assessment of the tensile properties of coir, bamboo and jute fibre. *Composites Part A: Applied Science and Manufacturing*. 41: 588-595.

Dimitrov, K., and Heydenrych, M. (2009). Relationship between the edgewise compression strength of corrugated board and the compression strength of liner and fluting medium papers. *Southern Forests: A Journal of Forest Science.* 71(3): 227-233.

Douglas, D. S., Qinglin, W. and Guangping, H. (2014). *Introduction to Wood and Natural Fiber Composites (1st ed.)*, ed. J. Mussig, p.10-40. UK: John Wiley & Sons, Ltd.

Dunno, K. D. (2016). Application of the stress-energy method to evaluate enclosed air cushion systems. *International of Advanced Packaging Technology*. 4(1): 216-225.

Dutt, D, Upadhyaya, J.S., Malik, R. S., Tyagi, C. H. (2005). Studies on pulp and paper making characteristics of some indian non-woody fibrous raw material: Part-1. *Journal of Cellulose Chemistry Technology*. 39(1-2): 115-128.

Dutt, D., Tyagi, C.H. (2011). Comparison of various eucalyptus species for their morphological, chemical, pulp and paper making characteristics. *Indian Journal of Chemical Technology*. 18: 145-151.

Dutt, D., Upadhyay, J. S., Singh, B., and Tyagi, C. H. (2009). Studies on Hibiscus cannabinus and Hibiscus sabdariffa as an alternative pulp blend for softwood: An optimization of kraft delignification process. *Industrial Crops and Products.* 29(1): 16-26.

EFSA (2012). Reasoned opinion on the review of the existing maximum residue levels (MRLs) for anthraquinone according to Article 12 of Regulation (EC) No 396/2005. *EFSA Journal.* 10(6): 2761.

El-Hosseiny, F., Yan, J. F. (1980). Analysis of Canadian standard freeness-2: practical implications. *Pulp and Paper Canada*. 81(6):67-70.

Eugenio, M. E., Martin-Sampedro, R., Revilla, E., and Villar, J. C. (2012). Evaluation of Hesperaloe funifera pulps obtained by a low energy consumption process as a reinforcement material in recycled pulps. *Forest Systems.* 21(3): 460-467.

European Union (2014). Commission regulation (EU) no 1146/2014, Official Journal of European Union. https://www. fsai.ie/ uploaded Files/ Legislation/ Food_ LegisationLinks/Pesticides_Residues_in_food/Reg1146_2014.pdf. Retrieved on March 2105.

Evans, D. F., and Wennerstrom, H. (1999). *The Colloidal Domain Where Physics, Chemistry, Biology, and Technology Mee*t. Canada: Wiley-VCH

FAO (2007). The Pulp and Paper Industry in Malaysia. www.fao.org/forestry/12745-014ee55f045bcc33f63e34ded2bae0acc.pdf. Retrieved on January 2016.

FDA (2014). Code of federal regulations title 21, Food and Drug Administration. http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=176.170. Retrieved on March 2105.

Fellers, C. (2009). Paper physics. In *Paper Products Physics and Technology: Pulp and Paper Chemistry & Technology*, pp. 52, ed. E. Monica, G. Goran, and H. Gunnar. Germany: Walter de Gruyter GmbH & Co. KG., Berlin.

Feng, H., and Tomonari, S. (2012). China's sustainable strategy on waste paper as reusable resources. *Journal of Environmental Science and Engineering.* A, 1(9A): 1142.

Ferrer, A., Vargas, F., Jameel, H., and Rojas, O. J. (2015). Influence of operating variables and model to minimize the use of anthraquinone in the soda-anthraquinone pulping of barley straw. *BioResources.* 10(4): 6442–6456.

Fleming, B. I., Kubes, G. J., MacLeod, J. M., and Bolker, H. I. (1978). Soda pulping with anthraquinone. *Tappi*. 61(6): 43-46.

Folke, L. A. A., Leland, L. R. S., Norman, S. T., Earl, W. M., 1979. Anthraquinone Induced Scission of Polysaccharide Chains. IPC Technical Paper, The Institute of Paper Chemistry, Wisconsin.

Frank, B. (2003). Ring crush and short span compression for predicting edgewise compressive strength. *Tappi Journal.* 2(11): 12.

FRIM (2009). Wastes to wealth, FRIM in Focus, Forest Research Institute, Malaysia. http://www.frim.gov.my/v1/fif/pdf_file/FRIM_Sept_20091.pdf. Retrieved on January 2015.

