

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA** 

# RESEARCH AND DEVELOPMENT OF KENAF CORE AND GYPSUM FOR CEILING DECORATIONS



# BACHELOR OF MANUFACTURING ENGINEERING TECHNOLOGY WITH HONOURS

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## Faculty of Mechanical and Manufacturing Engineering Technology



**Bachelor of Manufacturing Engineering Technology with Honours** 

# RESEARCH AND DEVELOPMENT OF KENAF CORE AND GYPSUM FOR CEILING DECORATIONS

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## UNIVERSITI TEKNIKAL MALAYSIA MELAKA

#### DECLARATION

I declare that this thesis entitled "Research and Development of Kenaf Core and Gypsum for Ceiling Decorations" is the results 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.



## APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (Aerospace Manufacturing/Industrial Design/Digital Manufacturing) with Honours.



#### **DEDICATION**

#### Dedicated to

My honourable father, Lye Teik Khon

My precious mother, Chiow Wai Kam

My beloved family, Michelle Lye Chuok Fang, Merlyn Lye Chuok Zhin and Adrian Lye Qe Bin

My supporting teammates Nur Hazirah Iffah Binti Hashim, Meryl Anyie Tomy, Muhammad

Fikri Bin Zulkifli and Dr Mohd Amirhafizan Bin Husin

My supervisor for his guidance, Prof. Madya Ir. Ts. Dr. Mohd Yuhazri Bin Yaakob

Thank you so much

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#### ABSTRACT

Natural fibers are commonly used as reinforcement in various industries and fields as they offer high mechanical performance and are environmentally friendly. This study explored on kenaf core that is used for reinforcing with gypsum for ceiling decoration application. Five different kenaf core sizes used in this research were 0.4 mm, 0.84 mm, 10mm, 20 mm, and 30 mm. The samples were later prepared by mixing a constant value of gypsum and kenaf core with an increased weight percentage from 10 % to 90 %. The mixtures are then mixed with water and poured into a plywood mould with a dimension of 320 mm x 300 mm x 10 mm. As the curing process is done, each sample is cut into a standard dimension for each mechanical testing according to the ASTM standard. Flexural test, compression test, and water absorption test were carried out to determine mechanical performance. A scanning electron microscope (SEM) was then used to observe the fracture surface of each sample and analyze its physical characteristic. In the study, the overall results revealed that 50 % loading of 40 mesh kenaf core reinforced gypsum composite provided the best performance among all reinforced composites, which shows the highest flexural strength and modulus with 1.89 MPa and 1.48 kPa, respectively. However, due to budget concerns, the proposed kenaf core size and loading is 50 % loading of 20 mesh kenaf core as it is only slightly lower in performance than the 40 mesh kenaf core. In the compression test, 10 mm kenaf core reinforced gypsum composite reaches the highest compressive strength among all composites with 0.277 MPa. Other than that, the water absorption rate significantly increases as the amount of kenaf core is added more and the size of the kenaf core gets bigger. These have shown that the kenaf core has a great potential for offering environmentally friendly ceiling decoration applications with an improvement of flexural properties and compressive strength of the composite but also causes an increment of water uptake due to its hydrophilic nature.

#### ABSTRAK

Gentian semulajadi biasanya digunakan sebagai tetulang dalam pelbagai industri dan bidang kerana ia menawarkan prestasi mekanikal yang tinggi dan mesra alam. Kajian ini meneroka teras kenaf yang digunakan untuk tetulang dengan gipsum untuk aplikasi hiasan siling. Lima saiz teras kenaf berbeza yang digunakan dalam penyelidikan ini ialah 0.4 mm, 0.84 mm, 10mm, 20 mm, dan 30 mm. Sampel kemudiannya disediakan dengan mencampurkan nilai malar gypsum dan teras kenaf dengan peningkatan peratusan berat daripada 10% kepada 90%. Campuran kemudian dicampur dengan air dan dituangkan ke dalam acuan papan lapis berdimensi 320 mm x 300 mm x 10 mm. Apabila proses pengawetan dilakukan, setiap sampel dipotong mengikut dimensi standard untuk setiap ujian mekanikal mengikut piawaian ASTM. Ujian lentur, ujian mampatan, dan ujian penyerapan air telah dijalankan untuk menentukan prestasi mekanikal. Mikroskop elektron pengimbasan (SEM) kemudiannya digunakan untuk memerhati permukaan patah setiap sampel dan menganalisis ciri fizikalnya. Dalam kajian itu, keputusan keseluruhan mendedahkan bahawa 50% pemuatan komposit gipsum bertetulang teras kenaf 40 mesh memberikan prestasi terbaik di kalangan semua komposit bertetulang, yang menunjukkan kekuatan lentur dan modulus tertinggi dengan masing-masing 1.89 MPa dan 1.48 kPa. Walau bagaimanapun, disebabkan kebimbangan bajet, saiz dan pemuatan teras kenaf yang dicadangkan ialah 50% pemuatan teras kenaf 20 mesh kerana prestasinya hanya rendah sedikit daripada teras kenaf 40 mesh. Dalam ujian mampatan, komposit gipsum bertetulang teras kenaf 10 mm mencapai kekuatan mampatan tertinggi antara semua komposit dengan 0.277 MPa. Selain itu, kadar penyerapan air meningkat dengan ketara apabila jumlah teras kenaf ditambah lebih banyak dan saiz teras kenaf semakin besar. Ini telah menunjukkan bahawa teras kenaf mempunyai potensi besar untuk menawarkan aplikasi hiasan siling mesra alam dengan penambahbaikan sifat lentur dan kekuatan mampatan komposit tetapi juga menyebabkan peningkatan pengambilan air kerana sifat hidrofiliknya.

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اونيومرسيتي تيكنيكل مليسيا ملاك

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## **TABLE OF CONTENTS**

PAGE

DEC	CLARATION	
APPI	ROVAL	
DED	DICATION	
ABS	TRACT	i
ACK	KNOWLEDGEMENTS	iii
TAB	LE OF CONTENTS	iv
LIST	Γ OF TABLES	vii
LIST		viii
LIST	F OF SVMROLS AND ARREVIATIONS	vii
LIST	$\Gamma \cap \Gamma \to \Gamma \cap I \cup I$	
	I OF ALLENDICES	AIII 1
	MILKI PODUCTION ALAYS/	1
	RODUCTION	1
1.1	Background of Study	1
1.2	Problem Statement	3
1.3	Objective	5
1.4	Scope of Study	5
1.5	Rationale of Research	6
1.6	Summary of Methodology	6
1.7	Thesis Organization	8
CHA	APTER 2 Malunda Contraction	9
LITE	ERATURE REVIEW	9
2.1	Introduction of Ceiling	9
2.1.	.1 Types of ceiling ERSITI TEKNIKAL MALAYSIA MELAKA	9
2.1.	.2 Types of ceiling decorations	12
2.2	Types of Ceiling Materials That Commonly Used	14
2.2.	.1 Wood	15
2.2.		16
2.2.		17
2.3	Fabrication Process of Ceilings	19
2.3.	1 Layered	19
2.3.		21
2.3. 7 A	Konaf	22
2.4 2.4	<b>Nellal</b>	24
2.4.	2 Kenaf core	23
2.4.	A.3 Applications of kenaf	28
2.5	Testing	29
2.5.	5.1 Flexural test	29
2.5.	5.2 Compression test	30
2.5.	3.3 Water absorption test	31

2.6	Summ	ary 31
СНАЕ	TER 3	33
METHODOLOGY		
2 1		remaining of Mothe delegan 22
3.1	Anov	Verview of Mielhodology 5.
3.2	Raw N	Aaterial Preparation 35
3.2.1	Kena	if core 3.
3.2.2	Gyps	30 30
3.3	Fabrio	cation Process 37
3.3.1	Curin	ng process 39
3.3.2	Cutti	ng process 40
3.4	Mecha	anical Testing 41
3.4.1	Flexu	aral test 4
3.4.2	Com	pression test 4.
3.4.3	Wate	er absorption test 4.
3.5	Scann	ing Electron Microscope 40
CHAF	YTER 4	4 48
RESU	LT AN	AD DISCUSSION 48
4.1	Fabrid	cation and Characteristic of Reinforced Composites 48
1 2	Mach	anical Proparties of Reinforced Composite
<b>T-2</b>	Flavi	
4.2.1 4	7 1 1	Pure gypsum
т. Д '	2.1.1	40 mesh kenaf core reinforced gypsum
4	2.1.2	20 mesh kenaf core reinforced gypsum
4 1	2.1.3	10 mm kenaf core reinforced gypsum
4.3	2.1.5	20 mm kenaf core reinforced gypsum
4.2	2.1.6.	30 mm kenaf core reinforced gypsum 54
4.2	2.1.7	Summary of flexural strength 5:
4.2	2.1.8	Summary of flexural modulus
4.2.2	Com	pressive performance 5'
4.2	2.2.1	Pure gypsum 5'
4.2	2.2.2	40 mesh kenaf core reinforced gypsum AL MALAY SIA MELAKA 58
4.2	2.2.3	20 mesh kenaf core reinforced gypsum59
4.2	2.2.4	10 mm kenaf core reinforced gypsum 60
4.2	2.2.5	20 mm kenaf core reinforced gypsum6.
4.2	2.2.6	30 mm kenaf core reinforced gypsum6
4.2	2.2.7	Summary of compressive strength 62
4.2.3	Wate	er absorption rate 6.
4.2	2.3.1	Pure gypsum 64
4	2.3.2	40 mesh kenai core reinforced gypsum
4	2.3.3	20 mesh kenal core reinforced gypsum 0.   10 mm kenaf core reinforced gypsum 60
4.	2.3.4	20 mm kenaf core reinforced gypsum
4. //	2.3.5	30 mm kenaf core reinforced gypsum 6
4 4 '	2.3.0	Summary of water absorption rate 60
<u>4</u> 3	SFM 4	analysis 71
т.J 4 4		anaryoro /(
4.4	Summ	iary of Analysis Findings 7.
4.5	Propo	se the Best Size and Composition of Kenaf Core Reinforced Gypsum
Comp	osite	77

CHAPTER 5	78
CONCLUSION	78
5.1 Conclusion	78
5.2 Recommendation	80
5.3 Sustainability Element	80
REFERENCES	
APPENDICES	61



## LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Samples of varying densities of sheep wool, coir, and gypsum composites	23
Table 2.2	Compressive strength and softening coefficient of plaster composite	30
Table 2.3	Summary of previous research findings	32
Table 3.1	Summary of kenaf core properties	35
Table 3.2	Price of five different sizes of kenaf core	36
Table 3.3	Properties of gypsum	37
Table 3.4	Volume fractions of each five sizes of kenaf core and gypsum	39
Table 3.5	Testing standard for mechanical testing	41
Table 4.1	ASTM standards	49
	UNIVERSITI TEKNIKAL MALAYSIA MELAKA	

## LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 1.1	Flow chart of overall methodology	7
Figure 2.1	Structure of suspended ceiling	10
Figure 2.2	Condition of ceiling (a) concealed ceiling and (exposed ceiling)	11
Figure 2.3	A RCF panel detail section	12
Figure 2.4	Decorative fibrous plaster ceilings in historical buildings in England	13
Figure 2.5	Plasterwork decorations of historical building in Granada	13
Figure 2.6	Architectural cornices of historical building in India	14
Figure 2.7	A wooden coffered ceiling at the Church of Santa Maria del Rio in Spain	16
Figure 2.8	Hydration process as monitored by X-ray tomographic observation	17
Figure 2.9	Characteristic appearances of calcium sulfate minerals	19
Figure 2.10	Four types of reinforcement mat weave styles	20
Figure 2.11	Section of fibrous plaster with exposed scrim layer A MELAKA	20
Figure 2.12	Manufacturing process of ceiling tiles with freeze drying technique	22
Figure 2.13	Fabrication process of reinforced gypsum tiles	23
Figure 2.14	Kenaf plants (a) stem (b) leaves (c) flower (d) seed	24
Figure 2.15	Fibers of kenaf plants	25
Figure 2.16	Acid retting process of kenaf fibers	26
Figure 2.17	Different kenaf core size and kenaf pith	28
Figure 3.1	Flow chart of methodology	34
Figure 3.2	Kenaf core size (a) 40 mesh (b) 20 mesh (c) 10 mm (d) 20 mm (e) 30 mm	36

