



**Faculty of Mechanical and Manufacturing Engineering
Technology**

**RESEARCH AND DEVELOPMENT OF ACOUSTICAL PANEL
MADE FROM KENAF CORE**

Nur Sima Syazwani Binti Hamzah

Bachelor of Manufacturing Engineering Technology (Process and Technology)

2020

**RESEARCH AND DEVELOPMENT OF ACOUSTICAL PANEL MADE FROM
KENAF CORE**

NUR SIMA SYAZWANI BINTI HAMZAH

**A thesis submitted
in fulfillment of the requirements for the Bachelor of Manufacturing
Engineering Technology (Process and Technology)**

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

**UTeM****UNIVERSITI TEKNIKAL MALAYSIA MELAKA**اوتيم سي تي تيكيكل ماليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA**BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA****TAJUK: RESEARCH AND DEVELOPMENT OF ACOUSTICAL PANEL MADE FROM KENAF CORE****SESI PENGAJIAN: 2019/20 Semester 1****Saya NUR SIMA SYAZWANI BINTI HAMZAH**

Mengaku membenarkan laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat Salinan untuk tujuan pengajian sahaja dengan izin penulis
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan bertukaran antara institusi pengajian tinggi
4. **Sila tandakan (✓)

- SULIT*** Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972.
- TERHAD*** Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan.
- TIDAK TERHAD**

Yang benar,

.....
Alamat Tetap:9F, LORONG APOLLO 2,
JALAN APOLLO, SIBU
96000 SARAWAK.

Tarikh : 3 JANUARY 2020

Disahkan oleh :


.....
Cop RasmiASSOCIATE PROFESSOR DR. MOHD YUHAZRI BIN YAAKOB
Deputy Dean (Research & Industrial Link)
Faculty of Mechanical and Manufacturing Engineering Technology
Universiti Teknikal Malaysia Melaka

10.01.2020

**** jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/ organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT dan TERHAD.**

DECLARATION

I declare that this thesis entitled “Research and Development of Acoustical Panel Made from Kenaf Core” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :.....
Author's Name : NUR SIMA SYAZWANI BINTI HAMZAH
Date : 3 JANUARY 2020

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfilment of Bachelor of Manufacturing Engineering Technology (Process and Technology).

.....
(ASSOC. PROF. IR/TS. DR. MOHD YUHAZRI BIN YAAKOB CEng MIMechE)

~~ASSOCIATE PROF. IR. TS. DR. MOHD YUHAZRI BIN YAAKOB
Deputy Dean (Research & Industrial Link)
Faculty of Mechanical and Manufacturing Engineering Technology
Universiti Teknikal Malaysia Melaka~~

10.01.2020

DEDICATION

Dedicated to

my beloved father, Hamzah bin Uran

my appreciated mother, Aminah binti Mahmud

my sweet brothers, Mohd Hafizal, Mohd Iftitah, Mohd Nizam, Mohd Zamri

my lovely sisters, Nur Nadirah and Rafidah binti Abd Rahman

my little heroes Mohd Darwisy Mieqael, Mohd Fieras Mieqael, Mohd Nazmie Mieqael,

Mohd Muqrie Mieqael and Mohd Ziqrie Mieqael

my sweetheart, Kim Seok Woo

for giving me moral support, cooperation, encouragement and understandings.

