MECHANICAL PERFORMANCE OF COMPOSITE SANDWICH CORE STRUCTURE FABRICATED BY FDM PRINTING TECHNIQUE

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Faculty of Industrial and Manufacturing Technology and Engineering

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A thesis submitted
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DEDICATION

Firstly, I would like to express my gratitude to Almighty Allah for His kind blessing for giving me a healthy body and mind to finish this project. Next, I would like to express my sincere appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for giving me opportunity to do my Final Year Project (FYP) here. I wish to give my special gratitude to my personal supervisor Dr. Mastura Binti Mohammad Taha, for the help and cooperation during my project period here and guiding me until I completed my research study.

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Last but not least, from the bottom of my heart a gratitude to my beloved family, especially my father, Azman Bin Mohtaram and my mother, Rohaidah Binti Hashim for the kind, understanding and moral support to finish my Final Year Project. Without their endless love, support and prayers, i will never be the person as i am today. Not to forget, from the bottom of my heart a gratitude to my beloved fiance, Nurul Ain Binti Mohd Norhizam, for her encouragements and who have been the pillar of strength in all my endeavors. Finally, thank you to all the individual(s) who had provided me with the assistance, support, and inspiration to embark on my study.

ABSTRACT

Honeycomb core sandwich structure (HCSS) is common strcuture that been used in many sectors especially aerospace. Most of the material that been used for honeycomb sandwich structure is non-biodegradable.The increasing environmental concerns over plastic waste calls for more sustainable alternatives in product design. This study aim is to address this issue by fabricate and designing honeycomb core sandwich structure (HCSS) using natural fibre materials and 3D printing method. The design is refer by past research. 3 typical design of honeycomb sandwich structure which is regular hexagon, triangular hexagon and double hexagon was choosen as the concept with the most relevant interest. The design then will be test the printability by using FDM printing technique with bio-composite filament. The specimens of the HCSS will be test the mechanical testing for sandwich structure which include tensile test, flexural test and flatwise tensile test.. The test will be will determine the mechanical properties of the material and sandwich structure in tensile, flexural and compressive. Result from the mechanical testing will be analyze to determine the ideal shape of the honeycomb core sandwich structure (HCSS). Overall, in terms of tensile and flexural, double hexagon show the superiority compared to regular hexagon and triangular hexagon pattern. However, in flatwise tensile, triangular hexagon pattern results is slightly higher compared to double hexagon. This is because of lack of samples on flatwise tensile. Overall, the reinforced ribs and additional hexagon core on double hexagon proved it can be stronger than regular hexagon. Eventho double hexagon pattern have better strength, it also consume more materials and almost double the weight.

ABSTRAK

Struktur sandwic teras sarang lebah (HCSS) adalah struktur biasa yang digunakan dalam banyak sektor terutamanya aeroangkasa. Kebanyakan bahan yang digunakan untuk struktur sandwic sarang lebah tidak boleh terbiodegradasi. Kebimbangan alam sekitar yang semakin meningkat terhadap sisa plastik memerlukan alternatif yang lebih mampan dalam reka bentuk produk. Kajian ini bertujuan untuk menangani isu ini dengan membuat dan mereka bentuk struktur sandwic teras sarang lebah (HCSS) menggunakan bahan gentian asli dan kaedah cetakan 3D. Reka bentuk dirujuk oleh kajian lepas. 3 reka bentuk tipikal struktur sandwic sarang lebah iaitu heksagon biasa, heksagon segi tiga dan heksagon berganda telah dipilih sebagai konsep yang paling relevan. Reka bentuk kemudiannya akan menguji kebolehcetakan dengan menggunakan teknik cetakan FDM dengan filamen bio-komposit. Spesimen HCSS akan menguji ujian mekanikal untuk struktur sandwic yang merangkumi ujian tegangan, ujian lentur dan ujian tegangan rata. Ujian ini akan menentukan sifat mekanikal bahan dan struktur sandwic dalam tegangan, lentur dan mampatan. Hasil daripada ujian mekanikal akan dianalisis untuk menentukan bentuk ideal struktur sandwic teras sarang lebah (HCSS). Secara keseluruhan, dari segi tegangan dan lentur, heksagon berganda menunjukkan keunggulan berbanding heksagon biasa dan corak heksagon segi tiga. Walau bagaimanapun, dalam tegangan rata, hasil corak heksagon segi tiga adalah lebih tinggi sedikit berbanding heksagon berganda. Ini adalah kerana kekurangan sampel pada tegangan rata. Secara keseluruhannya, rusuk bertetulang dan teras heksagon tambahan pada heksagon berkembar membuktikan ia boleh menjadi lebih kuat daripada heksagon biasa. Corak heksagon berkembar Eventho mempunyai kekuatan yang lebih baik, ia juga menggunakan lebih banyak bahan dan hampir dua kali ganda berat.

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Last but not least, from the bottom of my heart a gratitude to my beloved family, especially my father, Azman Bin Mohtaram and my mother, Rohaidah Binti Hashim for the kind, understanding and moral support to finish my Final Year Project. Without their endless love, support and prayers, i will never be the person as i am today. Not to forget, from the bottom of my heart a gratitude to my beloved fiance, Nurul Ain Binti Mohd Norhizam, for her encouragements and who have been the pillar of strength in all my endeavors. Finally, thank you to all the individual(s) who had provided me with the assistance, support, and inspiration to embark on my study.

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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
FDM	-	Fused Deposition Modelling
HCSS	-	Honeycomb Sandwich Structure
PLA	-	Polylactic Acid
FRP	-	Fiber-Reinforced Polymer
3D	-	3 Dimensional
ABS	-	Acrylonitrile Butadiene Styrene
SPF	-	Sugar Palm Fiber
PP	-	Polypropylene
mm	-	Millimeter
MPa	-	Mega Pascal
FAA	-	Federal Aviation Adminstration

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CHAPTER 1

INTRODUCTION

1.1 Background

Sandwich structures are a popular choice for load-carrying applications in aerospace, automotive, and locomotive industries because they offer high strength and stiffness with low weight. These structures consist of two thin, dense, and stiff facesheets bonded to a relatively thick, low-density core. The facesheets carry the in-plane loads, while the core supports the shear and transverse loads. Metallic and fiber-reinforced polymer (FRP) facesheets are both used in sandwich structures, but FRP offers several advantages over metallic alloys, including better fatigue properties, superior design flexibility, high strength-to-weight ratio, and better chemical stability and corrosion resistance. Synthetic fibers such as glass, carbon, and aramid are the most common reinforcements used in FRP facesheets. However, there are some environmental and sustainability concerns associated with synthetic fibers, such as limited recycling options, non-biodegradability, and greenhouse gas emissions during production.