George G. M. (1988). *Corrugated shipping containers: An engineering approach*. Plainview, New York: Jelmar Publishing Co., Inc.

Ghasemian, A., Ghaffari, M., and Ashori, A. (2012). Strength- enhancing effect of cationic starch on mixed recycle and virgin pulps. *Carbohydrate Polymers*. 87: 1269-1274.

Ghosh, U. K., and Pal, V. (2005). Blending effect of synthetic fiber on paper properties. *Journal of Scientific & Industrial Research.* 64: 116-118.

Goodwin, J. W. (2004). *Colloids and Interfaces with Surfactants and Polymers- An Introduction.* England: Wiley-VCH Publication.

GSPP. (2007). Product specifications, GS Paper and Packaging Group Malaysia. http://www.gspp.com.my/corp/doc/gspp.pdf. Retrieved on Jun 2014.

Gulsoy, S. K., Kustas, S., and Erenturk, S. (2013). The effect of old corrugated container (OCC) pulp addition on the properties of paper made with virgin softwood kraft pulps. *BioResources.* 8(4): 5842-5849.

Guo, Y., Xu, W., Fu, Y., and Wang, H. (2011). Dynamic shock cushioning characteristics and vibration transmissibility of X-PLY corrugated paperboard. *Shock and Vibration.* 18(4): 525–535.

Guo, Y., Xu, W., Fu, Y., and Zhang, W. (2010). Comparison studies on dynamic packaging properties of corrugated paperboard pads. *Engineering*. 2(5): 378.

Hans, J. P. (2013). Recovered paper, recycled fibers. In *Handbook of Paper and Board*, pp. 24-25, ed. H. Holik. Germany: Wiley-VCH Verlag GmbH & Co. KgaA.,Weinheim.

Heise, O. U. (2003). *Strength-enhancing Effects of Slurry Ad Treatments of Industrial Refining, Cationic Starch and Dynamic Nip Wet-pressing on Commercial Pulp Furnishes*. Doctoral dissertation, University of Wisconsin-Madison, USA.

Heydari, S., Ghasemian, A., and Afra, E. (2013). Effects of refining and cationic polyacrylamide on strength properties of paper made from old corrugated container (OCC). *World of Sciences Journal*.

Hocking, M. B. (2005). *Handbook of chemical technology and pollution control (3rd ed.).* San Diego, USA: Academic Press.

Holton, H. (1977). Soda additive softwood pulping: A major new process. *Pulp Paper Canada*. 78: 1-4.

Hubbe, M. A. (2000). Reversibility of polymer-induced fiber flocculation by shear. 1. Experimental methods. *Nordic Pulp and Paper Research Journal*. 15(5): 545-553.

Hubbe, M. A. (2006). Bonding between cellulosic fibers in the absence and presence of dry-strength agents-A review. *BioResources.* 1(2): 281-318.

Hubbe, M. A., Rojas, O. J., Argyropoulos, D. S., Wang, Y., Song, J., Sulić, N., & Sezaki, T. (2007). Charge and the dry-strength performance of polyampholytes: Part 2. Colloidal effects. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 301(1): 23-32.

Ibrahim, M., Wan Rosli, W. D., and Law, K. N. (2011). Comparative properties of Soda pulps from stalk, bast, and core of Malaysian grown kenaf. *BioResources*. 6(4): 5074-5085.

Ismail, A. L. and Abdul Shukur, J. (2016). *An Economic Analysis of the Malaysian Coconut Industry*. Paper presented at the National Coconut Workshop, August 9, Kuala Lumpur, Malaysia.

Jafari Petroudy, S. R., Syverud, K., Chinga Carrasco, G., Ghasemian, A., and Resalati, H. (2014). Effects of bagasse microfibrillated cellulose and cationic polyacrylamide on key properties of bagasse paper. *Carbohydrate Polymers*. 99: 311-318.

Jahan, M. S., and Rawshan, S. (2009). Reinforcing potential of jute pulp with trema orientalis (nalita) pulp. *BioResources.* 4(3): 921-931.

Jawaid, M. and Abdul Khalil, H. P. S. (2011). Cellulosic/ synthetic fibre reinforced polymer hybrid composites : A review. *Carbohydrate Polymers.* 86(1):1-18.

Jiménez, L., Pérez, I., Garcia, J. C., López, F., and Ariza, J. (2004). The influence of the ethanol pumping of wheat straw and of the beating of pulp on the resulting paper sheets. *Wood Science and Technology.* 38(2): 127-137.