Thank You So Much & Love You All Forever

ABSTRACT

Natural fibers such as kenaf core have the high potential to replace synthetic fibers because they offer high absorption properties, eco-friendly, low cost and low density. Therefore, the development of natural fibers has increased the interest of researchers and many fields of the manufacturers such as aircraft and automotive have been used as reinforcement to fabricate a high strength property of composite materials. In addition, there are many researchers focusing on the natural fibers based composite in the form of laminate, but there is no specific study on the kenaf core in acoustical applications. In this study, an experimental investigation was conducted to explore the kenaf core with different size to develop acoustical panel. There are three (3) size of kenaf core has been used in this research which is 3 mm (A), 20 mesh (B) and 40 mesh (C). Kenaf core was used as reinforcement, polyurethane (PU) and natural rubber latex (NRL) as a matrix. The raw materials were mixed with the composition of matrix which is kenaf core filled with PU and kenaf core filled with NRL. The method used to develop acoustic panel is cold press machine. The laminated technique was used to develop the acoustic panel to propose the best layup sequence of kenaf core acoustic panel layout for optimum properties. The acoustic panel testing was conducted by using impedance tube testing. This types of acoustic panel typically deals with the low, medium and high frequency range. Furthermore, all the fabrications and testing method are based on ASTM E1050-09 standard. Next, the morphological characteristic is identified by using scanning electron microscope (SEM). At the end, due to their cost effectiveness, good performance and eco-biodegradable composite, kenaf has high potential to develop through this research. The use of natural fibres can reduce the cost of material compared synthetic fibre. For suggestion, the sound insulation materials must be placed on the wall to allow the sound vibration passed through the wall. The addition of art on the acoustic panel can be discretely integrated and simple to install as painting hanging up. The findings of this study suggest that kenaf core filled with NRL samples for AAB layup with coefficient of 0.90 at 1000 Hz has a good airflow resistivity and porosity for the application in the low frequency. It is very interesting to find out that natural fibres from kenaf plants are capable of absorbing sound at low frequency range. For medium frequency application, ABB layup with 0.88 at 1000 Hz. The layup sequence for high frequency range are ACC with coefficient of 0.96 at 3150 Hz is the most suitable layout that can be utilized as an acoustic panel at high frequency because it reveals high absorption coefficient compared to the other kenaf core filled with PU samples. This kenaf core reinforced natural rubber latex is promising light-weight materials used and naturally biodegradable for acoustical panel.

ABSTRAK

Serat semulajadi seperti teras kenaf mempunyai potensi yang tinggi untuk menggantikan gentian sintetik kerana mereka menawarkan ciri serapan tinggi, mesra alam, kos rendah dan ketumpatan rendah. Oleh itu, pembangunan serat semulajadi telah meningkatkan minat penyelidik dan banyak bidang pengeluaran seperti pesawat dan automotif telah digunakan sebagai pengukuhan untuk menghasilkan sifat kekuatan yang tinggi bahan komposit. Di samping itu, terdapat banyak penyelidik yang memberi tumpuan kepada serat semulajadi berasaskan komposit dalam bentuk lamina, tetapi tidak ada kajian khusus mengenai teras kenaf dalam aplikasi akustik. Dalam kajian ini, satu siasatan eksperimen telah dijalankan untuk meneroka teras kenaf dengan saiz yang berbeza untuk membangunkan panel akustik. Terdapat tiga (3) saiz teras kenaf telah digunakan dalam kajian ini iaitu 3 mm (A), 20 mesh (B) dan 40 mesh (C). Teras kenaf digunakan sebagai tetulang, poliuretana (PU) dan lateks getah asli (NRL) sebagai matriks. Bahan mentah ini dicampur dengan komposisi matriks yang kenaf teras diisi dengan PU dan teras kenaf diisi dengan NRL. Kaedah yang digunakan untuk membangunkan panel akustik adalah mesin tekanan sejuk. Teknik laminasi telah digunakan untuk membangunkan panel akustik untuk mencadangkan jujukan terbaik untuk susun atur panel akustik inti teras kenaf untuk sifat yang optimum. Ujian panel akustik dijalankan dengan menggunakan ujian tiub impedans. Jenis panel akustik ini biasanya berkaitan dengan julat frekuensi rendah, sederhana dan tinggi. Tambahan pula, semua fabrikasi dan kaedah ujian adalah berdasarkan ASTM E1050-09 standard. Seterusnya, ciri morfologi dikenalpasti menggunakan pengimbasan elektron mikroskop (SEM). Pada akhirnya, disebabkan keberkesanan kos, prestasi yang baik dan komposit eko-biodegradasi, kenaf mempunyai potensi yang tinggi untuk membangunkan melalui kajian ini. Penggunaan serat semula jadi boleh mengurangkan kos bahan berbanding serat sintetik. Untuk cadangan, bahan penebat bunyi mesti diletakkan pada dinding untuk membenarkan getaran bunyi yang diluluskan melalui dinding. Penambahan seni pada panel akustik boleh secara tegas bersepadu dan mudah untuk memasang sebagai lukisan tergantung. Dapatan kajian ini mencadangkan bahawa teras kenaf diisi dengan sampel NRL bagi AAB dengan pekali 0.90 pada 1000 Hz mempunyai aliran udara yang baik kerintangan dan porositi untuk permohonan dalam frekuensi rendah. Ia adalah sangat menarik untuk mengetahui bahawa serat semulajadi dari tumbuh-tumbuhan kenaf mampu menyerap bunyi pada julat frekuensi rendah. Untuk aplikasi frekuensi sederhana, ABB layup dengan 0.88 pada 1000 Hz. Jujukan layup untuk julat frekuensi tinggi ACC dengan pekali 0.96 pada 3150 Hz adalah susun atur yang paling sesuai yang boleh digunakan sebagai panel akustik pada frekuensi tinggi kerana ia mendedahkan pekali penyerapan tinggi berbanding dengan sampel teras kenaf lain yang diisi dengan PU. Teras kenaf getah asli menjanjikan bahan berat ringan yang digunakan dan secara semulajadi boleh dikompos untuk panel akustik.