Natural fibers are one of the alternatives of synthetic fibers to use as reinforcement in composite materials. The natural fibers such as flax, jute, kenaf, ramie, sisal as a reinforcement material in composites are reported in several research studies.

3D printing, or additive manufacturing, has come a long way in recent years. It's now possible to create complex objects without the need for specialized tools or molds. This makes it ideal for prototyping and customizing products.

One popular method of 3D printing is fused deposition modelling (FDM). FDM printers melt plastic filament and deposit it layer by layer to create objects. There are many different types of filaments available, including bio-composite filaments. Bio-composite filaments are made from natural materials, such as wood fibres or hemp, and synthetic materials, such as PLA or ABS. They offer several advantages over traditional synthetic filaments, including lower cost, higher strength-to-weight ratio, and better sustainability.

As 3D printing technology continues to evolve, bio-composite filaments are becoming increasingly popular. They're a great option for anyone looking for a sustainable and affordable way to create 3D printed objects.

1.2 Problem Statement

The honeycomb sandwich structure was a marvel of engineering, combining flexibility and pliability with high flexural rigidity and minimal weight. Sandwich construction is a well-established technique in industry, but there has been a lack of design variables for composite sandwich structures. Nowadays, most of the 3D printer use plastic-based filament. Some of the plastic-based filament such as ABS filament is non-biodegradable plactic. The product that made from the this plastic will bring harm to the environment such as emission of the greenhouse gases and limited option of recycling the waste product. Hence, the bio-composite filament is great choice to make replacement of fully plastic-based material.

Bio-composite is a versatile material as it have many advantages such as high strength and recyclable. Despite of all the advantage, there are also disadvatges of this material such as it more brittle and more easily damaged. Damage mechanics of composite materials is concerned with the various damage mechanisms, their evolution under thermomechanical loading, and their effect on the elastic, failure, and fatigue behavior of a composite structure.

1.3 Research Objective `

The main aim of this research is to study the influence of sugar palm composite material using different pattern of HCSS base by using FDM printing technique. Specifically, the objectives are as follows:

a) To design and fabricated Honeycomb Sandwich Structure (HCSS) using bio composite filament through Fused Deposition Modelling (FDM) printing technique.

b) To analyse the effect of bio composite on different type of honeycomb core sandwich structure through mechanical testing.

1.4 Scope of Research

The scope of this research are as follows:

- Testing and analyze physical, morphological, and mechanical of sugar palm and polylactic acid (PLA) composite by using FDM technique.
- Develope 3 alternative patterns of HCSS which include regular hexagonal, triangular and double hexagonal cell patterns of honeycomb .
- Produce 3D printed sample by using composite SPF Filament (10%)
- Using 3 type of ASTM testing method to test the sample : ASTM C297, ASTM D638, ASTM C393

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The sections begin by providing essential of the theory of honeycomb sandwich structure (HCSS) especially in material and mechanical properties. Other than that, this sections will discuss briefly about 3D printing process theory and common bio-composite plastic used in honeycomb sandich structure. Next, I'll go over the natural fiber and composite materials used in 3D printing that are already on the market. Second, some relevant information about the materials under consideration for this work, which is Sugar Palm composite for natural fibers with a focus on PLA (Polylactic acid), is reviewed. In addition, in-depth look at the mechanical testing procedure used in the structural sandwich core was provided, goes as well for some theoretical information on the other method employed in the experiment.

2.2 Honeycomb Sandwich Structure (HCSS)

This research introduces a new method for designing honeycomb sandwich panels with varying patterns, based on the weight ratio range of the honeycomb core that optimizes its mechanical properties. The theoretical results suggest that the weight of the honeycomb core should be between 50 and 66.7% of the total weight of the honeycomb sandwich panels. Experimental results confirmed the theoretical predictions, demonstrating that the proposed method is a viable way to design honeycomb sandwich structures with improved performance. (He & Hu, 2008)

Sandwich structures are like two slices of bread with a layer of honey in the middle (Figure 2.1). The bread represents the thin, rigid, and strong facesheets, while the honey represents the light and dense core. The adhesive is like the butter that holds everything together. The goal of this structure is to achieve high rigidity and strength with a low overall weight. (Jędral, 2019)

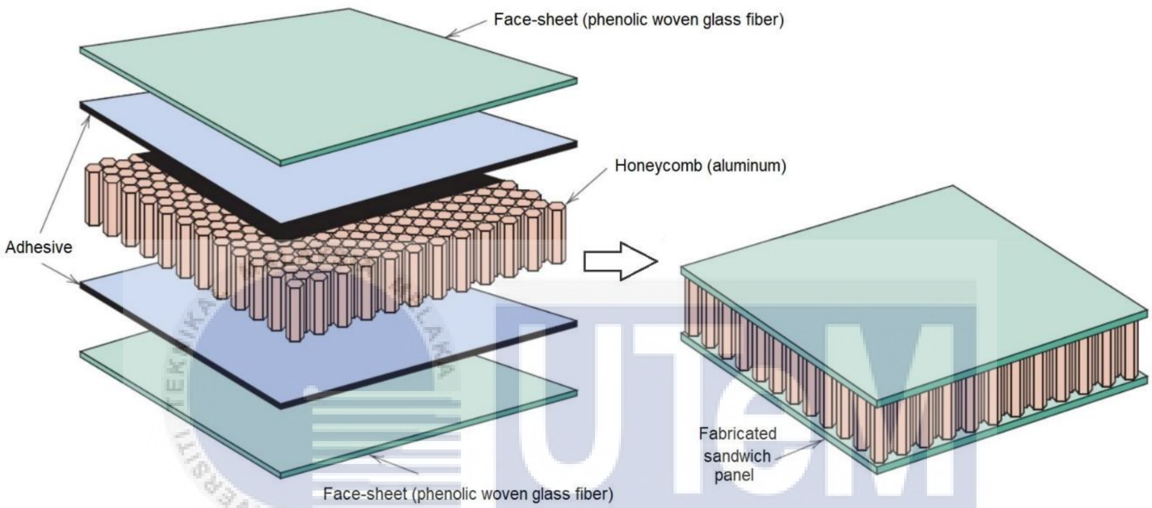


Figure 2.1 Honeycomb sandwich panel structure structure

(Al-Fatlawi, Jármai, & Kovács, 2021)

Figure 2.2 shows 2 typical reinforced honeycomb core structures (HCSS) and 1 regular hexagonal cell. Basically, it can be categorized as two types. The first is hexagon reinforced with ribs. They are generally known as triangular hexagonal. Meanwhile, the second is hexagonal with additional ribs and hexagonal core inside. This hexagonal shape is most likely known as double hexagonal (Wang, et al, 2015).