Figure 3.3	Gypsum stopping compound	37	
Figure 3.4	A illustration of plywood mould	38	
Figure 3.5	Bandsaw with LB1200F Makita model	40	
Figure 3.6	The dimension of flexural test sample (ASTM C1341)	42	
Figure 3.7	Standard setup for flexural test	42	
Figure 3.8	A universal testing machine (Shimadzu AGS- X series model)	43	
Figure 3.9	The dimension of compression test sample (ASTM C1358)	44	
Figure 3.10	Standard setup for compression test	44	
Figure 3.11	A universal testing machine (Shimadzu AGS- X series model)	45	
Figure 3.12	The dimension of water absorption test sample (ATSM D570)	46	
Figure 3.13	Standard setup for water absorption test	46	
Figure 3.14	Standard setup for SEM analysis	47	
Figure 3.15	A scanning electron microscope (SEM)	47	
Figure 4.1	Flexural strength and flexural modulus of pure gypsum	50	
Figure 4.2	Flexural strength and flexural modulus of 40 mesh kenaf core reinford	ced gypsum	
	by increasing the compositions	51	
Figure 4.3	Flexural strength and flexural modulus of 20 mesh kenaf core reinforc	ed gypsum by	
	increasing the compositions	52	
Figure 4.4	Flexural strength and flexural modulus of 10 mm kenaf core reinforced gypsum by		
	increasing the compositions	53	
Figure 4.5	Flexural strength and flexural modulus of 20 mm kenaf core reinforced gypsum by		
	increasing the compositions	54	
Figure 4.6	Flexural strength and flexural modulus of 30 mm kenaf core reinforce	ed gypsum by	
	increasing the compositions	55	

Figure 4.7	.7 Flexural strength of all five sizes of kenaf core reinforced gypsum composite with		
	its best composition	56	
Figure 4.8	Flexural modulus of all five sizes of kenaf core reinforced gypsum composite w	vith	
	its best composition	57	
Figure 4.9	Compressive strength of pure gypsum	58	
Figure 4.10	Compressive strength of 40 mesh kenaf core reinforced gypsum by increasing t	he	
	compositions	58	
Figure 4.11	Compressive strength of 20 mesh kenaf core reinforced gypsum by increasing t	he	
	compositions	59	
Figure 4.12	Compressive strength of 10 mm kenaf core reinforced gypsum by increasing the	e	
	compositions	60	
Figure 4.13	Compressive strength of 20 mm kenaf core reinforced gypsum by increasing th	e	
	compositions	61	
Figure 4.14	Compressive strength of 30 mm kenaf core reinforced gypsum by increasing th	e	
	compositions	62	
Figure 4.15	Compressive strength of all five sizes of kenaf core reinforced gypsum compos	ite	
	with its best composition KNIKAL MALAYSIA MELAKA	63	
Figure 4.16	Water absorption rate of pure gypsum	64	
Figure 4.17	Water absorption rate of 40 mesh kenaf core reinforced gypsum by increasing t	he	
	compositions	65	
Figure 4.18	Water absorption rate of 20 mesh kenaf core reinforced gypsum by increasing t	he	
	compositions	66	
Figure 4.19	Water absorption rate of 10 mm kenaf core reinforced gypsum by increasing the	e	
	compositions	67	
Figure 4.20	Water absorption rate of 20 mm kenaf core reinforced gypsum by increasing the	e	
	compositions	68	

х

Figure 4.21	Water absorption rate of 30 mm kenaf core reinforced gypsum by increasing the		
	compositions	68	
Figure 4.22	Water absorption rate of all five sizes of kenaf core reinforced gypsum compo	osite	
	with its best composition	70	
Figure 4.23	SEM images of pure gypsum fracture surface	71	
Figure 4.24	SEM images of 40 mesh kenaf core reinforced gypsum composite fracture sur	face	
		71	
Figure 4.25	SEM images of 20 mesh kenaf core reinforced gypsum composite fracture sur	face	
		72	
Figure 4.26	SEM images of 30 mm kenaf core reinforced gypsum composite fracture surfa	ace	
	and the second sec	73	
Figure 4.27	Flexural strength of all five sizes of kenaf core among all compositions	74	
Figure 4.28	Flexural modulus of all five sizes of kenaf core among all compositions	75	
Figure 4.29	Compressive strength of all five sizes of kenaf core among all compositions	76	
Figure 4.30	Water absorption rate of all five sizes of kenaf core among all compositions	76	
Figure 4.31	Sample failure SITI TEKNIKAL MALAYSIA MELAKA	77	

## LIST OF SYMBOLS AND ABBREVIATIONS

cm	-	Centimeter
mm	-	Millimeter
g	-	Gram
kg	-	Kilogram
kN	-	Kilonewton
MPa	-	Mega Pascal
°C	-	Degree Celsius
wt %	- 3	Weight percentage
SEM	- B	Scanning electron microscope
ASTM	- 1118	American Society for Testing and Materials
	UNI	VERSITI TEKNIKAL MALAYSIA MELAKA

## LIST OF APPENDICES

APPENDIX	TITLE	PAGE
APPENDIX A	Gantt chart for PSM 1	89
APPENDIX B	Gantt chart for PSM 2	90



#### **CHAPTER 1**

#### INTRODUCTION

#### 1.1 Background of Study

Composites is a material that made from two or more distinct substances which can create stronger and better performance component. There are two main types of composites which are matrix-based composites and reinforcement-based composites (Sharma et al., 2020). Natural fiber is one of the fiber reinforcements in composites and it is widely used nowadays in various applications. Those natural fiber reinforced composites generally used in engineering applications like aircraft, automobile, building and also other commercial applications (Prabhu et al., 2021). It can substitute synthetic composites in order to provide greener environment. Tonk (2020) stated that natural fibers are obtained from animals, plants, and mineral sources such as kenaf, hemp, jute, flax and silk (Yashas et al., 2019).

Kenaf is an herbaceous plant that have no woody tissue in its stem hence its fiber is commonly used as natural reinforcement. According to Tholibon et al. (2019), they stated that kenaf fiber can be derived from the bast and core which also known as outer fiber and inner fiber. They also mentioned that there are roughly 35% of bast fiber and 65% of core fiber consist in a kenaf stalk. Kenaf fiber provides a lot of potential applications due to it is easily available, economically, and environmentally friendly and also outstanding performance (Tholibon et al., 2019). Mechanical properties of kenaf bast fiber are related to its cellulose (Shrivastava and Dondapati, 2021); the higher the cellulose content resulting the better value of tensile strength. Meanwhile, kenaf core mainly used for fillers (Mohamad Aini et al., 2020) and thus less further development on kenaf core. However, there is a firmly believe that kenaf core has a great potential for improving mechanical properties. Consequently, kenaf core is chosen as reinforcement for this research instead of kenaf fiber.

Gypsum also known as calcium sulphate dihydrate (CaSO<sub>4</sub>·2H<sub>2</sub>O); it is a natural mineral which obtained from the sedimentary rock layer. By adding water into gypsum powder, it will be hardening and forming into same shape with the mold. Gypsum is one of the common building materials that used for construction purpose. Compared to other building materials, gypsum apparently is the best choice because of the benefits it offers. Gypsum is light weight (Kuqo and Mai, 2021), heat insulating (Boquera et al., 2021), and fire retardant (Aiken et al., 2021)However, the structure of gypsum composed of needled like calcium sulphate dihydrate crystals that interconnected with each other. This causing brittleness and hydrophilic hence reinforcement like natural fiber needed to improve the strength and water resistance properties (Vidales-Barriguete et al., 2020).

Next, mixing is one of the simplest and easiest technique to fabricate a gypsum product. In order to create a reinforced gypsum product, ratio of water, gypsum and reinforcement play important role. Therefore, the ratio of each substances needs to be precise so that at the end of the product would be in good condition and achieve expected analysis performance. According to the research of Guna et al. (2021), the result show that different value fraction of composites have bring impact to the mechanical properties and physical properties. They stated that the ideal proportion is 30% of reinforcement while 70% of gypsum as it carries out excellent outcome among other proportions. Besides, the ratio of water to gypsum mixture which is mixed gypsum and reinforcement is crucial in another aspect as well (Darvell, 2018). A mixed proper proportion,

the gypsum slurry will become opaque and creamy state. If water exceeded, the set slurry will become soft and weaken the structure due to the water molecules pushed gypsum crystals further apart. While if there is too much of gypsum mixture, the set slurry will be in non-homogenous state as there will be porous on top and hard at the bottom.

In summary, many interesting results indicating the potential of kenaf and gypsum in various application have been reported. However, most of the studies in the open literature did not simultaneously examine the effect of kenaf core reinforced gypsum composite. Therefore, this study will investigate the potential of kenaf core reinforced gypsum composite for ceiling decoration application.

#### **1.2 Problem Statement**

Currently, most of the gypsum-based ceiling products provide low performance which not long lasting and easily to break. The cause of this can be explained as the unsuitable ratio of mixing reinforcement and gypsum. It is the crucial part of the fabrication process in order to have good result of reinforced composite. In theoretically, there will be a significant improvement of mechanical properties of reinforced product with ideal proportion of gypsum and reinforcement. Therefore, the importance of controlling the optimum value of fraction between gypsum and reinforcement is necessary to implement.

Besides, the common issue that always come out with ceiling is the growth of mold and mildew (Guna et al., 2021). Due to high moisture content in ceiling which resulting the phenomenon occurred thus the materials of making a ceiling product is needed to pay attention with. Since kenaf has great tendency of water absorption, it will be added to the gypsum as reinforcement as providing enhancement of water repellence. On top of that, kenaf core also has the potential of improving the mechanical properties of matrix material. So kenaf core will be used to investigate the improvement ability to the gypsum-based ceiling product in this research.

Furthermore, commercial ceiling products are generally non-biodegradable as synthetic reinforcement are added to the matrix material (Guna et al., 2019). It can bring impact on environmental issue which synthetic reinforcement may release toxic gases to the surrounding and affect human health. Next, it is non-renewable source that can become hazardous waste to mother earth. Once it is no longer to use again and it will be dumped without making any cleaning process. Hence, natural reinforcements were introduced to make better and green ceiling product.

Moreover, natural reinforcements are usually expensive and harder to get than synthetic reinforcement. Natural reinforcements are obtained either from animals or plants which meaning that the duration from yield to harvest required a long period which can up to months. Other than that, the harvested reinforcements also needed to take action for processing. It will be required another additional processing time and cost. Therefore, this resulting more manufacturing companies are more likely to choose synthetic reinforcements due to it is low cost and time saving.

Last but not least, the studies relating to kenaf core have been relatively scanty and that there are few studies focusing on its size and properties. Therefore, there will be difficult to obtained relevant information from similar research and articles. All of these issues will be takes in consideration. Hence, this research that will covered of the research and development of kenaf core and gypsum for ceiling decorations will be an interesting topic to explore with.

## 1.3 Objective

The objectives of the research are as follows:

- a) To fabricate the different sizes of kenaf core reinforced gypsum with different loadings of kenaf core.
- b) To investigate the mechanical properties of the proposed sizes and loadings of kenaf core reinforced gypsum.
- c) To propose the optimum sizes and ratio of kenaf core reinforced gypsum composite for ceiling applications.

## 1.4 Scope of Study

The scope of study are as follows:

- a) Kenaf core will be used as reinforcement while gypsum will be used as matrix in this study.
- b) Each five different sizes of kenaf core will be mixed with gypsum with different proportions.
- c) Distinguish mechanical properties and physical properties of kenaf core reinforced gypsum composite which including compression strength, flexural strength, and water absorption rate.
- e) The performance of kenaf core reinforced gypsum composite will be examined by comparing different sizes of kenaf core and loadings of kenaf core reinforced gypsum.

 f) Observe and analyze final result of the kenaf core reinforced gypsum composite with scanning electron microscope (SEM) observation.

#### **1.5** Rationale of Research

The rationale of research are as follows:

- a) To understand more about the behavioral and properties of kenaf plant and gypsum in order to obtain better performance of the reinforced composite.
- b) To improve the mechanical properties of composite by adding kenaf core which act as reinforcement to gypsum.
- c) To propose low cost but high performance of reinforced composite with simplest fabrication process.
- d) To reduce environmental problems which related to disposal of non-biodegradable composites.