Jiménez, L., Serrano, L., Rodríguez, A., and Sánchez, R. (2009). Soda-anthraquinone pulping of palm oil empty fruit bunches and beating of the resulting pulp. Bioresource Technology. 100(3): 1262-1267.

Johansson, A. (2011). Correlations between fibre properties and paper properties. http://www. diva- portal. org/ smash/ get/ diva2: 460467/ FULLTEXT01. pdf. Retrieved on January 2017.

Josephine, F. (2010). Paper or Plastic: A Fresh Look at Protective Packaging. http:// mhlnews. com/ transportation- amp- distribution/ paper-or- plastic- fresh-look-protective-packaging. Retrieved on April 2015.

Jukka, T. (2011). Highlight on paper and paperboard: 1999–2009, FAOSTAT-ForesSTAT, Food and Agriculture Organization of the United Nations, http://faostat.fao.org/Portals/_Faostat/documents/pdf/Paper%20and%20paperboard.pdf. Retrieved on November 2014.

Karlsson, H., Beghello, L., Nilsson, L., and Stolpe, L., (2007). Abaca as a reinforcement fiber for softwood pulp. *Tappi Journal.* 6(10): 25-32.

Karthikeyan, A. and Balamurugan, K. (2012). Effect of alkali treatment and fiber length on impact behavior of coir fiber reinforced epoxy composites. *Journal of Scientific & Industrial Research.* 71: 627-631.

Kaur, H., Dutt, D., and Tyagi, C. H. (2010). Optimization of soda pulping process of ligno-cellulosic residues of lemon and sofia grasses produced after steam distillation. *BioResources.* 6(1), 103-120.

Kaushal, M. C., Sirohiya, V. K., and Rathore, R. K. (2017). Corrugated board structure: a review. *International Journal of Application of Engineering and Technology*. 2(3): 228-234.

Kenneth, W. B., 1970. *Handbook of pulp and paper technology (2nd ed.)*. New York: Van Nostrand Reinhold Company.

Khedari, J., Nankongnab, N., Hirunlabh, J., and Teekasap, S. (2004). New low-cost insulation particleboards from mixture of durian peel and coconut coir. *Building and Environment.* 39(1): 59-65.

Khider, T., Omer, S., & Taha, O. (2011). Alkaline pulping with additives of Southern cattail stems from sudan. *World Applied Sciences Journal*. 15(10): 1449-1453.

Khristova, P., and Karar, I. (1999). Soda-anthraquinone pulp from three *Acacia nilotica* subspecies. *Bioresource Technology.* 68(3): 209-213.

Khristova, P., Bentcheva, S., and Karar, I. (1998). Soda-AQ pulp blends from kenaf and sunflowers stalks. *Bioresource Technology.* 66: 99-103.

Khristova, P., Kordsachia, O., Patt, R., and Dafaalla, S. (2006). Alkaline pulping of some eucalypts from Sudan. *Bioresource Technology.* 97(4): 535-544.

Kline, J. E., (1982). *Paper and paperboard manufacturing and converting fundamentals*. San Francisco: Miller Freeman.

Koetz, J. and Kosmella, S. (2007). *Polyelectrolytes and Nanoparticles*. German: Springer-Verlag Berlin Heidelberg Publication.

Krogerus, B., Fagerholm, K., and Tiikkaja, E. (2002). Fines from different pulps compared by image analysis. *Nordic Pulp & Paper Research Journal*. 17(4): 440-444.

Kubes, G. J., Fleming, B. I., MacLeod, J. M., Bolker, H. I., (1980). Alkaline pulping with additive. A review. *Wood Science Technology.* 14: 207-228.

Laivins, G.V., and Scallan, A. M. (1993). The mechanism of hornification of wood pulps. In Proceedings of the 10th Fundamental Research Symposium. Oxford, UK, pp. 1235-1260.

Latifah, J., Ainun, Z. M. A., Rushdan, I., and Mahmudin, S. (2009). Restroring strength to recycled fibres by blending with kenaf pulp. *Malaysian Journal of Science.* 28(1): 79-87.

Law, K. N., and Wan Rosli, W. D. (2000). CMP and CTMP of a fast growing tropical wood: Acacia mangium. *Tappi*. 83(7): 61-68.

Law, K.-N., Daud, W. R. W., and Ghazali, A. (2007). Morphological and chemical nature of fiber strands of oil palm empty-fruit-bunch (OPEFB). *BioResources.* 2(3): 351–362.