Figure 2.2 Regular hexagon, triangular Hexagon, Double Hexagon

2.2.1 Application Honeycomb Core Sandwich Structure (HCSS)

Sandwich panels made of honeycomb are employed in a wide range of sectors, including but not limited to military applications, rotorcraft, commercial and business aircraft, some high-end boats, and high-end automotive applications. Honeycomb sandwich panels are also used in some high-end boats.

When it comes to panels that are utilised in industry, the key objective is to decrease the weight of the panels while simultaneously enhancing the strength and stiffness of the panels. In order to prevent fires from spreading throughout aeroplanes, the panel is outfitted with fire resistant qualities that are in accordance with the regulations set out by the Federal Aviation Administration (FAA).

Honeycomb sandwich panels are also used in aircraft flights for the purpose of controlling surfaces such as the rudder, flap, aileron, and spoiler, in addition to other surfaces. Honeycomb sandwich panels are also used in various applications.

In addition to this, honeycomb sandwich panels are employed in the process of developing and constructing aircraft structures.

Honeycomb sandwich panels have a variety of other uses, including those in the building and architectural sectors. It is discovered in residential dwellings, commercial and industrial structures, and even buildings that are undergoing repair. It is also found in private residences.

The following is a summary of the characteristics of honeycomb sandwich panels that have contributed to the amazing growth of these components, particularly in the construction industry:

i) Thermal Resistance : When honeycomb sandwich panels are included into a system, the thermal bridging that occurs across the joints is reduced to a minimum.

ii) Mechanical Properties : Depending on the panel that is being used and the frequency with which the panel is being applied, the distance that exists between the supports might be anything from three to five metres.

iii) Fire Behavior : There are several distinct forms of fire behaviour that can occur in sandwich panels, and these behaviours are determined by the thickness of the metal, the foam, and the coating. Users have the ability to select a sandwich panel that best suits their needs from among the available options.

Figure 2.3 HCSS application on a airplane

2.2.2 Material of Honeycomb Sandwich Structure (HCSS)

Honeycomb saandwich Strcuture (HCSS) are fabricated from a wide variety of materials. These range from bio-composite and aluminium, used to provide low strength and stiffness for low load applications, to higher strength and stiffness for enhanced performance applications, as in aircraft structures. Honeycombs are processed into flat or curved composite structures. They form complex compound curved shapes without excessive mechanical force or heating. Table 2.1 show some of the popular materials used in honeycomb sandwich structure (HCSS).

Table 2.1 Materials of HCSS

No.	Type of Materials	Description
1.	Nomex	Nomex is a materials that made from aramid composite paper and covered by phenolic resin. The materials is very sturdy but lightweight. This type of material usually found on flooring and interior of aircratf. (Xie, Wang, Jing, & Feng, 2022)
2.	Aluminium	Aluminium HCSS is great fire mould and corrosive resistance. This material also recyclable. Most of the time, aircraft parts such as flap and spoiler is made of aluminium. (Uğur, Duzcukoglu, Sahin, & Akkuş, 2017)
3.	Polypropylene	Fiber glass material is used on upper and lower layer of the HCSS and the core usually made of polypropylene material.
4.	Kevlar	Kevlar is know for it heat-resistant fibre with very high tensile strength, known for its ability to withstand high impact.

2.2.2.1 Natural Fibre Composite (SPF)

Over the last several years, synthetic fibres have been used in a significant manner in the production of valuable commercial items, notably in the composites sector. Natural fibres, on the other hand, have become more popular as an alternative to synthetic fibres as a result of the adverse impact that synthetic fibres have on both the environment and human health. Natural fibres may also result in the production of tonnes of lignocellulosic biomass, which is a term that is usually used to refer to waste from agricultural and industrial processes. The processing of this lignocellulosic biomass may result in the production of a wide range of bioproducts, such as bio composites, biofuels, bio sugars, bio adsorbents, and many more. (Imraan, et al., 2023)

Natural fibres have attracted a lot of material scientists due to their accessibility, affordability, processability, renewability, recyclability, and biodegradability. Furthermore, natural fibres outperformed synthetic fibres in terms of particular tensile strength, health concerns, acceptable insulating characteristics, low density, and energy use during processing. (Asyraf, et al., 2021) (Ilyas, et al., 2021)

The most frequent and widely used natural fibres are flax, kenaf, hemp, jute, coir, sisal, and abaca. Meanwhile, sugar palm fibre (SPF) has been known in rural communities for decades for its versatile traditional usage in a variety of meals and beverages. The SPF are used in a range of conventional applications like as ropes, brooms, and roofing, among others. These fibres are used in their natural state, without any chemical modifications, in their traditional uses.

Recently, it has been utilised as a renewable energy source in the form of sugar palm sap-derived bioethanol. The three most notable products that the sugar palm can produce are palm sugar, crops, and fibres. Intriguingly, the sugar palm fiber (SPF) is acquiring popularity, particularly as a reinforcement in composites.

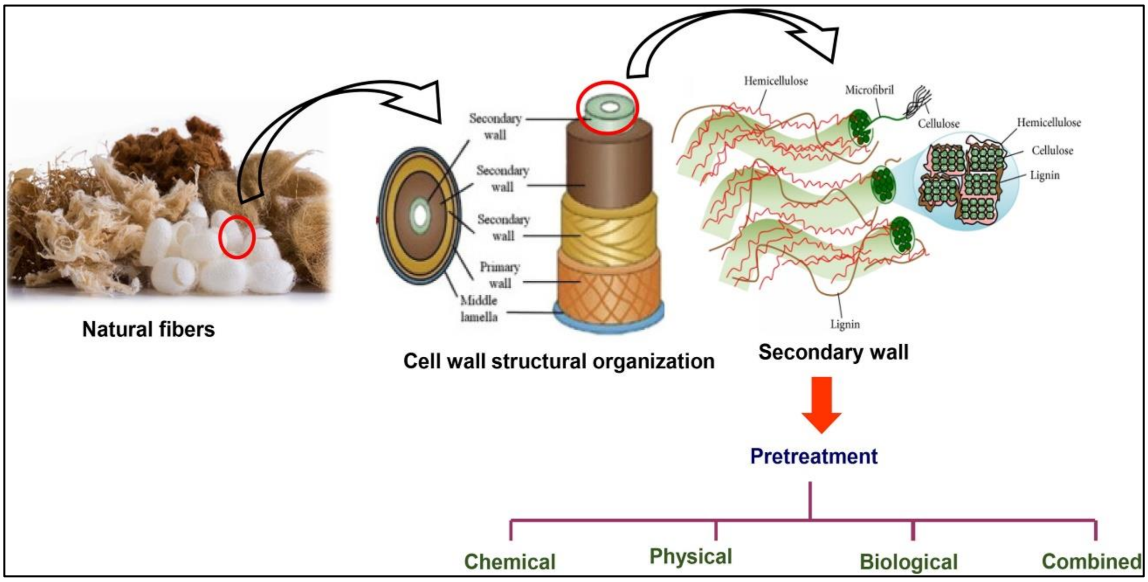


Figure 2.4 Overview of natural fibers pretreatment

2.2.3 Mechanical Properties of Honeycomb Sandwich Structure (HCSS)

Honeycomb sandwich structure possesses high flexural rigidity and bending strength with low weight. Flexural rigidity and bending strength are very important mechanical properties of honeycomb sandwich panels. The underlying assumptions of the theory presented in the deducing procedure are as follows (He & Hu, 2008):

a) The faceplates are extremely thin in comparison to the thickness of the structure as a whole.

b) The shear stress is regarded constant throughout the core's depth. This assumption may be made if the sandwich's interior is too feeble to contribute significantly to its flexural rigidity.

c) The honeycomb structure is anisotropy.

d) The face plates have negligible rotary inertia about their own centroidal axes.

e) The sandwich has face plates of equal thickness (symmetric sandwich), and both face plates are made of the same material and have similar properties.