#### 1.6 Summary of Methodology

Figure 1.1 illustrates the overflow of this research. There are four parts in the whole process which are raw material preparation, fabrication, testing and analysis. Firstly, gypsum powder and five different sizes of kenaf core were prepared. Second, gypsum powder and kenaf core were mixed with water. Then, the slurry poured into a mold and let the slurry set. After that, the composites made into standard specimen for laboratory testing where ASTM standards used as a guidance to analyze their properties. Next, all data of each test were collected and examined. Lastly,

the result was reviewed and concluded from overall the interpretation of data. At the end of this research, the best performance of reinforced composite was evaluated, and all the details was assembled. After all, it will be able to put forward in particular application that related to natural composite which relevant with kenaf core and reinforced gypsum composite.



Figure 1.1 Flow chart of overall methodology

## 1.7 Thesis Organization

First, thesis organization of PSM 1 starts with Chapter 1. Chapter 1 introduces to the background of the study, problem statement, objective, and scope of the research. Then, Chapter 2 is about literature review which associated with previous studies that have tackled the topic in kenaf, gypsum and the properties of reinforced gypsum composite. These research findings allow to gather vital and essential information to enhance gypsum composite with natural reinforcement. Coming next with Chapter 3, it is the methodology to fabricate kenaf reinforced gypsum composite. It will outline the raw materials that needed to prepare and the process of making composite. The final product will be test with standard testing such as tensile test, compression test and flexural test. After that, in Chapter 4, the result of mechanical tests and morphological features will be observed, analyzed, and discussed. Last, from the research findings and discussions based upon the objectives for this study will be concluded in Chapter 5.

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#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction of Ceiling

Ceilings are commonly known as a fundamental interior part in every building construction. It is an overhead area that install at the upper surface of the room. According to Hanna et al. (2017), early humans were exposed in a danger surrounding so they started to build fencing around their habitat by using tree trunks. It can protect them from the enemies and wild animals. Gradually, ceilings are invented to ensure they and their habitats are in safe condition under bad weather. It has similar concept with the fences, but it is built in horizontal direction and underneath the roof. The purposes of a ceiling not only providing aesthetic appearance but also in some other functional ways based on their material use and structural design. Therefore, the selection of materials used designs of ceiling play important roles as they can affect the quality in terms of strength, thermal conductivity (Bogatu et al., 2021), fire resistance (Steau et al., 2020), water absorption rate (Ezenwa et al., 2019) and acoustic (Sygulska, 2019).

#### 2.1.1 Types of ceiling

Suspended ceilings are the second ceiling that suspended from the main structural ceiling wall. It installed by using support metal wires which can hang the ceiling grid and then the ceiling tiles are placed to each of the grid frame. Advantages of installing suspended ceilings are they can conceal the mechanical, electrical and plumbing (MEP) system without affecting the performances at the same time create a clean and tidy display (Cha et al., 2019). Next, it is good at against fire which increases the safeness of the room. While for disadvantages are reduction of ceiling height that could not be ignored and the possibility of decolorization, saggy tile happened (Li et al., 2019). Besides, the MEP system that stored at the plenum space which located between the main ceiling wall and suspended ceiling might hard to find out if there is in bad condition. In Figure 2.1 shown the schematic drawing of drop ceiling which also known as suspended ceiling or false ceiling.



**UNIVE** Figure 2.1 Structure of suspended ceiling **ELAKA** 

Exposed ceilings are the arrangement of ceiling including all mechanical components, electrical wiring system and plumbing system (MEP) that fixed on the wall are entirely exposed. In Figure 2.2 illustrated that the difference between exposed ceiling and concealed ceiling. Although this kind of ceiling may not look good as it does not require any finishing design or decorations to cover but it has some advantages that other types of ceiling that do not have. Exposed ceilings are cost effectively since there is no ornaments or other materials needed to hide the uncover part (Cha et al., 2019). According to Juan & Hsing (2017), they stated that an exposed

ceiling is easy to access and fix when it comes up with maintenance issues time spend for constructions would be productively decreased compared to other ceilings. Despite there are multiple benefits, the bad sides of this ceiling design are it would be difficult to clean which can cause the environment at risk from dust exposure and there is no protection if any component parts falling from the wall.



Figure 2.2 Condition of ceiling (a) concealed ceiling and (b) exposed ceiling

Ceilings with the fuction of thermal control well known as radiant ceiling which can help the environment more comfortable by controlling the temperature at optimum. Methods of installing radient ceilings are similar to suspended ceiling and tighly attached ceiling as the radiant system was embedded in the ceiling (Labat et al., 2020). For example, for the radiant heated ceilings, pipes or tubing needed to place between the joists then stamped heat emission plate on top of the pipework and covered it with reflective barrier and insulation. At last screwed the drywall or false wall into the joists. While for the radiant chilled ceilings, metal supporting structure had to mount to the joists to place the ceiling panels and other way is to hang the metal supporting structure just like suspended ceiling installation. A radiation ceilings and fresh air system technology (RCF) panel detail section was shown in Figure 2.3. According to the study of (Karakoyun et al., 2021), they claimed that radiant ceiling considered as environmentally friendly equipment as it has low energy consumption compared to heater and air conditioner. Moreover, it transmits temperature based on electromagnetic waves thus it is more hygiene and safe as there is no medium for bacteria.



Figure 2.3 A RCF panel detail section (Tian et al., 2020)

#### 2.1.2 Types of ceiling decorations

Stucco is one of the types of construction decorative coating for either external or interior of a building (Aksamija et al., 2019). It can be applied on construction materials such as metal, metal lath, brick, and concrete for structural purposes (Caroselli et al., 2019). From the investigation of Aksamija et al. (2019), they found out that the composition of ancient stucco were added with organic additives which they believed that there would be an enhancement of the stucco quality. For example, decorative fibrous plaster ceilings in historical buildings in England shown in Figure 2.4.



Figure 2.4 Decorative fibrous plaster ceilings in historical buildings in England. (a) Durbar Room of Osborne House in Isle of Wight, 1891 (b) Former Daily Express Building, London, 1932. (c) Wyndham's Theatre, London, 1899 (Awang Ngah et al., 2020)

Fibrous plaster ceiling defined as ceiling which composed of plaster that reinforce with fiber. From the Figure 2.5, the technique of mixing fibers into plaster apparently had been developed in early century. Until this modern era, this technique still using for building decorations and other applications. The difference across the age is the fibrous material that mixed with gypsum plaster as each material has its own characteristics whichever maybe provide varying mechanical properties and performances.



Figure 2.5 Plasterwork decorations of historical building in Granada (a) royal chamber of Santo Domingo (b) oratory in the Madrasa (c) royal Alcazar of Seville (Martínez et al., 2020)

Crown molding or cornice is a horizontal decorative molding that install along at the edge top of an interior wall. An example of architectural cornices of historical building in India shown in Figure 2.6. There are some purposes of these elements that been created and one of them which are to conceal the join between the wall and ceiling. Moreover, it also provides an illusion of the room that the height of ceiling extended. An interesting fact of cornice, it added to the outside of ancient buildings and jutted out from it to help direct rainwater away from the building but nowadays used as ornamental feature for both external and interior design of building.



Figure 2.6 Architectural cornices of historical building in India. (a) Porter Town Hall, Kumbakonam (b) one of the buildings at Mahamahakulam East Street (Kiruthiga and Thirumaran, 2017)

#### 2.2 Types of Ceiling Materials That Commonly Used

Since the early days, there are a lot of materials used for making ceilings which are wood, plaster, gypsum, limestone, rock and so many others. Each different types of ceiling material may influence the appearance and functional of the ceiling. Therefore, the selection of ideal ceiling material is very critical. The general ceiling materials that still using nowadays are well known as wood, plaster, and gypsum.

#### 2.2.1 Wood

Wood is an elementary natural raw material with an increasing demand worldwide up to now. As early as the prehistoric period, wood has been used for ceiling and decorations until now. It is never out of date and would continue to be one of the most popular options when finishing the interior design. Figure 2.7 illustrates a wooden coffered ceiling at the Church of Santa Maria del Rio in Spain. From the view of sustainable perspective, it is easy to recycle and biodegradable because wood considered as natural resource that is always available in nature. Besides, wood is a natural thermal insulator and versatile. It can adapt to any situation and help to reduce the amount of energy needed to heat a space. From the research of Pelliccia et al. (2020), they had investigated wood hygromorphic panels with the concept of pine cone structure. Hygromorphic defines as the wood panels able to control the room humidity by changing its geometry. The wood panels are in curve condition when they exposed the panels to low humidity while there is high humidity, the panels straighten its selves into flat condition. This shown that wood is responsive to thermal and reduce humidity. Other than that, it also overcome high cost for equipment at the same time improve energy efficiency of buildings.

Despite the above mentioned, wood ceiling does not really perform well in fire resistant hence it might exist potentially hazardous which the wooden structure encourages the spread of fire in the building (Popescu, 2017). Moreover, it prone to insect attack and growth of fungi since wood is hygroscopic material that able to absorb water in the air. Consequently, the ceiling becomes more easier to crumble and it is unsafe for living.



Figure 2.7 A wooden coffered ceiling at the Church of Santa Maria del Rio in Spain (M. C. Fernández-Cabo et al., 2020)

#### 2.2.2 Plaster of Paris

Plaster of Paris which also called calcium sulphate hemihydrate (CaSO4 $\frac{1}{2}$ H<sub>2</sub>O) or mineral bassanite (Van Driessche et al., 2019), it is in fine and white powdery form that obtained by burning gypsum at high temperature to allow partial dehydration. A study from Van Driessche et al. (2019) claimed that when mineral bassanite exposed to water, the water molecules recombined to harden and formed in to either gypsum or anhydrite depends on the temperature. It commonly used in building constructions as filler, protection coating, decorations and so on. Other than applications in building industry, plaster of Paris also used for immobilizing fractures, preoperative protection, pain relief and casts of the teeth in dentistry. Water ratio plays important role to create a good quality product of plaster. An article from Szostakowski et al. (2017) mentioned that the plaster quality, proportion of water and plaster, product age and storage condition are factors that affect the mechanical performance of plaster cast. Dry plaster of Paris is an extremely porous material which will absorb any new water that touches its surface, resulting low strength

and waterproof. According to Khalil et al. (2018), they proved that plain pop mixture has the lowest compression strength compared to other composites due to its interstitial pores as the additive particles would filled in the matrix interstitial spaces thus improved strength and water resistance. Figure 2.8 illustrated the hydration process of plaster as monitored by X-ray tomographic observation. At first, dry plaster powder was mixed with water then following by hemihydrate plaster particles started to dissolve and gypsum crystals formed gradually. Once the excessive water in the mixture were completely dried off, there are some air traps leave at the final setting.



Figure 2.8 Hydration process as monitored by X-ray tomographic observation. (1) The dry plaster powder mixed with water. (2-3-4) smallest hemihydrate plaster particles start to dissolve and gypsum crystals formed gradually (5-6) when the excessive water dry off, there are some air traps leave at the final setting (Beaugnon et al., 2019)

#### 2.2.3 Gypsum

Gypsum is a natural mineral that obtain from surface or underground deposits. It composed of calcium sulphate (CaSO<sub>4</sub>) and water (H<sub>2</sub>O). It exists in three levels of hydration which are calcium sulphate dihydrate (CaSO<sub>4</sub>·2H<sub>2</sub>O), calcium sulphate anhydrite (CaSO<sub>4</sub>) and calcium sulphate hemihydrate (CaSO<sub>4</sub>· $\frac{1}{2}$ H<sub>2</sub>O) (Van Driessche et al., 2019). Calcium sulphate hemihydrate also known as plaster of Paris, its originally extracted from gypsum when it heated with flame in
the temperature range of 130°C and it converted the heated part of solid rock into powdery state (Herrero and Zartman, 2021a). However, by adding water into plaster of Paris, gypsum formed again. In another case, if gypsum heated continuously then anhydrous calcium sulphate formed as all the water molecules are evaporated.

There is no odor for gypsum, and it commonly appears with white or colorless but sometimes it might tinge with other color based of its impurities. Gypsum can be in different forms including rocks, crystals, and glass pane. Figure 2.9 described the vary appearance of calcium sulfate minerals. According to Masuda et al. (2018), they had executed a depth-sensing indentation test to determine the hardness of different minerals. From the scale of 1 to 10, gypsum is at rank 2 for Mohs hardness scale thus it indicates that gypsum is soft.

Gypsum is not only a popular material in building construction but also used in a wide variety of applications such as binder (Han et al., 2020), fertilizer (Barčauskaite et al., 2020), artwork (Caroselli et al., 2019), medical agent (Kim et al., 2021) and so on. In building industry, gypsum is commonly made as drywalls or false ceilings by reasons of its marvelous benefits. For instance, it comes up with high durability, sound absorption, fire resistance, economical sufficient and ecologically friendly. In order to achieve better performance of gypsum drywalls, people started to explore more onto the reinforcement of gypsum with other the materials. In this research, gypsum act as important material as it selected as a binder to mix with reinforcement for further study.