Liu, Z., Cao, Y., Yao, H., and Wu, S. (2013). Oxygen delignification of wheat straw soda pulp with anthraquinone addition. *BioResources.* 8(1): 1306–1319.

Lowendahl, L., and Samuelson, O. (1977). Carbohydrate stabilization during kraft cooking with addition of anthraquinone. *Svensk Papperstidn.* 80: 549-551.

Lyklema, J.,Van Leeuwen, H. P., and Minor, M. (1999). DLVO-theory, a dynamic re-interpretation. *Advances in Colloid and Interface Science.* 83(1): 33-69.

MacLeod, J. M., Iwase, H., Bolker, H. I. (1984). The carbohydrate composition ofsoda- additive pulps. *Tappi J.* 67(5): 123-124.

Main, N. M., Talib, R. A., Ibrahim, R., Rahman, R. A., and Mohamed, A. Z. (2015). Linerboard made from soda-anthraquinone (soda-AQ) treated coconut coir fiber and effect of pulp beating. *BioResources. 10*(4): 6975-6992.

MAO (2016). *Overview of coconut industry in Malaysia,* Ministry of Agriculture and Agro Based Industry, Malaysia. Paper presented at the National Coconut Workshop, August 9, Kuala Lumpur, Malaysia.

Marcondes, P., Batt, G., Darby, D., and Daum, M. (2008). Minimum Samples Needed to Construct Cushion Curves Based on the Stress Energy Method. *Journal of Applied Packaging Research.* 2(3): 191-198.

Marsoem, S. N., Sulistyo, J., Prasetyo, V. E., Andhini, Y., & Setiaji, F. (2012). Maintaining Environmental Quality : Fiber Characterization as a Tool for Verifying Pulp Fiber Composition. http:// teknologihutan. fkt. ugm. ac. id. Retrieved on January 2017.

Masliyah, J. H. and Bhattacharjee, S. (2006). *Electrokinetic and Colloid Transport Phenomena.* New Jersey: John Wiley & Sons, Inc.

Masrol, S. R., Ibrahim, M. H. I., Adnan, S., Shah, A., Amin Syah, M. M. S., Main, N. M., Othman, M. H. (2014). Effect of beating process to soda anthraquinone pulp of oil palm male flower spikes fibre. http:// eprints. uthm. edu. my/ 6357/ 1/32.pdf. Retrieved on January 2017.

Mayers, G. C., and Bagby, M. O. (1994). Suitability of kenaf CTMP for linerboard. *Tappi Jornal.* 77(12): 113-118.

McDonough, T. J., and Herro, J. L. (1982). Influence of low-lignin pulping conditions on bleachability: effects of anthraquinone and effective alkali charge. *Tappi J.* 65(9): 117-121.

McDonough, T. J., and Van Drunen, V. J. (1980). Pulping to low residual lignin contents in the kraft-anthraquinone and kraft processes. *Tappi J.* 63(11): 83-87.

Md Zin, I. (2002). *Analisa Spectrum Kejutan Terhadap Papan Gelugur Sebagai Bahan Pengkusyenan Pembungkus.* Master dissertation, UTM, Malaysia.

MetsäFibre (2014). http://www.metsafibre.com/News/Articles/Pages/ Papers- inorder. aspx. Retrieved on October 2016.

Minor, J. L., and Atalla, R. H. (1992). Strength loss in recycled fibers and methods of restoration. In *MRS Proceedings*, Cambridge University Press. 266: 215-228.

Minor, J.L., Tim Scott, C., and Rajai, H.A. (1993). *Restoring bonding strength to recycled fibers.* Paper presented at the Recycling Symposium, February 28-March 1-4, New Orleans, LA, Atlanta.

Miranda, R., Bobu, E., Grossman, H., Stawicki, B., and Blanco, A. (2010). Factors influencing a higher use of recovered paper in the European paper industry. *Cellulose Chemistry & Technology*. 44(10): 419.

Mohamad Jani, S., and Rushdan, I. (2014). Effect of bleaching on coir fibre pulp and paper properties. *Journal of Tropical Agriculture and Food Science.* 42(1): 51-61.

Mohamad Jani, S., and Rushdan, I. (2016). Mechanical properties of beating pulp and paper from rice straw. *Journal of Tropical Agriculture and Food Science.* 44(1): 103-109.