2.2.4 Fabrication of Honeycomb Core Sandwich Structure (HCSS)

2.2.4.1 Expansion Method

Before beginning the expansion method, it is necessary to first cut a thin sheet of metal into the proper shape and size. This is a prerequisite for the process. After this step, adhesive strips are applied to the sheet in a pattern that has been selected in advance. Generally speaking, the glue is positioned in such a way that the strips on neighbouring sheets are offset by half the distance between the strips on the same sheet. This is done in order to align the strips. In the process of applying the glue, this step is carried out.

Following the curing of the adhesive, the sheet is then attached to another sheet, with the adhesive strips pointing in opposite directions from one another compared to the direction in which they were originally pointed. After the "sandwich" has been made, it is frequently chopped into very small pieces using a waterjet or laser cutter. This is done frequently after the sandwich has been created. After that, the honeycomb core is created by stretching the slices to their full size, which makes the honeycomb core.

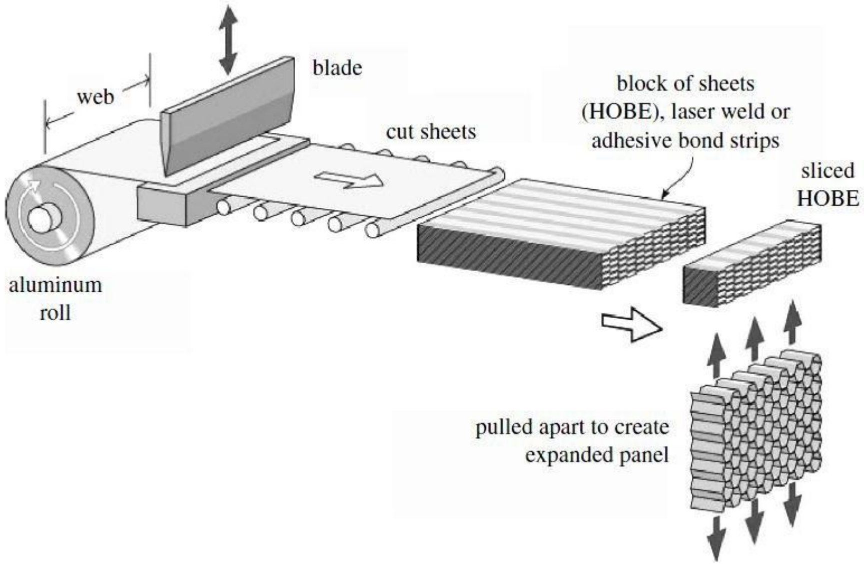


Figure 2.5 Expansion method

2.2.4.2 Corrugation Method

Before beginning the process of corrugation, a thin sheet of metal is first corrugated, which means that it is shaped into a series of waves. This is done in order to get the process started. Following this step, the tops of the waves are coated with strips of adhesive, which are then glued to the surface. Following the curing of the adhesive, the sheet is then attached to another sheet, with the adhesive strips pointing in opposite directions from one another compared to the direction in which they were originally pointed.

After the "sandwich" has been made, it is frequently chopped into very small pieces using a waterjet or laser cutter. This is done frequently after the sandwich has been created. After everything is said and done, the honeycomb core is created by flattening the segments of the honeycomb structures.

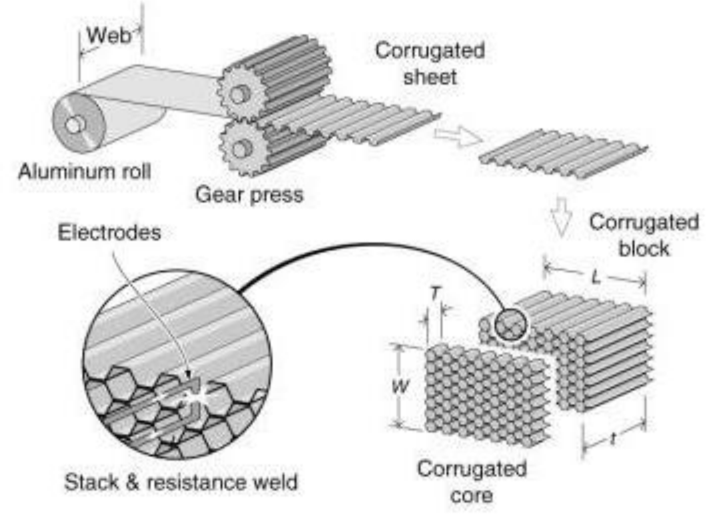


Figure 2.6 Corrugation Method

2.3 Fused Deposition Modelling (FDM)

Fused deposition modeling (FDM) is the most popular 3D printing technique for a reason. It's simple to understand, doesn't require hazardous chemicals, and the printers are relatively inexpensive and compact. The basic operation of FDM is shown in Figure 2.2. A thermoplastic filament is continuously fed into a small, heated chamber, where it melts and becomes a highly viscous fluid. The molten material is then extruded through a nozzle and deposited layer by layer onto a heated build plate, according to a pattern generated by the printer's control software. This pattern reproduces the desired geometry of the object, which can be input as a CAD file in the STereo Lithography interface format (STL). (Mazzanti, Malagutti, & Mollica, 2019)