ACKNOWLEDGEMENT

I would like to express my sincere thank you to everyone who supported me throughout this research study especially my beloved supervisor Prof. Madya Ir. Dr. Mohd Yuhazri Bin Yaakob for providing me with all the necessary facilities for my research. His guidance to help me in all the time of research and writing of this thesis.

Next, I would like to acknowledge with my gratitude, the support and love of my family, my parents Hamzah bin Uran and Aminah bt Mahmud for fully supporting me spiritually throughout my life.

Other than that, I would like to thank to my senior, Mohd AmirHafizan bin Husin, my research teammates, Tan Rui Jie, Lee Set Foon, Nur Atiqah bt Abd Ghani and Renuka A/P Ragu, for the stimulating discussions, for the sleepless nights we were working together before the deadlines, and for all the fun we have during this research works. Thanks for the great friendship

TABLE OF CONTENTS

	PAGE
DECLARATION	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xviii
LIST OF SYMBOLS	xix
CHAPTER	
1. INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	4
1.3 Objectives	6
1.4 Scopes	7
1.5 Rational of Research	7
1.6 Summary of Methodology	9
1.7 Thesis Arrangement	11
2. LITERATURE REVIEW	
2.1 Introduction of Composite	12
2.1.1 Natural fibre composites	13
2.1.2 Classification of natural fibre composites	14
2.2 Kenaf	15
2.2.1 Fibre	16
2.2.2 Core	17
2.2.3 Summary of kenaf	19
2.3 Product Made from Kenaf	19
2.3.1 Product from kenaf fibre	20
2.3.2 Product from kenaf core	22
2.3.3 Summary of product made from kenaf	23
2.4 Acoustic Panel	24
2.4.1 Acoustic properties of arenga pinnata fibre	26
2.4.2 Acoustic properties of oil palm fibre	28

2.4.3	Acoustic properties of kapok fibre	29
2.4.4	Acoustic properties of kenaf fibre	31
2.4.5	Acoustic properties of kenaf core particleboard	32
2.4.6	Acoustic characterization	32
2.4.7	Summary of acoustic panel	33
2.5	Sound Absorb Testing	34
2.5.1	Impedance tube testing	34
2.5.2	Reverberation room	36
2.5.3	Summary of sound testing	37
2.6	Summary of Literature Review	38
3.	METHODOLOGY	42
3.1	An Overview of Methodology	42
3.2	Raw Material Preparation	44
3.2.1	Kenaf core	44
3.2.2	Polyurethane	45
3.2.3	Natural rubber latex	45
3.3	Preparation of Mould	47
3.4	Fabrication Process	48
3.4.1	Dry oven	48
3.4.2	Sample fabrication filled with PU	48
3.4.3	Sample fabrication filled with NRL	50
3.5	Cutting Process	50
3.5.1	Layup sequence of kenaf core	52
3.6	Sound Testing	53
3.6.1	Impedance tube test	53
3.7	Scanning Electron Microscope	54
4.	RESULTS AND DISCUSSIONS	56
4.1	Fabrication of Acoustic Panel	56
4.1.1	Type of layup KCPU	56
4.1.2	Type of layup KCNRL	58
4.1.3	Summary of fabrication acoustic panel	59
4.2	Performance of Sound Absorption Coefficient on Acoustic Panel	60
4.2.1	Performance of acoustic panel filled with PU	60
4.2.1.1	Sample AAA	60
4.2.1.2	Sample AAB	63
4.2.1.3	Sample AAC	64