Figure 2.9 Characteristic appearances of calcium sulfate minerals: (a) idiomorphic gypsum crystal (b) gypsum satin spar (c) gypsum desert rose (d) gypsum ram's horn (e) hydrothermal anhydrite fans and (f) White needle shaped bassanite crystallites with some gypsum crystals (Van Driessche et al., 2019)

### 2.3 Fabrication Process of Ceilings

There are several types of fabrication process to manufacture ceiling. To fabricate a good quality of product, important considerations like the types of material that used, properties of UNIVERSITI TEKNIKAL MALAYSIA MELAKA materials, physical geometry and size are needed to be specific.

### 2.3.1 Layered

In old centuries, people realized that pure gypsum plaster is not a good fit to use as supportive building material due to its fragility, low resistance to impact and can be dissolve in water easily. Hence, they invented reinforced plaster to enhance mechanical properties by merging layers of natural fiber to plaster slurry. According to Awang Ngah et al., 2020, they had investigated the structural performance of fibrous plaster with the use of potential materials to support the investigation of Historic England into structural failures. They found out that the fibrous plaster with glassfiber mat reinforcement provided significant improvement in mechanical properties compared to hessian reinforcement. They prepared two types of gypsum plasters which were alpha plaster (Prestia Creation) and beta plaster (Prestia Classic). Prestia Creation is a high strength plaster with low expansion rate while Prestia Classic is a standard casting plaster with faster setting time and extra durability. Next, hessian fiber and glass fiber used as reinforcement for respective alpha plaster and beta plaster. There are two different weave styles for hessian fiber were investigated that are loose plain weave and a tighter plain weave while for glass fibre, continuous fibreglass mat and quadaxial glass fabric were used. Figure 2.10 showed four types of reinforcement mat weave styles used in the investigation. The manufacture of fibrous plaster in Awang Ngah et al. research is to layer up the wet plaster and fabrics in a silicone rubber mold. As in final result, the section of fibrous plaster is shown in Figure 2.11.



Figure 2.10 Four types of reinforcement mat weave styles used in the investigation (a) loose weave hessian fiber (b) plain weave hessian fiber (c) continuous fiber glass mat and (d) quadaxial glass fabric (Awang Ngah et al., 2020)



Figure 2.11 Section of fibrous plaster with exposed scrim layer (Awang Ngah et al., 2020)

### 2.3.2 Freeze drying

Based on the research of Nadir Yildirim in year 2018, a bio-based nanocellulose ceiling tile with freeze drying technique were developed. The study claimed that this is the first study to use freeze drying to design and produce ceiling tiles. In the production process, no hazardous blowing agents or adhesives were used. The fabrication of nanocellulose ceiling tiles started from the water suspension also called water slurry that had been treated against flammability, hydrophilicity and mold growth. Next, the treated suspension was frozen and last, sublimination was performed to convert ice molecules to gases without cellular collapse. Figure 2.12 showed the manucturing process of ceiling tiles with freeze drying technique. Based on the study, the use of freezedrying technique had proven that the improvement of performance properties which also provided light in mass at the same it is a cost and time saving manufacture method.



Figure 2.12 Manufacturing process of ceiling tiles with freeze drying technique (Nadir Yildirim, 2018)

#### 2.3.3 Flexible shape

In year 2021, Vijaykumar Guna et al. investigated on mechanical properties performance with the reinforcement of fibers and gypsum ceiling tiles. There are two types of fibers used in their research which are wool fibers and coir fibers. In the process of making reinforced gypsum tiles, only water acts as a binder without adding any chemical substances or activators.

Figure 2.13 showed the fabrication process of reinforced gypsum tiles. Both sheep wool fibers and coir fibers were obtained from local then cleaned with warm water to get rid of impurities. Later the fibers were completely dried off and grinded into roughly 5mm size, fibers and gypsum powder were mixed together. Three different types of reinforced gypsum ceiling tiles with varying the proportion of fibers were carried out. The samples of varying densities of sheep wool, coir, and gypsum composites were illustrated in Table 2.1. Next, homogenization process was conducted, and distilled water added into the mixture then stirred at constant speed, 1000 rpm for 30 seconds. When the mixture was ready, poured it into open mold and set for 2 hours. After that, removed the tile from the mold and heated at 40°C for 48 hours to confirm it is free from

moisture then it was all done. With the fabrication method of Vijaykumar Guna et al., the good sides are there is no limitation of producing any complex shape product moreover it is time efficient and cost saving.



Figure 2.13 Fabrication process of reinforced gypsum tiles. (Vijaykumar Guna et al., 2021)

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Table / L	Samples o	t varving densi	ies of sheen Wo	ol coir and	owngum composites
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Sample		Gypsum (g)	Water (g)	W/G ratio	Coir (g)	Wool (g)
13	90/10	900	603	0.67	100	_
Gypsum/	80/20	800	536	0.67	200	• 1
Coir	70/30	700	469	0.67	300	اوير
	60/40	600	402	0.67	400	
UNI	90/10	900	603	0.67	A MEL	100
Gypsum/	80/20	800	536	0.67	-	200
Sheep wool	70/30	700	469	0.67	-	300
	60/40	600	402	0.67	-	400
Coir/ Sheep wool/ Gypsum	10/20/70	700	469	0.67	100	200
	15/15/70	700	469	0.67	150	100
	20/10/70	700	469	0.67	200	150
	10/20/70	700	469	0.67	100	200
	15/15/70	700	469	0.67	150	150
	20/10/70	700	469	0.67	200	100
	10/20/70	700	469	0.67	100	200
	15/15/70	700	469	0.67	150	150

(Vijaykumar Guna et al., 2021)

### 2.4 Kenaf

Kenaf also known as hibiscus cannabinus. It is a plant in Malvaceae family with Hibiscus gene. Kenaf plants are largely unbranched and able to grow up to 5 to 6 meters tall and the diameter of stem is approximately 25 to 35 millimeters (Khiari et al., 2020). In Figure 2.14, the physical appearance of kenaf plant were shown. Kenaf is one of the plants that can produce natural fibers that mostly obtained from bast and core. Kenaf compromised with 35 to 40% of bast fiber while 60 to 65% of core fiber by weight of the kenaf's stalk (Lim et al., 2018). Bast fibers also called phloem fibers, they are present in inner bark. Bast fibers are much longer compared to core fibers. Core fibers are obtained from the ligneous core.

Kenaf plant has wide range of adaptation to climates and soils opposed to other fiber plants in commercial production. For example, jute, hemp, flax, wool and so on. It only takes 150 days to harvest. The development of high-performance engineering products made from natural resource is increasing worldwide due to renewable and environmental issues. Therefore, kenaf plants has been extensively exploited all over the world.



Figure 2.14 Kenaf plants (a) stem (b) leaves (c) flower (d) seed (Sim and Nyam, 2021)

### 2.4.1 Kenaf fiber

In Asia, kenaf is cultivated predominantly for the fiber. Kenaf fiber is extracted from the bast of the plant and has been extensively used as a jute-like material in the past. It commonly used as reinforcement to the matrix material in various applications especially in automotive and aerospace field for enhancing the properties of the end product. Figure 2.15 demonstrated an image of kenaf plant fibers.



According to Guo et al. (2020), at the early stage of the extraction process involves soaking the stalks which also known as the acid retting process and then manual removal raw kenaf fibers from kenaf core. Next, to further improve the properties of the fibers, the raw kenaf fibers were alkaline treated by soaking the fibers in 5% sodium hydroxide solution (NaOH) for 1 hour at room temperature. After the treatment, kenaf fibers were washed by distilled water until neutral and then dried in air for 24 hours then followed by drying again to remove excessive water molecules with 105 °C for 4 hours in oven. Then the alkaline treated fibers were further being soaked in 100 ml of hydrogen peroxide solution (H<sub>2</sub>O<sub>2</sub>) for 2 hours at 85 °C. These important steps had been found to give superior reinforcement quality however the alkaline treatment will increase the cost and additional time needed for this preparation process. Acid retting process of kenaf fibers were displayed in Figure 2.16.



Figure 2.16 Acid retting process of kenaf fibers (a) kenaf stalks (b) raw kenaf fiber (c) alkaline treated kenaf fiber (d) alkaline hydrogen peroxide treated kenaf fiber (Guo et al., 2020)

A study from Lim et al. (2018) were conducted normal and random sound incidence sound absorption coefficient measurement regarding to kenaf fiber. The results revealed which proved that kenaf fiber have high potential on sound absorption. Moreover, Wu et al. (2020) stated that kenaf fiber used as reinforced fiber due to its environmental advantages which including low energy consumption, reduce greenhouse effect, able to replace non-renewable sources and improve biodegradability. Thus, they had undergone an experiment in order to produce high performance of kenaf fiber bio-composite by using zinc oxide nanoparticles. At the end of results showed the physical and mechanical properties of kenaf fiber bio-composite were better compared to commercial composite which the statement was verified.

#### 2.4.2 Kenaf core

Kenaf core is originally obtaining from the center of the kenaf stalk. Kenaf core consists of short fibrous material that is able to absorb water in its open porous cell system. Besides, it has a rigid open cell structures and it is not easy to compact. However, the applications of kenaf core are still little in the industry but it will be had a high potential for developing if there are more studies are carrying out. Currently, most of the use of kenaf core materials are as absorbents especially in animal bedding material or paper products as it is excellent in water absorption. Unlike other filling materials, kenaf core is biodegradable at the same time provides perfect water absorption and low dust content (Alias et al., 2019).

Preparation of kenaf core fraction from Lips et al research in 2009, they were performed by dry fractionating with a stack of vibrating DIN 4188 sieves while kenaf pith was manually separated from core particles. As from the result, Lips *et al.* observed that large kenaf particles have a higher absorbency than the medium and small particles. They stated that the large kenaf particles originate mainly from the bottom part of the stem and that contains only 1 to 2% of pith material. It is obvious that despite the high absorption capacity, differences in amount of pith cannot be the only cause of the higher absorption of the fraction with the large particles. They believed that internal structure of pores and water transport vessels of the large particles or a different chemical composition must be the reason for the higher water absorption. However, in this research that covered with gypsum-based ceiling application, large kenaf core size are not preferable as it will decrease the performance of composite due to the reinforcement dislocation interactions. Figure 2.17 demonstrated different kenaf core size and kenaf pith that used for experimenting from the research of Lips et al.



Figure 2.17 Different kenaf core size and kenaf pith (Lips et al., 2009)

# 2.4.3 Applications of kenaf

Kenaf is edible, it can be consumed as human food and livestock feed (Giwa Ibrahim et al., 2019). In some countries, the citizens take kenaf leaves and young shoot of kenaf as home dish. Kenaf seeds also yield an edible vegetable oil (Cheng et al., 2016). The kenaf seed oil is also used for cosmetics, industrial lubricants and for biofuel production.

According to previous study from Rafidah et al. (2017), they mentioned both kenaf fibers, bast fibers and core fibers can use for pulp and paper. They believed that the bast fibers has higher mechanical performance than core fibers. This is because of the longer the fibers able to provide more strength to support writing or drawing application as well as packaging and print. From the research, even though the kenaf based paper making process is much economic and easier but the quality of final paper product showed higher than conventional tree paper.

Moreover, kenaf has potential for bioplastic and bio-composite industry due to the fiber can be used as reinforcing fiber in composite (Venkategowda et al., 2021). Compared to glass fiber, kenaf based materials are cheaper and environmentally friendly in spite of that mechanical performance of kenaf based composite products show a huge improvement.

#### 2.5 Testing

Mechanical testing covers a wide range of tests which are standardized to determine various mechanical properties of materials or object. This is because of certain properties can be affected by specimen size or geometry. The analysis result after the testing had been required for further exploration to make better product.