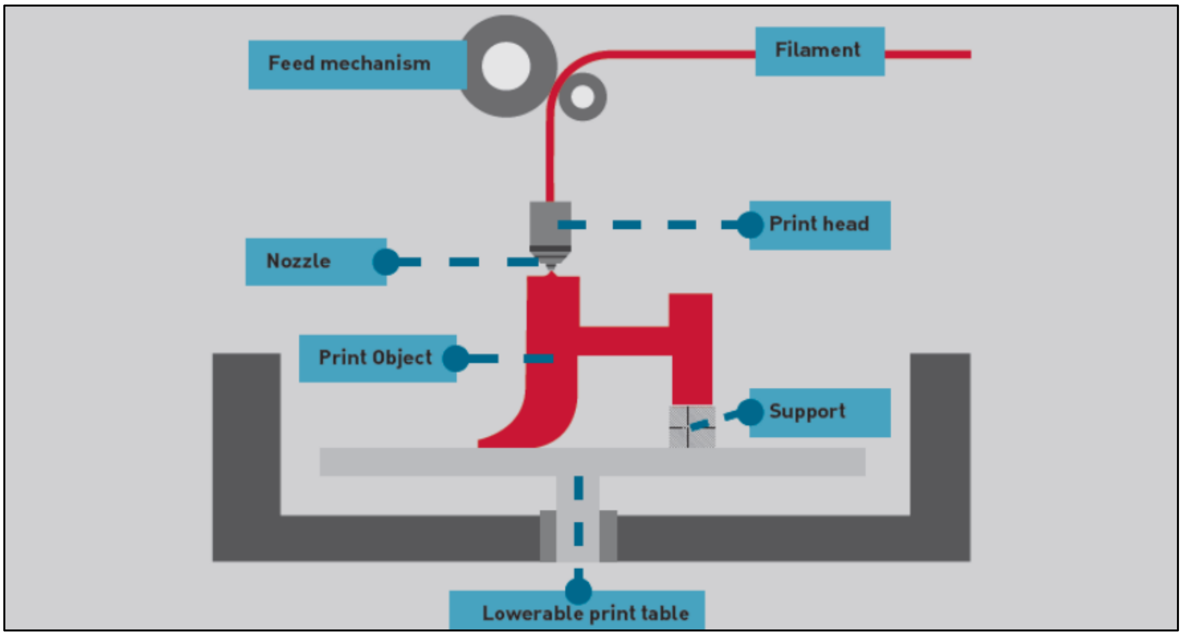


Figure 2.7 Fused Deposition Modelling (FDM)

2.3.1 Modelling

Before 3D printing, the object needs a digital design. This can be created with CAD software like SolidWorks, or scanned using a 3D scanner or specialized photogrammetry software. CAD models often reduce printing errors, as issues can be identified and addressed beforehand. While traditional sculpting involves manual shaping, 3D modeling tools offer similar control for digital creations. Once the model is complete in a software-specific format (e.g., .in, .skp), it needs conversion to STL or OBJ format for compatibility with the 3D printing software.(Mazzanti, Malagutti, & Mollica, 2019)

2.3.2 Printing

Before printing, STL files undergo a "fixup" to address errors common in CAD-generated files, such as self-intersections, holes, and face normal issues. Next, a "slicer" program divides the model into layers and creates a G-code file, containing specific instructions for the 3D printer. The printer then uses this G-code file, loaded and executed by 3D client software, to guide the printing process. Popular client and slicer programs include Cura, Slic3r, and Simplify3D.

The 3D printer follows the G-code instructions to build the model layer by layer, using materials like plastic, powder, paper, or sheets. These layers correspond to virtual cross-sections from the CAD model and are fused together to create the final shape. Print times vary from minutes to hours, depending on printer speed and model complexity.

Printer resolution is measured in dots per inch (dpi) or micrometers (µm), affecting both layer thickness and X-Y precision. Typical layer thicknesses are around 100µm, but some machines can achieve 16µm layers. X-Y resolution is comparable to laser printers, with particle sizes ranging from 50 to 500µm (510 to 250 DPI).

Overall model construction time can range from a few hours to several days, depending on factors like model size, printing technology, speed, and complexity. However, with advancements in printer technology and size, print times are often reduced to a few hours.

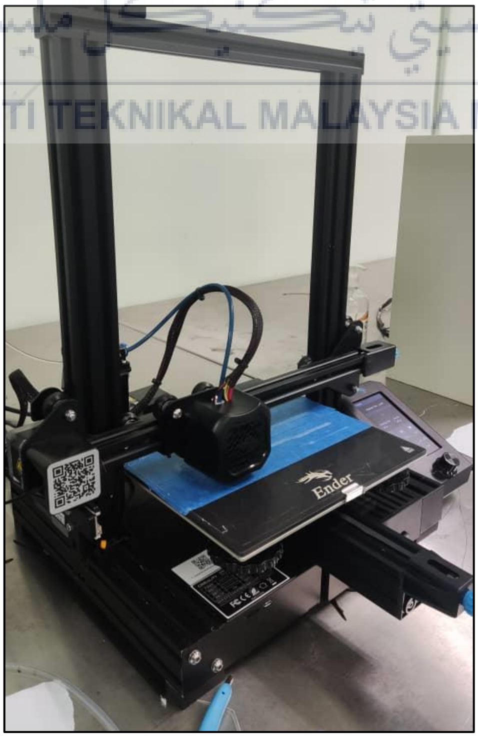


Figure 2.8 Printing Process

2.3.3 Post Processing

For Post-processing plays a crucial role in refining the final appearance, functionality, and durability of 3D printed objects created using Fused Deposition Modeling (FDM). It involves various techniques that address the inherent layer lines and imperfections that can result from the FDM process.

One of the first steps often involves the careful removal of support structures, which are temporary scaffolds used to uphold overhanging features during printing. These supports can be detached manually or dissolved using special solutions, depending on the material used.

To enhance the surface smoothness and visual appeal, sanding is a common practice. It typically starts with coarse-grit sandpaper and progresses to finer grits to gradually reduce layer lines and blemishes. For intricate details or hard-to-reach areas, specialized tools like needle files or rotary tools can be employed.

To achieve a more uniform and professional-looking finish, priming and painting are often applied. Priming creates a base layer that improves paint adhesion and helps conceal any remaining imperfections. Once primed, various paints and finishes can be used to achieve the desired visual effects and protect the surface from wear and tear.

Other advanced finishing techniques can be employed depending on the desired outcome. These include:

- Vapor smoothing: This technique exposes the printed object to acetone vapors, which partially dissolve the outer layers, creating a smoother and more glossy finish.

- Polishing: Using polishing compounds and cloths, a high-gloss finish can be achieved, often employed for aesthetic parts or those requiring low friction.

- Electroplating: This process involves coating the object with a thin layer of metal, such as copper or nickel, to enhance its visual appeal, durability, and electrical conductivity.

The choice of post-processing techniques depends on several factors, including the material used, the desired surface finish, the functional requirements of the object, and personal preferences.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In a methodical and all-encompassing way, this chapter detailed all of the approaches that were used in the process of designing and completing this capstone project for the seniors. Throughout the whole of this study, a number of different research approaches and tools have been used in order to be successful in making progress. Methodology is a term that refers to the processes or approaches that are used in order to finish the project in its entirety. It is essential to have this procedure in place throughout the execution of the project since it guarantees that the project will be finished successfully and on schedule. Moreover, a significant number of the strategies that are discussed in this chapter may be used to successfully complete the project.