4.2.1.4	Sample ABA	66
4.2.1.5	Sample ABB	67
4.2.1.6	Sample ABC	69
4.2.1.7	Sample ACA	70
4.2.1.8	Sample ACB	72
4.2.1.9	Sample ACC	73
4.2.1.10	Sample BAA	75
4.2.1.11	Sample BAB	76
4.2.1.12	Sample BAC	77
4.2.1.13	Sample BBA	79
4.2.1.14	Sample BBB	80
4.2.1.15	Sample BBC	81
4.2.1.16	Sample BCA	83
4.2.1.17	Sample BCB	84
4.2.1.18	Sample BCC	85
4.2.1.19	Sample CAA	87
4.2.1.20	Sample CAB	88
4.2.1.21	Sample CAC	89
4.2.1.22	Sample CBA	91
4.2.1.23	Sample CBB	92
4.2.1.24	Sample CBC	93
4.2.1.25	Sample CCA	95
4.2.1.26	Sample CCB	96
4.2.1.27	Sample CCC	97
4.2.2	Summary the effect of acoustic performance on KCPU	99
4.2.3	Performance of acoustic panel filled with NRL	101
4.2.3.1	Sample AAA	101
4.2.3.2	Sample AAB	103
4.2.3.3	Sample AAC	105
4.2.3.4	Sample ABA	107
4.2.3.5	Sample ABB	108
4.2.3.6	Sample ABC	110
4.2.3.7	Sample ACA	111
4.2.3.8	Sample ACB	113
4.2.3.9	Sample ACC	114
4.2.3.10	Sample BAA	116
4.2.3.11	Sample BAB	117
4.2.3.12	Sample BAC	119

4.2.3.13	Sample BBA	120
4.2.3.14	Sample BBB	122
4.2.3.15	Sample BBC	123
4.2.3.16	Sample BCA	125
4.2.3.17	Sample BCB	126
4.2.3.18	Sample BCC	128
4.2.3.19	Sample CAA	129
4.2.3.20	Sample CAB	131
4.2.3.21	Sample CAC	132
4.2.3.22	Sample CBA	134
4.2.3.23	Sample CBB	136
4.2.3.24	Sample CBC	137
4.2.3.25	Sample CCA	139
4.2.3.26	Sample CCB	140
4.2.3.27	Sample CCC	142
4.24	Summary the effect of acoustic performance on KCNRL	143
4.2.5	Summary the performance of sound absorption	146
4.3	Layup Sequence	147
4.3.1	The best layup sequence of KCPU	147
4.3.1.1	The best layup sequence of KCPU in low frequency range	147
4.3.1.2	The best layup sequence of KCPU in medium frequency range	148
4.3.1.3	The best layup sequence of KCPU in high frequency range	149
4.3.2	The best layup sequence of KCNRL	150
4.3.2.1	The best layup sequence of KCNRL in low frequency range	150
4.3.2.2	The best layup sequence of KCNRL in medium frequency range	151
4.3.2.3	The best layup sequence of KCNRL in high frequency range	152
4.3.3	Comparison between KCPU and KCNRL samples	153
4.3.3.1	Comparison KCPU and KCNRL samples in low frequency	153
4.3.3.1	Comparison KCPU and KCNRL samples in medium frequency	154
4.3.3.1	Comparison KCPU and KCNRL samples in high frequency	155
4.5	Summary	156

5. CONCLUSION	158
5.1 Conclusion	158
5.2 Recommendations	161
5.3 Sustainability Element	163
5.4 Commercial Value and Potential	164
5.5 Research Achievement	166
REFERENCES	167
APPENDICES	176
Gantt chart PSM I	176
Gantt chart PSM II	178

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Advantages and disadvantages of natural fibre	13
2.2	Thickness and mass of kenaf fibre	17
2.3	Reported work on kenaf fibre application	21
2.4	Reported work on kenaf core application	23
2.5	Types of fibre used in acoustic application	26
2.6	Sound absorption coefficient of arenga pinnata fibre	27
2.7	Sound absorption coefficient of oil palm fibre	29
2.8	Sound absorption coefficient of kenaf fibre	31
2.9	Reported work on acoustic material	40
3.1	Properties of kenaf core	45
3.2	Properties of PU	46
3.3	Mechanical properties of NRL	47
3.4	Arrangement of the sample in the impedance tube testing	52
4.1	Arrangement of the sample in the impedance tube testing.	56
4.2	The selected KCPU sample based on their acoustic performance	98
4.3	The selected KCNRL sample based on their acoustic performance	143