Mohanty, A. K., Misra, M., and Drzal, L. T. (2002). Sustainable bio-composites from renewable resources: opportunities and challenges in the green materials world. *Journal of Polymers and the Environment.* 10(1-2): 19-26.

Mohanty, A. K., Misra, M., and Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: An overview. *Macromolecular Materials and Engineering.* 276-277(1): 1–24.

Mojzes, Á., & Böröcz, P. (2015). Decision support model to select cushioning material for dynamics hazards during transportation. *Acta Technica Jaurinensis.* 8(2): 188-200.

Mojzes, A., Földesi, P., and Böröcz, P. (2012). Define cushion curves for environmental firendly packaging foam. *Annals of the Faculty of Engineering Hunedoara*. 10(1): 113.

Monteiro, S. N., Terrones, L. A. H. and D'Almeida, J. R. M. (2008). Mechanical performance of coir fiber/polyester composites. *Polymer Testing*. 27: 591-595.

Moulin, P. and Roques, H. (2003). Zeta potential measurement of calcium carbonate. *Journal of Colloid and Interface Science*. 261: 115-126.

Mwaikambo, L.Y., (2006). Review of the History, Properties and Application of Plant Fibres. *African Journal of Science and Technology*. 7(2): 120-133.

Myers, D. (1999). *Surfaces, Interfaces and Colloids*. New York: Wiley-VCH Publication.

Narendra, R., and Yiqi, Y. (2005). Biofibers from agricultural by products for industrial applications. *Trends in Biotechnology*. 23(1): 22-7.

Nassar, M. A., Awad, H. M., El-Sakhawy, M., and Hassan, Y. R. (2015). An optimum mixture of virgin rice straw pulp and recycled old newsprint pulp and their antimicrobial activity. *International Journal of Technology*. 6(1): 63-72.

Nazhad, M.M., and Sodtivarakul, S. (2004). OCC pulp fractionation-A comparative study of fractionated and unfractionated stock. *Tappi Journal*. 3(1): 35-50.

Nazhad, M. M. (2005). Recycled fiber quality-A review. *Journal of Industrial and Engineering Chemistry*. 11(3): 314-329.

Nelson, P. J., and Gniel, G. M. (1986). Delignification of Eucalyptus regnans wood during soda pulping. *APPITA-Australian Pulp and Paper Industry Technical Association*. 39(2): 110-114.

Nieschlag, H. J., Nelson, G. H., Wolff, J. A., and Perdue, R. E. (1960). A search for new fiber crops. *Tappi*. 43(3): 193-194.

Norbert, S., Ellen, K., Rainer, B., and Martin, R. (2009). Soda-AQ pulping of wheat straw and its blending effect on Old Corrugated Cardboard (OCC) pulp properties. *Tappsa Journal March*. 35-39.

Nurul Husna, M. H., Suhaimi, M., and Rushdan, I. (2013). Effect of soda-anthraquinone pulping conditions and beating revolution on the mechanical properties of paper made from gigantochloa scortechinii (semantan bamboo). *The Malaysian Jornal of Analytical Sciences.* 17(1): 75-84.

Nurul Husna, M. H., Suhaimi, M., and Rushdan, I. (2014). Properties of Gigantochloa scortechinii paper enhancement by beating revolution. *Journal of Tropical Resources and Sustainable Science*. 2: 59-67.

Ogbonnaya, C. I., Roy-Macauley, H., Nwalozie, M. C., Annerose, D. J. M. (1997). Physical and Histochemical Properties of Kenaf (Hibiscus Cannabinus L.) Grown under Water Deficit on a Sandy Soil. *Industrial Crops and Products.* 7(1): 9-18.

Otmar, T. (2006). Paper and board grades and their properties. In *Handbook of Paper and Board*, pp. 451-457, ed. H. Holik. Germany: Wiley-VCH Verlag GmbH & Co. KgaA.,Weinheim.

PaperAcademy (2015). Paper functional chemicals- dry strength resins. http:// www. paperacademy.net. Retrieved on May 2015.

PaperOnWeb (2015). Properties of pulp. http://www.paperonweb.com/pulppro.htm. Retrieved on March 2015.

Parkway Display (2017). Corrugated Board and Flute Type. http://www.displaycardboard.com/corrugated-board-and-flute-type. Retrieved on March 2017.

Pekkala, O. (1982). On the extended delignification using polysulfide or anthraquinone in kraft pulping. *Paperi ja Puu.* 64(11): 735-744.

Perkins, S., and Schnell, P. (2000). *The corrugated containers manufacturing process (1st ed.).* Atlanta: TAPPI Press.