#### 2.5.1 Flexural test

Flexural strength test is a measure of force that an object required to resist failure in bending. The findings of Vijaykumar Guna et al. (2021) revealed that flexural strength and modulus of reinforced gypsum tile are directly proportion to the ratio of fibers and gypsum. From the figure above presents that the modulus and strength of both reinforced gypsum ceiling tiles inclined as the proportion of fibers increased from 10% to 30%. As 30% of fiber used, it reached the optimum properties and provided the highest strength performance which indicates 30% are the most suitable ratio to mix with gypsum. However, when the ratio of fibers added up to 40%, both results of testing dropped. This occurred can be explained as there is not enough of gypsum particles to attach with fiber thus excessive water molecules in the mixture weaken the properties. The result of this study indicates that 30% of fiber reinforcement is the ideal proportion to make high quality of ceiling tiles. Moreover, research from Mustapa et al. (2020), they shown the flexural properties of composite had an improvement by gradually adding kenaf core fiber filler (KCF)to polypropylene. However, as the kenaf core fiber filler added up to 25%, the flexural strength

dropped. Corresponding to high content of filler compared to matrix, there was not enough of matrix to hold the filler in resulting weaken the properties.

# 2.5.2 Compression test

The aim of testing the compression strength of the modified gypsum composites is to identify the mechanical performance with addition of materials. Studies of Khalil et al. in 2018 have confirmed that the pure gypsum plaster is the lowest compression strength compared to other reinforced gypsum plasters which no matter with air curing or water curing methods. The result of compressive strength and softening coefficient of air and water curing plaster composites were shown in Table 2.2. Apparently, additives enhance the water resistance of their composites relatively to softening coefficient. Besides, the water curing composites had higher compression strength than air curing composites as gypsum is hydrophilic which water molecules able to fill in the pores of gypsum thus improved the strength.

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Composites	Compressive strength (kg/cm <sup>2</sup> )	Softening coefficient			
Neat plaster (blank)	133	0.93			
Plaster-fine sand	139	1.02			
Plaster-ultra fine sand	148	1.03			
Plaster-silica fume	154	1.04			
Plaster-silica gel	146	0.98			
Plaster-rice husk	151	1.03			
Plaster-slag	159	1.09			
Plaster-calcium carbonate	145	1.04			
Plaster-PVA polymer	150	1.05			

 Table 2.2
 Compressive strength and softening coefficient of air and water curing plaster composites (Khalil et al., 2018)

#### 2.5.3 Water absorption test

The purpose of conducting water absorption test is to determine the moisture content of the object. Vijaykumar Guna et al. (2021) carried out water absorption of reinforced gypsum-based ceiling tiles with varying of proportion and content of reinforcement. Each sample were cut into specific size according to ASTM standard. Then the dry weight and wet weight of specimens were recorded and determine the percentage of water absorption. They found out that pure gypsum board had the highest percentage of water absorption which was 27% compared to others sample with additional reinforcement. The reduction of water absorption occurred can be explained as the addition of the fibers.

#### 2.6 Summary

As a summary for this chapter, research and finding are based on the research scope which are more focusing on theoretical knowledge of ceiling materials which to propose the optimum ratio for ceiling decorations. The information mainly covers about the ceiling material used, characteristic and properties of kenaf, methods to fabricate a ceiling. Generally, ceiling decorations can be in many forms. One of the ceiling materials that commonly used is gypsum. This is because it is available in any places, cost effective and easy to make to desired pattern. However, there is not enough by only manufacture pure gypsum products. Most of the studies had developed the improvement of gypsum product by adding reinforcement in order to produce best quality and mechanical performance. Hence, natural reinforcement, kenaf was introduced in this research which allow the enhancement of the performance at the same time it is less harmful to the environment and synthetic reinforcement can be replaced. Kenaf is commonly known as an excellent natural water absorbent and can act as additives to strengthen composite material. However, there is less research that focused on kenaf core reinforcement hence it will be an interesting topic to explore in the composite material field. From the previous studies, flexural strength and water absorption test with ASTM standard are very common mechanical testing to determine the behavior of the composite material. Table 2.3 showed the summary of previous study that relevant to the ceiling product. In a nutshell, this study will be focus on the research and development of kenaf core and gypsum for ceiling decorations. At the end of this research, the final product will enable to provide good mechanical properties of ceiling decorations with simple fabrication and strong performance.

No.	Matrix	Reinforcement	Fabrication method	Testing	References
1	Gypsum (UNIVER	Wool, coir BITI TEKNIK/	Layered which reinforcement mat intermediate in between gypsum	Flexural test, Water absorption test, Thermal conductivity test, Flammability test, and Sound absorption test	(Guna et al., 2021)
2	Plaster	Fine sand, Ultra-fine sand, Silica fume, Silica gel, Rice husk, Slag, Calcium carbonate, and PVA polymer	Simple mixing technique	Water absorption test and Compression test	(Khalil et al., 2018)
3	Polypropylene	Kenaf core	Hot press compression	Water absorption and Flexural test	(Mustapa et al., 2020)
4	Carboxymethyl cellulose	Scripus grossus and Fiberglass	Simple mixing technique	Flexural test and Water absorption test	(Beddu et al., 2020)

 Table 2.3
 Summary of previous research findings

#### **CHAPTER 3**

### METHODOLOGY

In this chapter covered the process flow and methodology that used in this research. The methodology will be further discussed with the methods that later carried which including material preparation, fabrication, and related experimental testing. American Society for Testing and Materials (ASTM) is used as a guideline for the overall testing. Lastly, the data of these experimental testing is collected for data analysis.

# 3.1 An Overview of Methodology

This research starting from raw material preparation which gypsum powder and five different sizes of kenaf core were used. After that, gypsum powder mixed with each different sizes of kenaf core with increasing proportions. Later, the mixture mixed together with water and set until it formed in solid state. Next, each kenaf core reinforced gypsum composite sample cut into specific dimension based on relevant ASTM standard for mechanical testing that are flexural test, compression test, and water absorption test. All result data were collected for further analysis and the fracture surface of each sample was undergone morphological observation with the use of scanning electron microscope (SEM). The outcomes assessed with scientific discussion. At last, a conclusion is made and clearly justified with the supporting statement in this study. A flowchart is summarized the overall progress of this research in Figure 3.1.



Figure 3.1 Flow chart of methodology

### 3.2 Raw Material Preparation

Reinforced composite will be conduct in this study where kenaf core uses as reinforcement while gypsum uses as matrix. There will be more detailed information to clarify later according to each raw material specification and characteristic. It is crucial to understand the raw material behavioral attributes as the quality and performance of the product will be affected.

### 3.2.1 Kenaf core

Kenaf core will be use in this research as a reinforcement. It is well known as good binder which can held the matrix in order to provide performance enhancement of a product. In Table 3.1, it showed the kenaf core properties. Based on the study of Nayeri et al. (2013), there is considered as high percentage of lignin content in kenaf core. Lignin is a complex organic polymer that is particularly abundant in the formation of cell wall which it can provide mechanical support and resistance to stress. Therefore, kenaf core were selected as reinforcement due to its excellent properties.

Macro-fibril size/ Chemical content	Kenaf core
Fibril length, L (mm)	0.75
Fibril width, W (µm)	19.23
Cellulose (%)	1.50
Lignin (%)	19.20
Ash content (%)	1.90

 Table 3.1
 Summary of kenaf core properties (Nayeri et al., 2013)

There were five different mesh size of kenaf core used to mix with gypsum in order to determine the ideal mesh size of kenaf core to produce finest quality of product. Figure 3.2 showed the images of five different kenaf core mesh size. These kenaf core were supplied from Lembaga Kenaf dan Tembakau Negara and each price based on their size were illustrated in Table 3.2.



Figure 3.2 Kenaf core size (a) 40 mesh (b) 20 mesh (c) 10 mm (d) 20 mm (e) 30 mm

E		
Mesh size	Quantity (kg)	Price (RM)
40 mesh	1	12.00
20 mesh	، تيڪن <mark>ي</mark> ڪل م	و 9.00 سيخ
	TEKNIKAL MALAY	SIA MEL <sup>4.50</sup> KA
20 mm	1	4.00
30 mm	1	3.00

Table 3.2 Price of five different sizes of kenaf core

### 3.2.2 Gypsum

Gypsum uses as a matrix in this research to bind with kenaf core. The price of gypsum stopping compound per bag (20kg) is RM 18.00 which manufactured from Asian Super Gypsum Sdn. Bhd. Figure 3.3 illustrated the gypsum stopping compound. Gypsum is a common building material that used for interior designing works, partition system, and supporting constructions. It

is ideal material for building which corresponding to its excellent thermal and sound resistance, economical, environmentally friendly and low energy consumption (Zhu et al., 2018). Besides, the mechanical performance of gypsum can be significantly improved by adding reinforcements or natural fibers (Herrero and Zartman, 2021b). Table 3.3 showed the properties of gypsum.



# 3.3 Fabrication Process

The method of making kenaf core reinforced gypsum composites is by mixing the raw materials with water which are kenaf core and gypsum. The ratio for mixing gypsum and water is 1.5: 1 which the value of gypsum and water used is constant with 855 g and 570 g, respectively,

and it is the same volume with adding kenaf core reinforcements. By increasing the weight percentage for each five different size of kenaf core to reinforce with gypsum, there will be total number of 45 samples of composite. In Table 3.4 illustrates the composition for gypsum and five distinct sizes of kenaf core with an increasing weight percentage from 10 % to 90 %. Each sample is prepared in accordance with the composition fraction shown in Table 3.4 and well mixed in a container. Next, the mixture pours with water and stirred constantly to ensure that the mixture became homogenously slurry. As the slurry was ready then poured into a mold with dimension 320 mm x 300 mm x 10 mm that made from plywood. The illustration of plywood mould demonstrated in Figure 3.4. Let the slurry set at room temperature for curing till it is completely

dry.



Figure 3.4 A illustration of plywood mould

			Type A	Type B	Type C	Type D	Type E
Samula	Gypsum	Water	(wt. %)	(wt. %)	(wt. %)	(wt. %)	(wt. %)
Sample	(g)	(g)	40 mesh	20 mesh	10 mm	20 mm	30 mm
			Kenaf core	kenaf core	Kenaf core	Kenaf core	Kenaf core
1	855	570	10	10	10	10	10
2	855	570	20	20	20	20	20
3	855	570	30	30	30	30	30
4	855	570	40	40	40	40	40
5	855	570 L	WS/4 50	50	50	50	50
6	855	570	60	60	60	60	60
7	855	570	70	70	70	70	70
8	855	570	80	80	80	80	80
9	855	570	کل 90یسہ	90	رسيوقي تيع	<u>90 ويوم</u>	90

 Table 3.4
 Volume fractions of each five sizes of kenaf core and gypsum

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# 3.3.1 Curing process

Curing process is then carrying out for one week for each sample. The purpose of undergoing this process is to make sure the bonding between kenaf core and gypsum is stable and well combine. Within the period, each sample need to constantly flip to another side to prevent the water vapor trap at the bottom part and causes growth of mold. After waiting for one week, the quality of the samples is required to evaluate so that they are ready for proceeding next step.

# 3.3.2 Cutting process

As the samples are in good quality condition, the samples are then taken out from the mould and cut into standard specimen size for each mechanical testing according to ASTM standard. The type of bandsaw that will use for cutting process is LB1200F Makita model that shown in Figure 3.5. It is a machine that cut object with a long tooth blade that rolling on a wheel and the object is placed on a table. It can adjust the mode of cutting speed with 400 m/min or 500 m/min as low speed either 800 m/ min or 1000 m/min as high speed. Next, this bandsaw has a built-in dust collection system which can keep the workplace clean and easy to move with caster. There is six LED job light that help the operator for better insight.



Figure 3.5 Bandsaw with LB1200F Makita model

### 3.4 Mechanical Testing

There are three mechanical testing were carried out which are flexural test, compression test, and water absorption test. These tests will be performed based on ASTM. Table 3.5 illustrates the ASTM for these mechanical testing.

Mechanical testing	Testing standard		
Flexural test	ASTM C1341		
Compression test	ASTM C1358		
Water absorption test	ASTM D570		
st	<b>JIEN</b>		

 Table 3.5
 Testing standard for mechanical testing

### 3.4.1 Flexural test

Flexural test is a mechanical parameter for brittle material to measure the force required to bend a material under three-point loading condition. It can use to determine flexural strength and flexural modulus whereby the ability of material to withstand bending force can be evaluated. The material placed between two supports and applied load with a third point. Failure will occur when the strain or elongation exceeds the material's limits. The specimens were prepared according to ASTM C1341 standard. As the sample breaks during testing, maximum load and type of fracture were recorded for further analysis. The flexural strength is calculated by using the Equation (1) as shown as below.

$$Flexural Strength, (MPa) = \frac{3FL}{2wh^2}$$
(1)

Figure 3.6 shows that the standard sample size for flexural testing based on ASTM standard. A universal testing machine, Shimadzu AGS - X series that shown in Figure 3.8 and standard setup for this flexural test is displayed in Figure 3.7. Three specimens of each reinforced composite samples will be test and the average result will be recorded.