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Flow chart of methodology	10
2.1	Classification of natural fibres	14
2.2	Kenaf plant	15
2.3	Example of kenaf fibre	16
2.4	Absorption coefficient of kenaf fibre of varied thickness with constant bulk density of 93.5 kg/m^3	17
2.5	Kenaf core size (a) 3 mm, (b) 20 mesh, (c) 40 mesh	18
2.6	Kenaf leaves as main ingredient	20
2.7	Mercedes automobile components made from natural fibre	22
2.8	Kenaf core bedding (a) large, (b) medium, (c) small, (d) pith	23
2.9	Acoustic baffles (a) baffles, (b) oriented baffles, (c) foam material, (d) vertically and inclined-oriented baffles	25
2.10	Arenga pinnata (a) arenga pinnata tree, (b) a sketch	27
2.11	Oil palm fibre	28
2.12	Kapok fibre	30
2.13	Non-woven fibre	31
2.14	Kenaf core particleboard for sound absorption test	32
2.15	Impedance tube set up	35
2.16	Acoustic absorption coefficient of kenaf fibre binds with natural rubber ad rockwool	36
2.17	The experimental set-up of reverberation room	37

3.1	Flow chart of methodology	43
3.2	Kenaf core particle size (a) 3 mm; (b) 20 mesh; (c) 40 mesh	44
3.3	PU liquid (a) Part A; (b) Part B	45
3.4	Natural latex	46
3.5	Dimension of mould size for the composite samples	46
3.6	Heating drying oven	47
3.7	Illustration process of acoustic panel fabrication	48
3.8	Sample prepared for sound absorption coefficient measurement using impedance tube testing.	50
3.9	Details dimension of sample preparation	50
3.10	Example of kenaf core arrangement of ABC	51
3.11	Diagram of impedance tube	53
3.12	Scanning electron microscope (SEM).	54
4.1	Shrinkage of KCPU sample	58
4.2	The sample AAA	60
4.3	Sound absorption coefficient against frequency of AAA sample filled PU	60
4.4	Microscopic image of KCPU under scanning electron microscope (SEM)	62
4.5	The sample AAB	62
4.6	Sound absorption coefficient against frequency of AAB sample filled PU	63
4.7	The sample AAC	64
4.8	Sound absorption coefficient against frequency of AAC sample filled PU	64
4.9	The sample ABA	65
4.10	Sound absorption coefficient against frequency of ABA sample filled PU	66
4.11	The sample ABB	67

4.12	Sound absorption coefficient against frequency of ABB sample filled PU	68
4.13	The sample ABC	68
4.14	Sound absorption coefficient against frequency of ABC sample filled PU	69
4.15	The sample ACA	70
4.16	Sound absorption coefficient against frequency of ACA sample filled PU	71
4.17	The sample ACB	71
4.18	Sound absorption coefficient against frequency of ACB sample filled PU	72
4.19	The sample ACC	73
4.20	Sound absorption coefficient against frequency of ACC sample filled PU	73
4.21	The sample BAA	74
4.22	Sound absorption coefficient against frequency of BAA sample filled PU	75
4.23	The sample BAB	75
4.24	Sound absorption coefficient against frequency of BAB sample filled PU	76
4.25	The sample BAC	77
4.26	Sound absorption coefficient against frequency of BAC sample filled PU	77
4.27	The sample BBA	78
4.28	Sound absorption coefficient against frequency of BBA sample filled PU	79
4.29	The sample BBB	79
4.30	Sound absorption coefficient against frequency of BBB sample filled PU	80
4.31	The sample BBC	81

4.32	Sound absorption coefficient against frequency of BBC sample filled PU	81
4.33	The sample BCA	82
4.34	Sound absorption coefficient against frequency of BCA sample filled PU	83
4.35	The sample BCB	83
4.36	Sound absorption coefficient against frequency of BCB sample filled PU	84
4.37	The sample BCC	85
4.38	Sound absorption coefficient against frequency of BCC sample filled PU	85
4.39	The sample CAA	86
4.40	Sound absorption coefficient against frequency of CAA sample filled PU	87
4.41	The sample CAB	87
4.42	Sound absorption coefficient against frequency of CAB sample filled PU	88
4.43	The sample CAC	89
4.44	Sound absorption coefficient against frequency of CAC sample filled PU	89
4.45	The sample CBA	90
4.46	Sound absorption coefficient against frequency of CBA sample filled PU	91
4.47	The sample CBB	91
4.48	Sound absorption coefficient against frequency of CBB sample filled PU	92
4.49	The sample CBC	93
4.50	Sound absorption coefficient against frequency of CBC sample filled PU	93
4.51	The sample CCA	94