3.2 Research Design

The first stage is data collecting, the design of the HCSS have been created for reference in term of shape, paramenter mechanical properties, and material that usually used by sandwich structure manufacture. Any of information was created by consulting all thesis, publications, and journals written by anyone who has conducted research on this issue. Following the completion of the research, the information will be classified using specification analysis.

The second stage is fabrication process. This process include the technique of FDM printing and setting the parameter. It is important to find suitable parameter according to type of materials use for 3D print filament in order to get satisfied result. Otherwise, data collecting process must take over again to study and find the perfect parameter to print bio-composite filament.

The third stage is mechanical testing. In this study, 3 mechanical testing were test on 3 different reinforced honeycomb core sandwich structure (HCSS) which is regular hexagon, triangular hexagon and double hexagon. These mechanical testing was made to study the tensile, flexural and flawise tensile strength between 3 different reinforced HCSS.

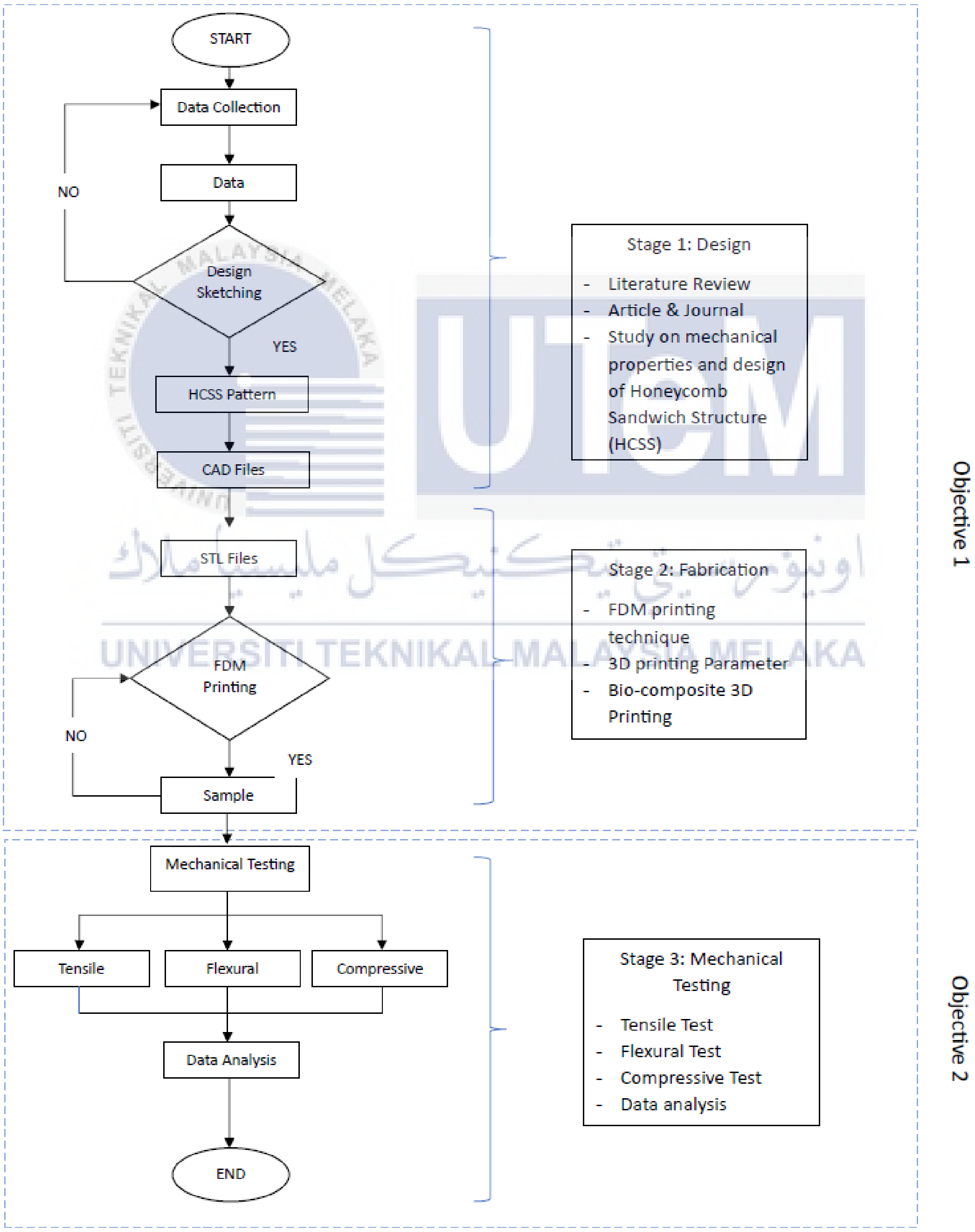


Figure 3.1 Flowchart of the developement of the studies

3.3 Design of Honeycomb Core Sandwich Structure (HCSS)

The pattern of HCSS was developed based on the research study on literature review. There are 3 patterns that will be focused on this study such as double hexagonal, triangular, and regular hexagon for the bench marking. Each of the patterns will be tested on 3 types of mechanical testing which is tensile test, flexural test, and compressive test. Each of the mechanical testing has a different type of medium pattern to testing. Mechanical testing that will be tested is specifically for sandwich structures construction test. The patterns of HCSS will be imbued to the standard dimension of medium testing for each testing. The pattern is then visualized and designed by using Solidworks 2021 to create the CAD model.

3.3.1 CAD Drawing

The CAD design of the honeycomb structure was created by using Solidworks 2021. Each of the patterns was designed and measured to blend into the standard dimensions of the mechanical testing for sandwich construction. Honeycomb itself pattern is complex design, but when designing of any CAD designing software, the software tends to get lag as its graphic card has been pushed to process the multiple complex shape hexagons. The table below shows the design of the HCSS imbued with standard shape of mechanical testing for sandwich structures.