Figure 3.7 Standard setup for flexural test



Figure 3.8 A universal testing machine (Shimadzu AGS- X series model)

### 3.4.2 Compression test

Compression test used to determine a material behavior when force applied on it. The test conducted by loading specimen between two sides and often done to a rupture or to a limit. The specimens were prepared according to ASTM C1538 standard. Figure 3.9 represents the size of a sample for compression test. The standard specimen size used to determine the compressive strength is 60 mm width x 60 mm length x 10 mm height. Shimadzu AGS- X series model universal testing shown in Figure 3.11 used for carrying out compression testing. The standard setup for compression test is illustrated in Figure 3.10. The compressive strength is calculated by using the Equation (2) as shown as below. Three samples will be test and the average result will be recorded.

Compressive Strength, (MPa) = 
$$\frac{3FL}{2wh^2}$$
 (2)



Figure 3.9 The dimension of compression test sample (ASTM C1538)



Figure 3.10 Standard setup for compression test



Figure 3.11: A universal testing machine (Shimadzu AGS- X series model)

### 3.4.3 Water absorption test

Water absorption test is to determine the moisture content where water penetrate material when immersed. To ensure the accuracy of water absorption rate, all samples are put in oven and baked for 5 hours with 110 °C so that the moisture in sample can be removed. Later, the test was conducted by immersing the specimens in distilled water at room temperature for 24 hours. Then the specimens taken out and wipe off the water on specimen surface and weighted using digital electronic analytical balance. The water absorption percentage was calculated by weight difference using Equation (3) and all the data for each specimen were collected.  $W_i$  represents as the initial weight of the sample while  $W_f$  is the weight of sample after immersed in water for 24 hours. The specimens were prepared with dimension of 30 mm long and 30 mm wide with 10 mm of thickness followed as the Figure 3.12 shown and set up as Figure 3.13 shown. Three samples will be test and the average result will be recorded.

Water absorption, Wt (%) = 
$$\frac{W_f - W_i}{W_i} \times 100$$
 (3)



Figure 3.12 The dimension of water absorption test sample (ASTM D570)



# 3.5 Scanning Electron Microscope

Scanning electron microscope (SEM) will be used in this study, it is an electron microscope that scans the surface of a sample with a focused beam of high energy electrons. The electrons hit on the surface of the sample and bounce off, signals of these scattered electrons are generated and create magnified image of the surface. After the mechanical testing were tested on each vary proportion of different sizes of kenaf core reinforced gypsum composite sample, the fracture part of sample will be cut out. Since the composite samples are non-conductive thus a thin layer of gold sputtering coating needed to place on the sample so that electron signals able to receive and observe with the use of SEM. The model of SEM that will be use is JEOL6010PLUS which illustrate in Figure 3.14 and the setup is same as shown in Figure 3.15.



Figure 3.15 A scanning electron microscope (SEM)

#### **CHAPTER 4**

#### **RESULT AND DISCUSSION**

This chapter discusses the analysis of experimental results following the fabrication of samples and the completion of a variety of testing experiments. The statement and hypothesis were supported by previous research, and they will be clarified as well as given additional justification in this paper.

# 4.1 Fabrication and Characteristic of Reinforced Composites

In this research, kenaf core fiber is used a natural fiber reinforcement to bind with gypsum as in ceiling decorations applications. There are five different sizes of kenaf core as reinforcement including 40 mesh, 20 mesh, 10 mm, 20 mm, and 30 mm. The goal of this research is to investigate and study how the size of the kenaf core and the proportion of gypsum reinforcement affects the properties of kenaf core reinforced gypsum composites. Each five sizes of kenaf core reinforce with gypsum with an increasing weight composition ranging from 10% to 90%. In general, the thickness of a ceiling approximately 9.5mm thus 10 mm thickness of composite sample applied in this study. The volume of gypsum and water are fixed which is 855 grams and 570 grams respectively followed by the ratio of 1.5: 1. Gypsum and kenaf core are mixed homogeneously so that gypsum is firmly bind with kenaf core then later poured with water and mixed together until it become slurry form. Next, the mixture is then poured into a mould and quickly wipe the surface so that it is even. Then let it dry and cure for one week to stabilize the bonding between gypsum and kenaf core.

### 4.2 Mechanical Properties of Reinforced Composite

The mechanical properties of kenaf core reinforced gypsum composite were evaluated by conducting flexural test, compression test, and water absorption test according to ASTM standard. At last, under scanning electron microscope (SEM) observation, the morphological of the surface failure of each composite sample after flexural testing was examined. In Table 4.1 illustrates the ASTM standards that will be using for conducting all the mechanical tests.



# 4.2.1 Flexural performance

The flexural performance of the pure gypsum and kenaf core reinforced gypsum composite was tested on rectangular specimens using the universal testing machine Shimadzu with the AGX-V series model. The specimen dimensions are 130 mm  $\times$  15 mm  $\times$  10 mm according to ASTM C1341. The test was conducted using the load cell of 10 kN at a 1 mm/min loading rate. For each composite type, three identical specimens are tested, and the mean value is reported as the flexural strength and modulus of that sample.

#### 4.2.1.1 Pure gypsum

Based on the Figure 4.1, three pure gypsum samples were tested to obtain the flexural strength and modulus which are 1.53 MPa and 0.085 kPa respectively. The results will be later compared with kenaf core reinforced gypsum composites by increasing the compositions.



Figure 4.1 Flexural strength and flexural modulus of pure gypsum

# 4.2.1.2 40 mesh kenaf core reinforced gypsum

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Figure 4.2 illustrates the flexural strength and flexural modulus of 40 mesh kenaf core reinforced gypsum composites from composition 10% to 90%. The bar chart of flexural strength shows that there is a slight undulation starting from 10 % to 50 % at 1.64 MPa, 1.55 MPa, 1.73 MPa, 1.52 MPa, and 1.45 MPa, respectively. Then a sudden increase to 1.89 MPa, which is the highest flexural strength among all the compositions. Followed by then a gradually decreased from 70% to 90% at 1.80 MPa, 1.72 MPa, and 1.39 MPa respectively. The finding is consistent with findings of past studies by Suresh Babu and Ratnam (2021), which they found out that when the composite is exceed to the limit of optimum value of reinforcement, the mechanical performance decrease significantly.

While for flexural modulus, the trend is continuously going down from 20% until 90 %. This highlights the significance of the elasticity of reinforced composites decreasing when there is an increment of reinforcements. This is supported by Rajak *et al.* (2019) study which reveals that the greater number of reinforcement loading added into the composite, the elasticity of composite flexural modulus also decreases thus it become stiffer and harder in physical.



Figure 4.2 Flexural strength and flexural modulus of 40 mesh kenaf core reinforced gypsum by increasing the compositions

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### 4.2.1.3 20 mesh kenaf core reinforced gypsum

An interesting observation from the bar chart in Figure 4.3 illustrates that there is a frequent change in flexural strength by adding more weight of 20 mesh kenaf core. One reason for this situation occurred could be explained as the distribution of 20 mesh kenaf core in reinforced gypsum composite is not equally spread; hence the maximum force that could break each composite sample is not average. The above finding is consistent with the study by Anifowose, Abubakar and Zhihong in year 2020. They examined that the mechanical properties of composition affected by the distribution of reinforcements. They found out that random dispersed of

reinforcements resulting inconsistency of the result when there is a increment of reinforcement loading. Besides, the highest flexural modulus among all compositions is 0.155 kPa which is the least weight that added into gypsum at 10%. In comparison, the lowest flexural modulus is 0.017 kPa at the second most weight of 20 mesh kenaf core with 80%.



Figure 4.3 Flexural strength and flexural modulus of 20 mesh kenaf core reinforced gypsum by increasing the compositions

#### UNIVERSITI TEKNIKAL MALAYSIA MELAKA 4.2.1.4 10 mm kenaf core reinforced gypsum

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Based on the bar chart illustrated in Figure 4.4, it outlines that the flexural strength reaches a peak at 40% loading of 10 mm kenaf core reinforced gypsum composite with 1.43 MPa, which also same goes with the flexural modulus with 0.188 kPa. Along with the growth in the proportion of 10 mm kenaf core increase up to 90 %, the flexural modulus shows a decline trend, especially at 50% of kenaf core loading, demonstrating a dramatically deterioration to 0.053 kPa.



Figure 4.4 Flexural strength and flexural modulus of 10 mm kenaf core reinforced gypsum by increasing the compositions.

# 4.2.1.5 20 mm kenaf core reinforced gypsum

Abnormal graph pattern displays in Figure 4.5, both results of flexural strength and flexural modulus of 20 mm kenaf core reinforced gypsum are rise and fall irregularly. The strongest flexural strength among all compositions is 1.38 MPa at 60 %, followed by the second strongest, which is 1.37 MPa at 70 %, whereas the weakest flexural strength is 0.77 MPa at 20%. On another view for the highest flexural modulus is 0.141 kPa at 50% of kenaf core loading, while the lowest is 0.033 kPa at 10 %. According to the previous research of Fauzi et al. (2016), they mentioned that high flexural modulus of the composite indicates that the more stiffness as there is more amount of reinforcements in the matrix. However, when the kenaf core reinforcement loading continues to increase, the adhesion bonding becomes weak due to lack of sufficient gypsum particles to bind with.




Figure 4.5 Flexural strength and flexural modulus of 20 mm kenaf core reinforced gypsum by increasing the compositions.

## 4.2.1.6. 30 mm kenaf core reinforced gypsum

The results of the numerical simulation in Figure 4.6 indicate that there is an undulation pattern toward the flexural properties of 30 mm kenaf core reinforced gypsum with increasing of weight percentage. The flexural strength of 30 mm kenaf core reinforced gypsum has shown a steady decline from 10 %, which is also the highest flexural strength with 1.79 MPa, then gradually drop to 1.16 MPa at 40 %. Interestingly, when the composition of kenaf core is added to 90%, the flexural strength is 1.61 MPa which is the third highest. This can be explained as the force is applied directly to the reinforcements where the composites are reinforced via mechanical interlocking of the most significant percentage of 30 mm kenaf core between the gypsum matrices.



Figure 4.6 Flexural strength and flexural modulus of 30 mm kenaf core reinforced gypsum by increasing the compositions.

# 4.2.1.7 Summary of flexural strength

Based on the results in Figure 4.7 presents the sample that provides the highest flexural strength if 60 % of 40 mesh kenaf core reinforced gypsum composite with 1.89 MPa. Then the strength starts to drop till to 20 mm kenaf core reinforced gypsum composite at the lowest flexural strength at 60 % of kenaf core loading with 1.38 MPa. Research finding by Fauzi, Ghazalli and Siregar (2016) points towards that a raise in reinforcements can cause to the aggregation of reinforcement in the composite. This can create difficulties on stress transferring as a result of that the flexural performance decline. However, the interesting point is that there is a sudden rise of flexural strength at 10 % of 30 mm kenaf core reinforced gypsum composite with 1.79 MPa, which is the second highest among all the five kenaf core sizes. An assumption for this may be related to the minor loading of 30 mm kenaf core that has been added. Similarly, the study by Shao and Billington (2021) found that high loading of reinforcements resulting the more localized cracks in the composite.



Figure 4.7 Flexural strength of all five sizes of kenaf core reinforced gypsum composite with its best composition

## 4.2.1.8 Summary of flexural modulus

It was found that the 40 mesh kenaf core reinforced gypsum composite with 20 % of loading hit the peak of flexural modulus with 1.48 kPa. Then a dramatically drop to 0.155 kPa with 10 % of 20 mesh kenaf core reinforced gypsum composite. This indicates poor dispersion of low content of kenaf core in the matrix therefore it weakens the interfacial adhesion bonding and resulting low flexural modulus. According to an investigation by Mustapa, Rozyanty and Pisal (2020), they explained that the low content of kenaf core in the composite may not distribute uniformly hence they suggested to increase the loading of kenaf core is composed of lignocellulosic components which offer the stiffness to the reinforced composite. However, poor elongation at the kenaf core break is another reason to increase the kenaf core size. As a result, the larger the kenaf core, the greater the risk of it failing to elongate according to the research of Ishak *et al.* (2010).



Figure 4.8 Flexural modulus of all five sizes of kenaf core reinforced gypsum composite with its best composition.