4.52	Sound absorption coefficient against frequency of CCA sample filled PU	95
4.53	The sample CCB	95
4.54	Sound absorption coefficient against frequency of CCB sample filled PU	96
4.55	The sample CCC	97
4.56	Sound absorption coefficient against frequency of CCC sample filled PU	97
4.57	The overall sample of KCPU	99
4.58	The sample AAA	101
4.59	Sound absorption coefficient against frequency of AAA sample filled NRL	101
4.60	Microscopic image of KCNRL under SEM	102
4.61	The sample AAB	103
4.62	Sound absorption coefficient against frequency of AAB sample filled NRL	104
4.63	Microscopic image of AAB KCNRL under SEM	104
4.64	The sample AAC	105
4.65	Sound absorption coefficient against frequency of AAC sample filled NRL	106
4.66	The sample ABA	106
4.67	Sound absorption coefficient against frequency of ABA sample filled NRL	107
4.68	The sample ABB	108
4.69	Sound absorption coefficient against frequency of ABB sample filled NRL	109
4.70	The sample ABC	109
4.71	Sound absorption coefficient against frequency of ABC sample filled NRL	110
4.72	The sample ACA	111

4.73	Sound absorption coefficient against frequency of ACA sample filled NRL	112
4.74	The sample ACB	112
4.75	Sound absorption coefficient against frequency of ACB sample filled NRL	113
4.76	The sample ACC	114
4.77	Sound absorption coefficient against frequency of ACC sample filled NRL	115
4.78	The sample BAA	115
4.79	Sound absorption coefficient against frequency of BAA sample filled NRL	116
4.80	The sample BAB	117
4.81	Sound absorption coefficient against frequency of BAB sample filled NRL	118
4.82	The sample BAC	118
4.83	Sound absorption coefficient against frequency of BAC sample filled NRL	119
4.84	The sample BBA	120
4.85	Sound absorption coefficient against frequency of BBA sample filled NRL	121
4.86	The sample BBB	121
4.87	Sound absorption coefficient against frequency of BBB sample filled NRL	122
4.88	The sample BBC	123
4.89	Sound absorption coefficient against frequency of BBC sample filled NRL	124
4.90	The sample BCA	124
4.91	Sound absorption coefficient against frequency of BCA sample filled NRL	125
4.92	The sample BCB	126

4.93	Sound absorption coefficient against frequency of BCB sample filled NRL	127
4.94	The sample BCC	127
4.95	Sound absorption coefficient against frequency of BCC sample filled NRL	128
4.96	The sample CAA	129
4.97	Sound absorption coefficient against frequency of CAA sample filled NRL	129
4.98	The sample CAB	130
4.99	Sound absorption coefficient against frequency of CAB sample filled NRL	131
4.100	The sample CAC	132
4.101	Sound absorption coefficient against frequency of CAC sample filled NRL	133
4.102	The sample CBA	133
4.103	Sound absorption coefficient against frequency of CBA sample filled NRL	134
4.104	The sample CBB	135
4.105	Sound absorption coefficient against frequency of CBB sample filled NRL	136
4.106	The sample CBC	137
4.107	Sound absorption coefficient against frequency of CBC sample filled NRL	138
4.108	The sample CCA	138
4.109	Sound absorption coefficient against frequency of CCA sample filled NRL	139
4.110	The sample CCB	140
4.111	Sound absorption coefficient against frequency of CCB sample filled NRL	141
4.112	The sample CCC	141

4.113	Sound absorption coefficient against frequency of CCC sample filled NRL	142
4.114	The overall samples of KCNRL	145
4.115	KCPU samples in the low frequency range	147
4.116	KCPU samples in the medium frequency range	148
4.117	KCPU samples in the high frequency range	149
4.118	KCNRL samples in the low frequency range	150
4.119	KCNRL samples in the medium frequency range	151
4.120	KCNRL samples in the high frequency range	152
4.121	Comparison between Pure PU, KCPU and KCNRL samples in low frequency.	153
4.122	Comparison between Pure PU, KCPU and KCNRL samples in medium frequency.	154
4.123	Comparison between Pure PU, KCPU and KCNRL samples in high frequency	155
4.124	Illustration of sound absorption of KCNRL (a) KCNRL sample without air gaps, (b) KCNRL sample with air gaps	158
5.1	Green Acoustical Panel	164
5.2	The art acoustic panel (a) house; (b) office; (c) lecture halls	165

LIST OF ABBREVIATIONS

PU	-	Polyurethane
NRL	-	Natural rubber latex
UF	-	Urea-formaldehyde
ASTM	-	American Society for Testing and Material
SEM	-	Scanning electron microscope
KCPU	-	Kenaf core filled with polyurethane
KCNRL	-	Kenaf core filled with natural rubber latex
NA	-	Not available