Table 3.1 Design of Honeycomb Sandwich Structure for Compressive Test

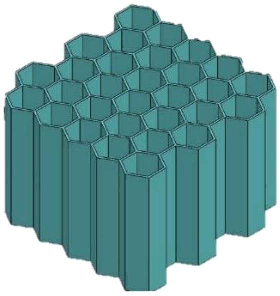
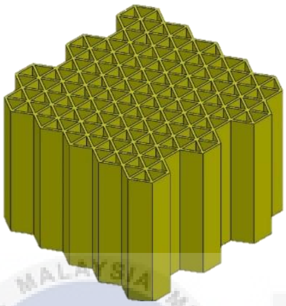
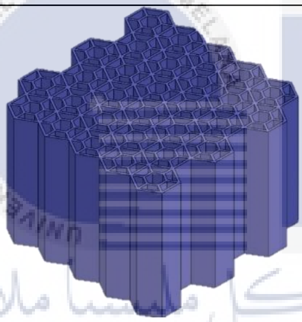
No.	CAD	Pattern Name	Size
1.		Hexagonal	
2.		Tringular Hexagon	50 mm x 50 mm x 9 mm
3.		Double Hexagon	

Table 3.2 Design of Honeycomb Sandwich Structure for Flexural Test

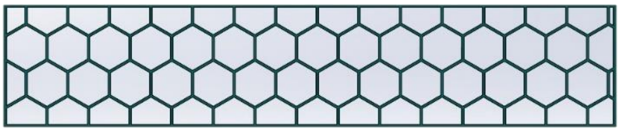
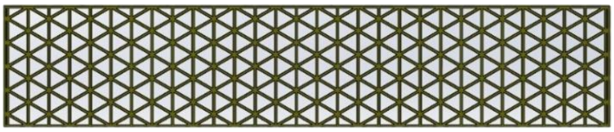
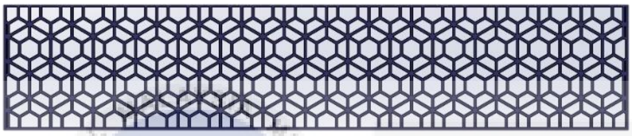
No.	CAD	Pattern Name	Size
1.		Hexagonal	125 mm x 25 mm x 3.2 mm
2.		Tringular Hexagon	
3.		Double Hexagon	

Table 3.3 Design of Honeycomb Sandwich Structure for Tensile Test

No.	CAD	Pattern Name	Size
1.		Hexagonal	165 mm x 19 mm x 3.2 mm
2.		Tringular Hexagon	
3.		Double Hexagon	

3.4 Fabrication by using FDM technique.

The sugar palm fibre (SPF) filaments were 3D printed using the Creality Ender 5, which is an FDM 3D printing machine. The open-source programme Ultimaker Cura 4.8.0 was used to produce STL files for the purpose of printing. The CAD model of the 30 test specimens, in accordance with ASTM D638, ASTM C393, and ASTM C297, was created using Solidworks 2021. Sugar palm fibre (SPF) filaments were used for producing samples for both tensile and flexural tests. A nozzle diameter of 0.4 mm was used for printing sugar palm fibre (SPF) filaments. Table 3.4 includes the printing parameters of a [0, 90] degree printing strategy with 100% infill. The filament is printed with a nozzle temperature ranging from 180 to 220 °C and a bed temperature of 80 °C. Once the filament reaches its melting point, it is passed through a 1mm needle, resulting in a layer thickness of 0.30mm. The first layer of the 3D-printed specimen had challenges in sticking to the printer build plate. PP filaments that are available for purchase are often composed of a mix or composite material in order to avoid warpage. By using Pritt adhesive and Kapton tape, the first layer of the print failed to stick to the printer bed, leading to the premature cessation of the printing process.

Table 3.4 Printing Settings

Parameters	**value**
Temperature Printing (˚C)	180
Initial plate temperature (˚C)	180
Build plate temperature (˚C)	80
Build plate temperature, initial layer (˚C)	80
Infill pattern	Line
Infill flow (%)	100

The height of the layer (mm)	0.3
Line width (mm)	0.3
Top and bottom layers (layers)	2
The print speed (mm/s)	100
The speed of initial layer (mm/s)	15
Build plate adhesion type	Brim

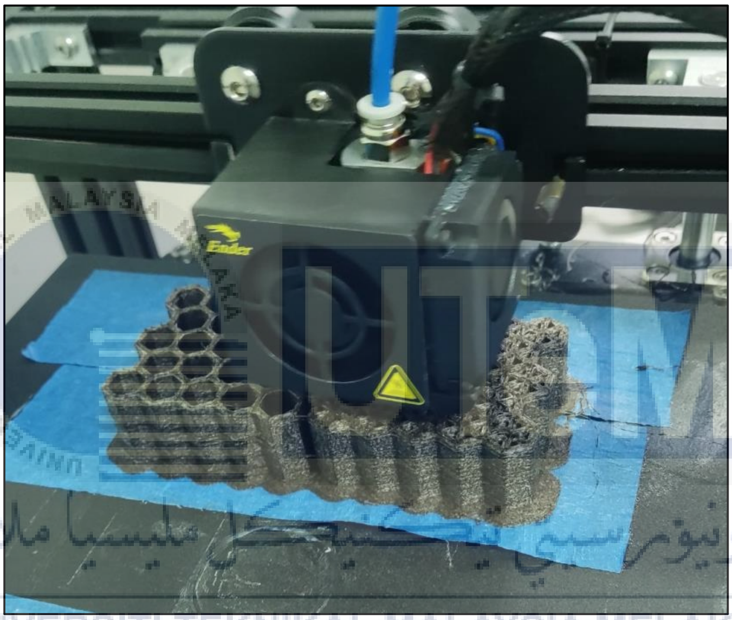


Figure 3.2 FDM Printing Process

3.5 Mechanical Testing for Honeycomb Core Sandwich Structure (HCSS)

3.5.1 Tensile Test

Shimadzu Precision Universal Tester, model Autograph AG-Xplus was used to perform the tensile testing. The following conditions were used: 5 mm/s displacement. Each HCSS pattern was tested with 3 samples

Using a Universal Testing Machine with a crosshead speed of 30mm/min, ASTM D7250 tensile characteristics were determined. After conditioning at ambient temperature and relative humidity of 30%, the dumbbell-shaped specimens were ready for testing.