## 4.2.2 Compressive performance

According to ASTM standard, the compression test was conducted on square specimens using the Shimadzu AGX-V series universal testing machine to determine the compressive strength of the kenaf core reinforced gypsum composite and pure gypsum. The specimen dimensions are cut into 60 mm x 60 mm x 10 mm. The test was performed at a 1 mm/min rate using a load cell of 10 kN. To determine the compressive strength of each composite sample, three identical specimens are subjected to testing.

## 4.2.2.1 Pure gypsum

From Figure 4.9 shows that the compressive strength of pure gypsum sample 1, 2, and 3 with 0.229 MPa, 0.217 MPa, and 0.178 MPa respectively. The average compressive strength of these three pure gypsum specimens is 0.208 MPa. The average result of pure gypsum will be later compared with other kenaf core reinforced gypsum composite.



Figure 4.9 Compressive strength of pure gypsum

# 4.2.2.2 40 mesh kenaf core reinforced gypsum

Figure 4.10 represents the results of compressive performance of 40 mesh kenaf core reinforced gypsum with increased composition of kenaf core. From the results shows that the highest compressive strength is 0.260 MPa at 90% while the lowest compressive strength is 0.198 MPa which 60% kenaf core added into gypsum.





#### 4.2.2.3 20 mesh kenaf core reinforced gypsum

The bar chart in Figure 4.11 outlines that there has been a steady improvement in compressive strength from 10% to 50% with 0.193 MPa up to 0.234 MPa. Nevertheless, a collapse at 60% with 0.215 MPa and start falling little by little to 0.193 MPa at 90%. This indicates that the optimum value for 20 mesh kenaf core to reinforce gypsum is 50%. If the value exceeds, the compressive strength begins to drop. From the saying by Ma, Chen and Wang (2021), when the loading of reinforcement exceeds the limit, the bonding between matrix and reinforcement will be weakened. They explained that a high content of reinforcements decreases the distance between them thereby making the cracks easy to spread across in the interface resulting poor adhesion bonds with matrix.



Figure 4.11 Compressive strength of 20 mesh kenaf core reinforced gypsum by increasing the compositions

## 4.2.2.4 10 mm kenaf core reinforced gypsum

A similar concept from the previous compressive performance from 20 mesh kenaf core reinforced gypsum composite; in Figure 4.12 outlines the best proportion is 50% of 10 mm kenaf core which clearly display the greatest compressive strength with 0.277 MPa among all the composition. When the amount of 10 mm kenaf core is added to 60 % and continues to 90 %, the results show a fluctuation trend. It may be relevant to the uneven dispersion of kenaf core in the gypsum matrix that caused the weak adhesion bonding. A study by Sarifuddin, Ismail and Ahmad (2013) suggests there should be a agglomeration in the 10 mm kenaf core reinforced gypsum composite when there is an increment of kenaf core loading.



Figure 4.12 Compressive strength of 10 mm kenaf core reinforced gypsum by increasing the compositions

#### 4.2.2.5 20 mm kenaf core reinforced gypsum

In Figure 4.13 shows that when the loading of 20 mm kenaf core increases to 40 %, it reaches at the optimum composition loading to reinforce with gypsum with the greatest compressive strength at 0.220 MPa. Followed by then, the compressive strength starts to drop to 0.218 MPa then 0.211 MPa at 50 % and 60 % respectively. However, the compressive strength rises and fall again from 70 % to 90 %. This undulation trend occurred may be because of the distribution of the kenaf core in the gypsum matrix which is same prediction from the previous result of 10 mm kenaf core reinforced gypsum composite. In addition, the size of kenaf core getting larger, it is more difficult to make it even when finishing during the fabrication process.



Figure 4.13 Compressive strength of 20 mm kenaf core reinforced gypsum by increasing the compositions

## 4.2.2.6 30 mm kenaf core reinforced gypsum

70 % of 30 mm kenaf core reinforced with gypsum is the highest compressive strength among all composition at 0.228 MPa which it has illustrated in Figure 4.14. From 20 % to 40 %

composition of 30 mm kenaf core, the trend of the bar chart demonstrates an improvement of compressive strength but yet it starts to drop to 60 %.



Figure 4.14 Compressive strength of 30 mm kenaf core reinforced gypsum by increasing the compositions

## 4.2.2.7 Summary of compressive strength

The numerical simulation results in Figure 4.15 indicate that the size of the kenaf core has a bring out the effects of composition loading on the reinforced composite compressive performance. There is high kenaf core content in 40 mesh and 30 mm reinforced gypsum composite which is 90 % and 70 % respectively, while 20 mesh, 10 mm and 20 mm of kenaf core content are considered as moderate with 50 %, 50 % and 40 %. However, there have been no controlled studies that compare the relationship between reinforcement size and loadings. In particular, the effects of these two factors remain unexplored.



Figure 4.15 Compressive strength of all five sizes of kenaf core reinforced gypsum composite

with its best composition

## 4.2.3 Water absorption rate

The water absorption rate is defined as the percentage of water intake that the sample can absorb. The specimen was cut into a square with a dimension of 30 mm x 30 mm x 10 mm. The original weight of sample is measured then baked in an oven for 5 hours with 110°C so that the moisture content in sample is removed. The weight of the sample after drying is measured again. Next, the sample was wholly immersed in a container filled with distilled water. After 24 hours, the sample was taken out and wiped off the surface moisture and weight again. Same as previous tests that have been conducted, three individual specimens are tested to get the average water absorption rate.

#### 4.2.3.1 Pure gypsum

In Figure 4.16, there is three identical samples of pure gypsum displays each sample water absorption rate which are 56.28 % for sample 1, 56.90 % for sample 2 and 58.14 % for sample 3. The average water absorption rate of these three samples of pure gypsum is 57.11%.



4.2.3.2 40 mesh kenaf core reinforced gypsum

The higher the loading of 40 mesh kenaf core added into gypsum, the higher the water absorption rate. Several studies have revealed that the hydrophilic nature of kenaf core can affect the tendency of water uptakes. For example, Tan *et al.* (2014) described that the cellulose that containing in kenaf core composed of hydroxyl groups which are sensitive to water thus resulting in the water absorption percentage of composite also significantly high. However, from the result that illustrated in Figure 4.17 shows a fluctuation from 60% to 90%. This seems to suggest that the kenaf core size and distribution of kenaf core may influence the result. It predicts as there is

more kenaf core content in the specimen samples. Consequently, it has affected the accuracy of the water absorption rate.



Figure 4.17 Water absorption rate of 40 mesh kenaf core reinforced gypsum by increasing the compositions

# 4.2.3.3 20 mesh kenaf core reinforced gypsum

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Overall, this bar chart in Figure 4.18 highlights the evidence that the more content of 20 mesh kenaf core in gypsum composite, the great amount of water intake to the kenaf core reinforced gypsum composite. This has supported the statement from the investigation of Mustapa et al. in year 2020. Thereby, there is a significant rise in water absorption rate from 10% to 70% weight of kenaf core added into gypsum, which reaches the highest average water intake percentage at 62.59%. However, a gentle fall and raise happened at 80% and 90%.





compositions

## 4.2.3.4 10 mm kenaf core reinforced gypsum

From the bar chart in Figure 4.19, it was found that there is a growth of the water absorption rate which followed by an increment the loading of kenaf cores except for one special case. Looking at the lowest water absorption rate among all composition is located at 20% loading of 10 mm kenaf core used, it is a sudden drop which the reinforced composite absorbs 53.18 % of water. One potential explanation that can be expressed is that the 10 mm kenaf core particles distribution may not be distributed uniformly throughout the composite matrix. As a result, less water was absorbed which corresponding to there was insufficient of kenaf core embedded in the composite sample.



Figure 4.19 Water absorption rate of 10 mm kenaf core reinforced gypsum by increasing the compositions

# 4.2.3.5 20 mm kenaf core reinforced gypsum

In Figure 4.20, the bar chart of water absorption rate for 20 mm kenaf core reinforced gypsum rises steadily from 10 % to 60 %. Then a surge at 70 % composition of 20 mm kenaf core has hit its highest point with 74.36 % water intake. This phenomenon is possible corresponding to the water content in the samples did not wholly evaporate when drying in the oven or else the samples did not keep in a proper way which may contact to the water vapor from the air. As highlighted by Osman et al. (2013), kenaf is a hygroscopic material which has the ability to attract and hold water molecules or humidity from the surrounding.



Figure 4.20 Water absorption rate of 20 mm kenaf core reinforced gypsum by increasing the compositions

# 4.2.3.6 30 mm kenaf core reinforced gypsum

The highest water absorption rate among all 30 mm kenaf core reinforced gypsum compositions is 75.64 % when the reinforcement is added to the maximum percentage at 90 %. Overall, the bar chart displays in Figure 4.21 shows an upward trend.





#### 4.2.3.7 Summary of water absorption rate

The water absorption rate result illustrated in Figure 4.22 shows that the rate of water absorption increases proportionally to the size of the kenaf core. The smallest size, which is 40 mesh reinforced gypsum composite, demonstrates that it absorbs 62.02 % of water, as well as the kenaf core, gets larger to 20 mesh, 10 mm, 20 mm and 30 mm, the water absorption rate also increases to 62.59%, 67.93%, 74.36% and 75.64% respectively. In another study, Lips et al. (2009) examined that the effect of kenaf core size to water uptake value on animal bedding. They found that the large size kenaf core particles had a 30 % higher than small and medium size of kenaf core while in this study, there is approximately 20% rise in 30 mm kenaf core compared with 40 mesh. In the meantime, the difference in water absorption between small and medium kenaf core which are 40 mesh and 10 mm kenaf core is only about 10%. Both results are consistent with the findings by Lips et al. (2009). A further view on their compositions, it is around 70% to 90% of loading which is considered a high percentage of loading. According to the Ling, Ismail and Bakar (2016), the number of hydroxyl groups that form hydrogen bonding with water molecules increases as the more amount of kenaf core is added, representing the growth at which the reinforced composite absorbs water.





## 4.3 SEM analysis

Scanning electron microscopy (SEM) is used to observe the fracture surface of kenaf core reinforced gypsum composites and analyze their microstructure and bonding between reinforcement (kenaf core) and matrix (gypsum). The reinforced gypsum composites from five different kenaf core sizes that provide the greatest flexural strength among all compositions are observed for evaluation under SEM same goes with pure gypsum which use to compare the difference.

Figure 4.23 illustrates the micrograph of pure gypsum fracture surface under magnification 100x and 500x. Gypsum chunk also known as a gypsum crystal that is larger in size is found when the magnification is set to 500x. The presence of gypsum chunk can affect the quality of bond strength due to the dislocation formation within the irregular crystal structures.



Figure 4.23 SEM images of pure gypsum fracture surface (a) magnification 100x (b) magnification 500x

From the view of SEM, the 40 mesh kenaf cores are embedded in the gypsum matrix which has clearly show in Figure 4.24 (a). The porosity at the binding area seems acceptable and considered as fine. Adhesion bonds are formed as the observation of SEM image represents the gypsum crystals are finely attached at the surface of 40 mesh kenaf core, which is shown in Figure 4.24 (b). In this case, 60 % of 40 mesh kenaf core reinforces gypsum composites are evaluated because it offers the highest flexural strength.



Figure 4.24 SEM images of 40 mesh kenaf core reinforced gypsum composite fracture surface (a) magnification 100x (b) magnification 500x

The strongest flexural strength among all compositions of 20 mesh kenaf core reinforced gypsum is 1.69 MPa at 30 % thus, it is observed under SEM. In Figure 4.25 shows that there are two gypsum chunks embedded in the composite. However, it does not affect much on the flexural strength and this may correspond to the less content of 20 mesh kenaf core in the composite.



Figure 4.25 SEM images of 20 mesh kenaf core reinforced gypsum composite fracture surface (a) magnification 100x (b) magnification 500x

SEM images in Figure 4.26 shows the fracture surface of 10 % of 30 mm kenaf core reinforced gypsum composite. Under a magnification of 18x displayed in Figure 4.26 (a), there is a large void, the 30 mm kenaf core that comes off from the gypsum after breaking. It can be noticeably seen that there are many airspaces at the joining part between the kenaf core and gypsum matrix. Besides, the porosity within the composite can be easily observed through the naked eye. These factors have affected the poor interfacial bonding between the surface of the kenaf core and gypsum compared to other kenaf cores smaller in size.