Poonam, and Dutt, D. (2014). Anthraquinone and tween 20 based kraft pulping technology for l. Leucocephala and E. Equisetifolia. *International Journal of Engineering & Science Research.* 4(11): 808-811.

Prop 65 (2011). Propostion 65 Safe harbour levels: No significant risk levels for carcinogens and maximum allowable dose levels for chemicals causing reproductive toxidity. http://oehha.ca.gov/prop65/pdf/Sept2011Status.pdf. Retrieved on March 2015.

Qualityfoam (2017). Packaging design guide: calculate fundamental cushion requirements and product fragility. http:// www. qualityfoam. com/ package-design- guide-3. asp. Retrieved on March 2017.

Rasa, M., and Resalati, H. (2014). Effect of CMC, cationic starch and carboxymethylation treatments on OCC pulp properties. *World Science Journal.* 2: 34-47.

Riley, A. (2012). Paper and Paperboard Packaging. In *Packaging Technology: Fundamentals, Materials and Processes*, ed. A. Emblem, H. Emblem, pp 178-179. UK: Woodhead Publishing Limited.

RISI (2015). Global production of paper and board hit record levels in 2014. http://www.risiinfo.com/press-release/global-production-of-paper-and-board-hit-record-levels-in-2014/. Retrieved on November 2016.

Rodríguez, A., Moral, A., Serrano, L., Labidi, J., and Jiménez, L. (2008). Rice straw pulp obtained by using various methods. *Bioresource Technology*. 99(8), 2881-2886.

Rong, M. Z., Zhang, M. Q., Liu, Y., Yang, G. C., and Zeng, H. M. (2001). The effect of fiber treatment on the mechanical properties of unidirectional sisal-reinforced epoxy composites. *Composites Science and Technology*. 61(10): 1437-1447.

Rowell, R. M., Han, J. S., & Rowell, J. S. (2000). Characterization and factors effecting fiber properties. *Natural Polymers and Agrofibers Bases Composites.* 115-134.

Rushdan, I. (2002). Chemical composition of alkaline pulps from oil palm empty fruit bunches. *Oil Palm Bulletin.* 44: 19-24.

Rushdan, I. (2003a). Effect of refining on fibre morphology and drainage of soda pulp derived from oil palm empty fruit bunches. *Journal of Tropical Forest Products*. 9(1-2): 26-34.

Rushdan, I., (2003b). Structural, mechanical and optical properties of recycled paper blended with oil palm empty fruit bunch pulp. *Journal of Oil Palm Research.* 15(2): 28-34.

Rushdan, I., Nurul Husna, M. H., Latifah, M. H., Mahmudin, S., and Mohd Nor, M. Y. (2009). *The effect of soda-AQ pulping parameters on pulp properties of kenaf*. Paper presented at the International Conference on Kenaf and Allied Fiber *(ICKAF 2009)*, Kuala Lumpur.

Salminen, K., Kataja-Aho, J., Lindqvist, H., Retulainen, E., Rantanen, T., and Sundberg, A. (2011). The effects of certain polymers on tensile strength and tension relaxation of wet web. In *TAPPI PaperCon Conference, Covington, KY, USA* (pp. 825–832).

Sarkhosh, F., and Talaiepour, M. (2009). Soda-AQ pulping of wheat straw and its blending effect on old corrugated cardboard (OCC) pulp properties. *Tappsa Journal*. March: 35-39.

Satyanarayana, K. G., Sukumaran, K., Mukherjee, P. S., Pavithran, C. and Pillai, S. G. K. (1990). Natural fibre-polymer composites. *Cement & Concrete Composites*. 12(2): 117-136.

Satyanarayana, K. G., Arizaga, G. G. C., and Wypych, F. (2009). Biodegradable composites based on lignocellulosic fibers- an overview. *Progress in Polymer Science.* 34(9): 982-1021.

Savard, J., Besson, A., and Morize, S. (1954). Chemical Analysis of Tropical Timber, Publication No. 5. France: Nogent-sur-Marne.

Scott, W. E. (1996). Principles of Wet end Chemistry. 1st Printing, Library of Congress Cataloging-in-Publication Data, Atlanta, Georgia. TAPPI PRESS.

Seth, R. S., and Page, D. H. (1990). Fiber properties and tearing resistance. *Tappi Journal*. 71(2): 103-107.