Figure 4.26 SEM images of 30 mm kenaf core reinforced gypsum composite fracture surface (a) magnification 18x (b) magnification 100x

## 4.4 Summary of Analysis Findings

In this research, there are five distinct kenaf core sizes act as an external reinforcement applied on the gypsum by increasing the compositions percentage. From the mechanical tests that have been conducted, it brings clear evidence that by adding reinforcements with different proportions to the gypsum can affect the performance of composite.

Flexural strength measures how much stress can be applied to an element before it deforms **UNERSITITEKNIKAL MALAYSIA MELAKA** permanently or fractures. While flexural modulus can be explained as the elasticity of reinforced composite. It defines the tendency of composite to return to its original form after being subjected to a force. In Figure 4.27 shows that the highest flexural strength among all five kenaf core sizes by increasing the composition is 1.89MPa at 60 % of 40 mesh kenaf core reinforced gypsum composite. It has shown a contrast of flexural strength between the smallest and biggest sizes of reinforcement when there is a fixed composition. This indicates that the larger the size of the kenaf core, the more difficult for gypsum particles to hold it hence resulting in poor adhesion bonding and low strength.



Figure 4.27 Flexural strength of all five sizes of kenaf core among all compositions

From the line graph in Figure 4.28, it demonstrates 40 mesh kenaf core reinforced gypsum composite has the greatest overall flexural modulus among all five kenaf core sizes. As the high the flexural modulus, the stiffer and harder to bend. Besides, the flexural modulus of 40 mesh kenaf core reinforced gypsum composite behave an outstanding result with 1.48 kPa especially compared to the second highest from overall flexural modulus which 20 mm kenaf core is used. It is almost 164 % difference compared to 20 mm kenaf core reinforced gypsum composite. The possible explanation can be described as 40 mesh kenaf core which is the smallest that can creates high density in the reinforced composite at the same achieves low porosity concentration. Eventually, it maximizes the amount of absorbed energy to break the composite.



Figure 4.28 Flexural modulus of all five sizes of kenaf core among all compositions

50 % of 10 mm kenaf core reinforced gypsum composite has the strongest compressive strength with 0.277 MPa, yet it is the weakest at 20% with 0.112 MPa from overall which displayed in Figure 4.29. Other than that, most of the kenaf core reinforced gypsum composites show an improvement of compressive strength from 20 % to 50 %, this can be explained as 50 % of kenaf core is the optimum value among all the compositions. There have been several studies in the literature reporting that the compressive strength increases with the number of reinforcements increases; however, it will start to drop when the content of reinforcement exceeds the limit.



Figure 4.29 Compressive strength of all five sizes of kenaf core among all compositions

It is obvious to notice that Figure 4.30 illustrates that when the composition in kenaf core reinforced gypsum composite increases, the water absorption rate also increases. Kenaf core is in hydrophilic nature as mentioned before; thus, more water intake in the reinforced composite is due to this factor. Furthermore, the water absorption rate can be influenced by the size of the kenaf core. As the size is bigger, the more surface area it can contact the water thus, more water is absorbed.



Figure 4.30 Water absorption rate of all five sizes of kenaf core among all compositions.

Figure 4.31 demonstrates that 80% of 30 mm kenaf core reinforced gypsum composite samples fail to conduct a water absorption test. This phenomenon happened can be described as the more content of kenaf core reinforcements, the more water it can absorb. Consequently, the size of the kenaf core increases in swelling, which can weaken the bonding between the kenaf core and gypsum; hence the sample dissolve easily in water after being immersed for 24 hours. Not only for this case, some of the reinforced gypsum composite samples with large size kenaf core and high composition features also fail during this test. This is supported by Osman *et al.* (2013) study which reveals that the increasing loading of kenaf core in the composite sample leads to more water molecules penetration into the interface through the micro-cracks, which is induced by the swelling of the kenaf cores. As the kenaf cores in the composite sample are swollen, they create swelling stresses; as a result be the cause of composite failure.



Figure 4.31 Sample failure

## 4.5 Propose the Best Size and Composition of Kenaf Core Reinforced Gypsum Composite

From the overall results, it has been proven that the size and loading of kenaf core reinforcements have bring interesting effects on the mechanical performance of gypsum composite. 50 % of 40 mesh kenaf core reinforced gypsum composite is the ideal size and composition that provide excellent mechanical performance. However, due to budget concerns, the size of the kenaf core is changed from 40 mesh to 20 mesh. As the finest the kenaf core, the more expensive it is.

#### **CHAPTER 5**

## CONCLUSION

#### 5.1 Conclusion

This research presents an overview of the potential of kenaf core to replace synthetic reinforcement for reinforced gypsum ceiling decorations. There are five different sizes of kenaf core including 40 mesh, 20 mesh, 10 mm, 20 mm, and 30 mm were used to compare. Gypsum used as the matrix with a constant weight which 855 g while the composition of kenaf core reinforcement increases by the weight of gypsum from 10 % to 90 %. All objectives of this research were successfully achieved.

The first objective to fabricate the different sizes of kenaf core reinforced gypsum with different loadings of kenaf core. The following is the summary conclusion for this objective:

- (a) The five sizes of kenaf core with all compositions were successfully fabricated.
- (b) During the finishing process, the higher content of kenaf core, the more difficult to make the composite surface even same goes with the increment of the kenaf core size.
- (c) For the curing process, time taken for high content of the kenaf core reinforced gypsum composite is relative long as the kenaf core absorb more water.

Next, the second objective is to investigate the mechanical properties of the sizes and loadings of kenaf core reinforced gypsum. Here are some of the important findings that contributed to this objective:

- (a) In flexural testing, 40 mesh kenaf core reinforced gypsum composite obtained the highest performance in both flexural strength and flexural modulus. 60 % loading of 40 mesh kenaf core reached at a peak among all composition with 1.89 MPa while 10 % loading of 40 mesh kenaf core has the greatest result in flexural modulus with 1.48 kPa.
- (b) 50 % loading of 10 mm kenaf core reinforced gypsum composite shows the optimum compressive strength with 0.277 MPa from overall five different sizes of kenaf core reinforced gypsum composites. While for the composite that revealed the weakest compressive strength is 20 % loading of 40 mesh kenaf core reinforced gypsum composite.
- (c) The composite sample that reveals the highest water absorption is 90 % loading of 30 mm kenaf core reinforced gypsum composite. As the size and loading of kenaf core increases, the water absorption rate also increases. High water absorption rate of kenaf core reinforced gypsum composite is not a good recommendation for ceiling decorations. It is not only weakening the mechanical properties but also encourage the growth of mold. Thus, low water absorption rate of kenaf core reinforced gypsum composite is preferable.

Lastly, the third objective is to propose the optimum sizes and ratio of kenaf core reinforced gypsum composite for ceiling applications. The following are the main conclusions reached in pursuit of this objective:

(a) The ideal size and loading of kenaf core reinforced gypsum composite that shows excellent mechanical performance is 50 % of 40 mesh kenaf core reinforced gypsum composite.

- (b) Due to on tight budget, 40 mesh kenaf core is much costly than other kenaf core in bigger size thus 20 mesh kenaf core used as an alternative.
- (c) Although 20 mesh kenaf core reinforced gypsum composite is not strong as 40 mesh kenaf core but its mechanical properties are still acceptable.

#### 5.2 Recommendation

The hydrophilic and hygroscopic nature of the kenaf core is the main issue that affects the performance of the kenaf core reinforced gypsum composite. Although it has shown an enhancement in flexural properties and compressive strength, but yet an unsatisfactory outcome on water absorption rate, which will later be applied in ceiling decorations. To overcome this problem, it is recommended to use waterproof paint on the surface of the reinforced composite so that the water moisture in the surrounding is not easily trapped in the ceiling decorations.

# 5.3 Sustainability Element of all sizes in Sustainability Element

According to the principles of sustainable development, replacing synthetic reinforcements with kenaf cores has a high likelihood of lowering global pollution levels. Due to the facts that synthetic reinforcements can release toxic gases into the environment during processing, whereas kenaf core does not, this is the case. Furthermore, it has the potential to reduce health risks to individuals. The kenaf core has a wide range of applications outside of construction, including a variety of other industries. As a result, the demand for kenaf on the market, both domestically and internationally, will be stimulated. As a result, local commercial plantation farming can benefit, and the economic system in our country can benefit as a result of this.

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# APPENDICES

# APPENDIX A Gantt chart for PSM 1

Gantt chart for PSM 1															
No	Task project	Plan/	Week												
	3	Actual	1	2	3	4	5	6	7	8	9	11	12	13	14
1	Registration of PSM title	Plan													
		Actual													
2	Briefing of PSM title	Plan													
		Actual						1							
3	Chapter 2 research and writing	Plan		S	1										
	AINO	Actual													
4	Submission Chapter 2	Plan													
	6 10 1	Actual	1		1		1. <sup>10</sup>				•				
5	Chapter 1 preparation	Plan		Ru			2	1	_ لئن	10	3.9				
	10	Actual					1 L	2.5	V		1				
6	Chapter 3 methodology writing	Plan													
	LINIVERSI	Actual	MIK	14	M.	41.0	AVS	A13	MF	1 4	KΔ				
7	Chapter 4, 5 expected outcome and	Plan		L.F. S. Day		The Deside of		P 1.2 1	1.1.1.1.	a bear					
	conclusion	Actual													
8	Submission of PSM draft 1	Plan													
		Actual													
9	Submission of PSM draft 2	Plan													
		Actual													
10	Presentation of PSM 1	Plan													
		Actual													
### APPENDIX B Gantt chart for PSM 2

Gantt chart for PSM 2															
No	Task project	Plan/	Week												
		Actual	1	2	3	4	5	6	7	8	9	11	12	13	14
1	Discussion and planning task with	Plan													
	supervisor	Actual													
2	Purchase raw materials and	Plan													
	equipment	Actual													
3	Fabricating process	Plan													
		Actual													
4	Testing	Plan													
	14	Actual													
5	Data analysis	Plan						Ξ.							
	A.L.	Actual													
6	Chapter 4 result and discussion	Plan													
	the later of the l	Actual	1		1		-								
7	Chapter 5 conclusion	Plan		2.	4		1	and a	4	100	40				
		Actual					. (	5.	14	1	1				
8	Submission of PSM 2 draft 1	Plan						1							
	LIMIVEDCI	Actual	MIL	AL.	5.4	A L	NVO	A 15	NAC	11. A	12 A				
9	Submission of PSM 2 draft 2	Plan	MIC	-ML			11.	PLM	IVIC	l la fre	In A				
		Actual													
10	Presentation of PSM 2	Plan													
		Actual													



# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

# TAJUK: RESEARCH AND DEVELOPMENT OF KENAF CORE AND GYPSUM FOR CEILING DECORATIONS

SESI PENGAJIAN: 2020/21 Semester 1

Saya MELANIE LYE CHUOK XIN

mengaku membenarkan tesis ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

- 1. Tesis 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 tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
- 4. \*\*Sila tandakan (✓)

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

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**TIDAK TERHAD** 

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Tarikh: <u>18/1/2022</u>

Disabilan oleh:

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\*\* Jika tesis ini SULIT atau TERHAD, sila lampirkan sekali daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh lapor<del>an PSM ini perlu dikelaskan seb</del>agai SULIT atau TERHAD.



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### FAKULTI TEKNOLOGI KEJURUTERAAN MEKANIKAL DAN PEMBUATAN

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### PENGKELASAN TESIS SEBAGAI TERHAD BAGI TESIS PROJEK SARJANA MUDA

Dengan segala hormatnya merujuk kepada perkara di atas.

2. Dengan ini, dimaklumkan permohonan pengkelasan tesis yang dilampirkan sebagai TERHAD untuk tempoh **LIMA** tahun dari tarikh surat ini. Butiran lanjut laporan PSM tersebut adalah seperti berikut:

#### Nama pelajar: MELANIE LYE CHUOK XIN (B091810389) Tajuk Tesis: RESEARCH AND DEVELOPMENT OF KENAF CORE AND GYPSUM FOR CEILING DECORATIONS.

3. Hal ini adalah kerana IANYA MERUPAKAN PROJEK YANG DITAJA OLEH SYARIKAT LUAR DAN HASIL KAJIANNYA ADALAH SULIT.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA" "KOMPETENSI TERAS KEGEMILANGAN"

Saya yang menjalankan a lanah.

**Profesor Madya Ir. Ts Or. Mohd Yuhazri Bin Yaakob** Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan Universiti Teknikal Malaysia Melaka