Seth, R. S., Soszynski, R. M., and Page, D. H. (1979). Intrinsic edgewise compression strength of paper. *Tappi Journal.* 62(12): 97-99.

Shakhes, J., Zeinaly, F., Marandi, M. A. B., and Saghafi, T. (2011). The effects of processing variables on the soda and soda-AQ pulping of kenaf bast fiber. *BioResources.* 6(4), 4626-4639.

Sharma, A. K., Dutt, D., Upadhyaya, J. S., & Roy, T. K. (2011). Anatomical, morphological, and chemical characterization of Bambusa tulda, Dendrocalamus hamiltonii, Bambusa balcooa, Malocana baccifera, Bambusa arundinacea and Eucalyptus tereticornis. *BioResources.* 6(4): 5062-5073.

Singh, J., Ignatova, L., Olsen, E., and Singh, P. (2010). Evaluation of the stress-energy methodology to predict transmitted shock through expanded foam cushions. *Journal of Testing and Evaluation.* 38(6): 1-7.

Singh, P., Sulaiman, O., Hashim, R., Peng, L. C., and Singh, R. P. (2012). Using biomass residues from oil palm industry as a raw material for pulp and paper industry: Potential benefits and threat to the environment. *Environment, Development and Sustainability*. 15(2): 367-383.

Sixta, H. (2006). *Handbook of pulp*. Weinheim: WEILY-VCH Verlag GmbH & Co KGaA.

Sjostrom, E. (1993). *Wood Chemistry: Fundamentals and Applications (2nd ed.)*. San Diego, California: Academic Press, Inc.

Smith, D. C. (1992). *Chemical additives for improved compression strength of unbleached board*. Paper presented at the Proc. TAPPI 1992 Papermakers Conference, TAPPI Press, Atlanta, 393-404.

Smook, G. A., (2002). *Handbook for Pulp and Paper Technologists (3rd ed.)*. Canada: Angus Wilde Publications.

Song, J., Wang, Y., Hubbe, M. A., Rojas, O. J., Sulic, N., and Sezaki, T. (2006). Charge and the dry-strength performance of polyampholytes. Part I: Handsheet properties and polymer solution viscosity. *Journal of Pulp and Paper Science. 32*(3): 156-162.

Soroka, W. (2009). *Fundamental of Packaging Technology*. *(4th ed.)*. United Kingdom: Institute of Packaging Professionals.

Sridach, W. (2010). Pulping and paper properties of Palmyra palm fruit fibers. *Sonklanakarin Journal of Science and Technology.* 32(2): 201-205 Daleski, E. J. (1965). The effect of elevated temperatures on the alkaline pulping processes. *Tappi*, *48*(6), 325–330.

Surewicz, W. (1962). The sorption of organic components from cooking liquor by cellulose fibres; its relation to the 'dangerous cooking crest' in alkaline pulping. *Tappi*. 45(7):570.

Tran, A. V. (2006). Chemical analysis and pulping study of pineapple crown leaves. *Industrial Crops and Products*. 24: 66-74.

Tsoumis, G. (1991). *Science and Technology of Wood: Structure, Properties and Utilization*, pp 494. New York: Van Nostrand Reinhold.

Tutuş, A., Kazaskeroğlu, Y., and Çiçekler, M. (2015). Evaluation of tea wastes in usage pulp and paper production. *BioResources.* 10(3): 5407-5416.

Twede, D., and Selke, S. E. M. (2015). *Carton, Crates and Corrugated Board: Handbook of Paper and Wood Packaging Technology (2nd ed.)*. Lancaster, USA: DEStech Publications.

Ulfa, M., Trisunaryanti, W., Setiaji, B, and Triyono (2014). Effect of beating on coir handsheet properties. *American Journal of Oil and Chemical Technologies*. 2(1): 12-24.

Van Dam, J. E. G., Van Den Oever, M. J. A, Keijsers, E. R. P., Van Der Putten, J. C., Anayron, C., Josol, F., and Peralta, A. (2006). Process for production of high density/ high performance binderless boards from whole coconut husk part 2: coconut husk morphology, composition and properties. *Industrial Crops and Products*. 24(2): 96-104.

Van Dam, J. E. G., Van Den Oever, M. J. A., Teunissen, W., Keijsers, E. R. P., and Peralta, A. G. (2004). Process for production of high density/high performance binderless boards from whole coconut husk Part 1: Lignin as intrinsic thermosetting binder resin. *Industrial Crops and Products* 19(3); 207-216.

Van, C (2015). Cellulose. https:// myorganic chemistry. wikispaces. com/ Cellulose. Retreived on May 2015.

Verma, D., Gope, P. C., Shandilya, A., Gupta, A. and Maheshwari, M. K. (2013). Coir fibre reinforcement and application in polymer composites : A Review. *Journal of Materials and Environmental Science.* 4(2): 263-276.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., and Santas, R. (2004). Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops and Products.* 19(3): 245-254.

Wambua, P., Vangrimde, B., Lomov, S. and Verpoest, I. (2007). The response of natural fibre composites to ballistic impact by fragment simulating projectiles. *Composite Structures.* 77(2): 232-240.

Wan Rosli, W. D., Zainuddin, Z. and Lee, L. K. (2004). Influence of pulping variables on the properties of *Elaeis guineensis* soda pulp as evaluated by response surface methodology. *Wood Science and Technology.* 38 (3): 191-205.

Wan Rosli, W. D., Zainuddin, Z., and Roslan, S. (2005). Upgrading of recycled papers with oil palm fibre soda pulp. *Industrial Crops and Products*. 21(3): 325-329.

Wang, G., and Jing, Y. (2014). Synthesis and application of a cationic polyacrylamide dry strength agent with anionic content. *BioResources.* 9(1): 1111-1120.

Wang, W. and Huang, G. (2009). Characterisation and utilization of natural coconut fibres composites. *Materials & Design.* 30(7): 2741-2744.

Wan, J., Yang, J., Ma, Y., and Wang, Y. (2011). Effects of pulp preparation and papermaking processes on the properties of OCC fibers. *BioResources.* 6(2): 1615-1630.

Wanrosli, W. D., Zainuddin, Z., Law, K. N., Asro, R. (2007). Pulp from oil palm fronds by chemical processes. *Industrial Crops and Products.* 25(1): 89-94.

Watson, A. J., and Dadswell, H. E. (1964). Influence of fiber morphology on paper properties 3: length diameter (l/d) ratio. *Appita Journal*. 17(6): 146-150.

Wise, L. E., Murphy, M., and D'Addieco, A. A. (1946). Chlorite holocellulose, its fractionation and bearing on summative wood analysis and studies on the hemicellulose. *Paper Trade J.* 122 (2): 35-43.

Wistara, N., and Hidayah, N. H. (2010). Virgin bamboo pulp substitution improved strength properties of OCC pulp. *Jurnal Ilmu Dan Teknilogi Hasil Hutan.* 3(1): 14-18.

Wong, K. J, Nirmal, U. and Lim, B. K. (2010). Impact behavior of short and continuous fiber-reinforced polyester composites. *Journal of Reinforced Plastics and Composites.* 29(23): 3463-3474.

Wutisatwongkul, J., Thavarungkul, N., Tiansuwan, J., and Termsuksawad, P. (2016). Influence of Soda Pulping Variables on Properties of Pineapple (Ananas comosus Merr.) Leaf Pulp and Paper Studied by Face-Centered Composite Experimental Design. *Advances in Materials Science and Engineering.* 2016.

Xiao, L., Salmi, J., Laine, J., and Stenius, P. (2009). The effects of polyelectrolyte complexes on dewatering of cellulose suspension. *Nordic Pulp & Paper Research Journal.* 24(2): 148-157.

Yamauchi, T., and Hatanaka, T. (2002). Mechanism of paper strength development by the addition of dry strength resin. *Appita Journal.* 55(3): 240-243.

Yao, J., Hu, Y., and Lu, W. (2012). Performance research on coir fiber and wood debris hybrid board. *BioResources.* 7(3): 4262-4272.

Yu, Y., Koljenen, K., and Paulauro, H. (2002). Surface chemical composition of some non-wood pulps. *Industrial Crops and Products.* 15(2): 123-130.

Yuhazri, M. and Dan, M. (2007). Helmet shell using coconut fibre. *Journal Advanced Manufacturing Technology.* 1(1): 23-30.

Zhao, B., & Kwon, H. J. (2011). Adhesion of polymers in paper products from the macroscopic to molecular level-an overview. *Journal of Adhesion Science and Technology.* 25(6-7): 557-579.

Zimmermann, T., Pöhler, E., and Geiger, T. (2004). Cellulose fibrils for polymer reinforcement. *Advanced Engineering Materials.* 6(9): 754-761.

Zion Market Research (2016). Paper Packaging Material Market. https://www.zionmarketresearch.com/report/paper-packaging-materialmarket. Retrieved on March 2017.