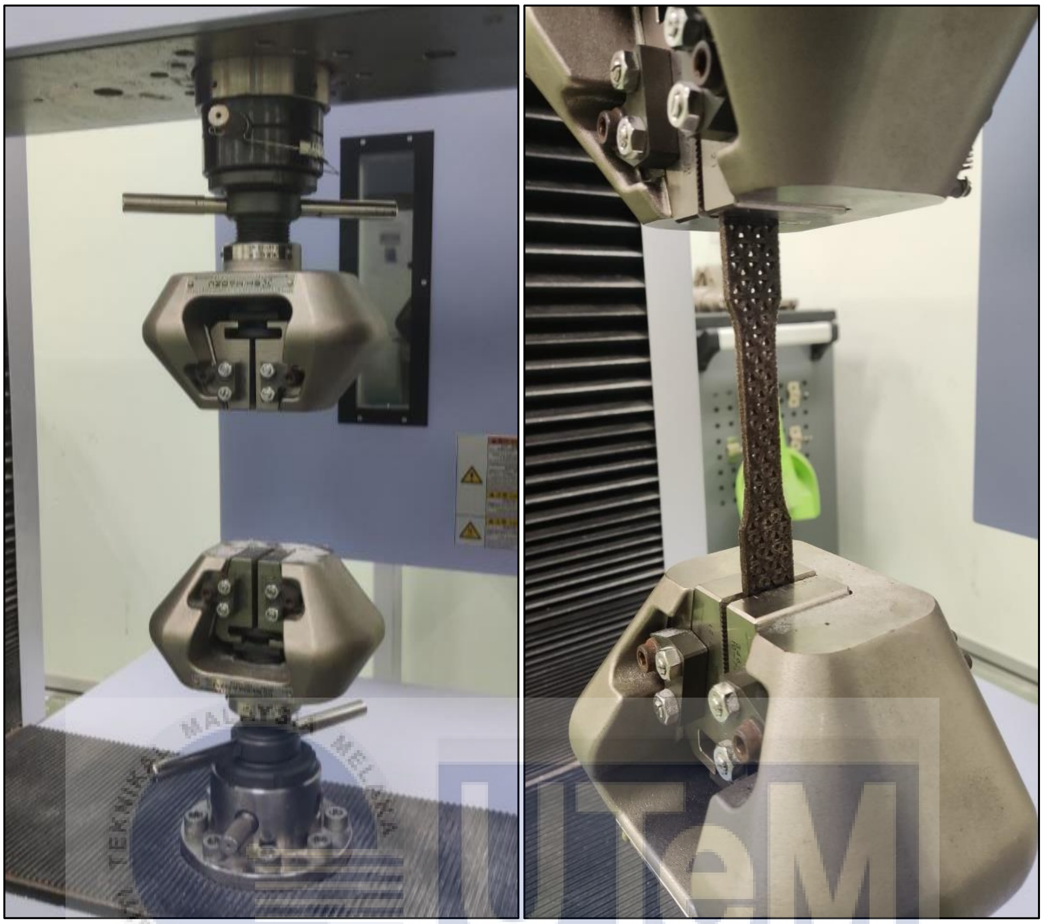


Figure 3.3 Precision universal tester machine (Tensile Test)

3.5.2 Flexural Test

Three-point bending tests will be performed according to ASTM C393 (Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure) standard at ambient conditions by using 100 kN universal testing machine. The cross-head speed will set to 2 mm/min. 5 mm thick plate having size of 50mm x 25mm was used between the samples and loading block in order to prevent the local indentation failure. Flexural tests were measured using a Shimadzu precision universal tester Autograph AG-X plus (Figure3.4).

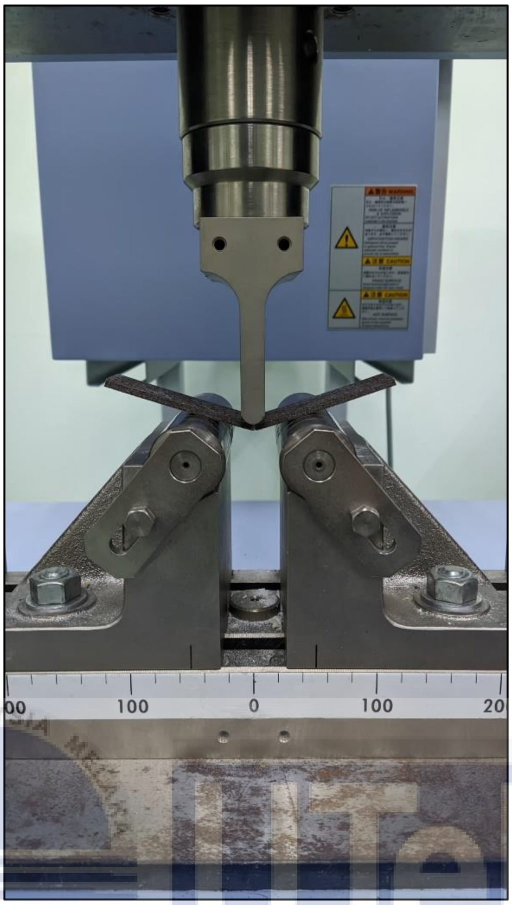


Figure 3.4 Precision universal tester machine (3-Point Bending Test)

3.5.3 Flatwise Tensile Test

A universal machine was used to perform the flatwise tensile testing. Each of the HCSS pattern was tested with 3 samples.

ASTM C297 (Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions) will be used as a standard method to get the tensile strength values of the samples. The data from the testing will provide an information for flatwise tensile strength data for the core material of composite sandwich. The sample dimension is 50 x 50 mm, and the overall thickness is 94 mm. A tensile machine with a maximum capacity of 100 kN will be used and the displacement rate will be set to be in the order of 0.5 mm/minute.

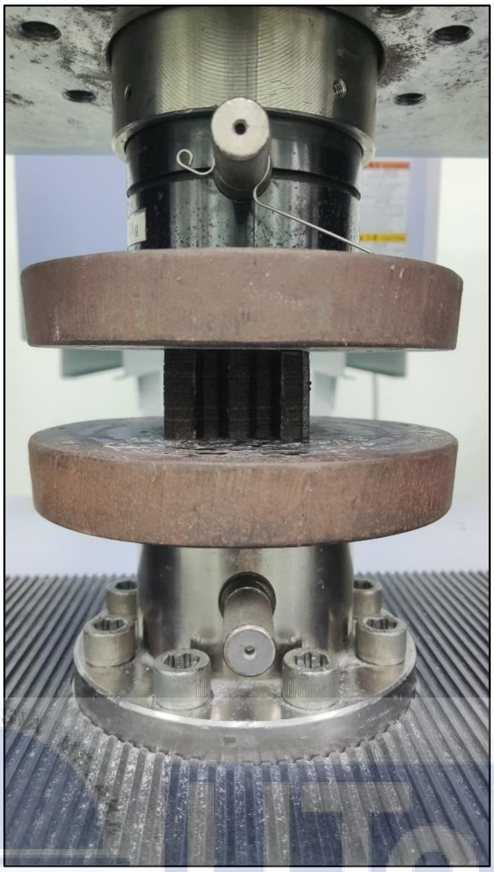


Figure 3.5 Precision universal tester machine (Compressive Test)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter present the result and analysis on the design of the honeycomb sandwich structure and the mechanical testing and simulation result for the fabricated structure. The expectation for this research for this study is to develop the best design model of honeycomb sandwich structure that met the limitatation for all the parameters of fabrication such as printability of product with bio-composite material and the capability of the product to sustain the mechanical testing at continous loading.

4.2 Printability of the Design

For testing the printability of design, FDM printing technique was used. At first, 3D filament of standard polymer such as polylactic acid (PLA) was used to test the printability of the design before actual printing by using bio-composite filament (SPF). As for the result the printability by using the PLA was a success. The finishing on the surface of the structure by using default parameters of the printer was smooth and accurate.

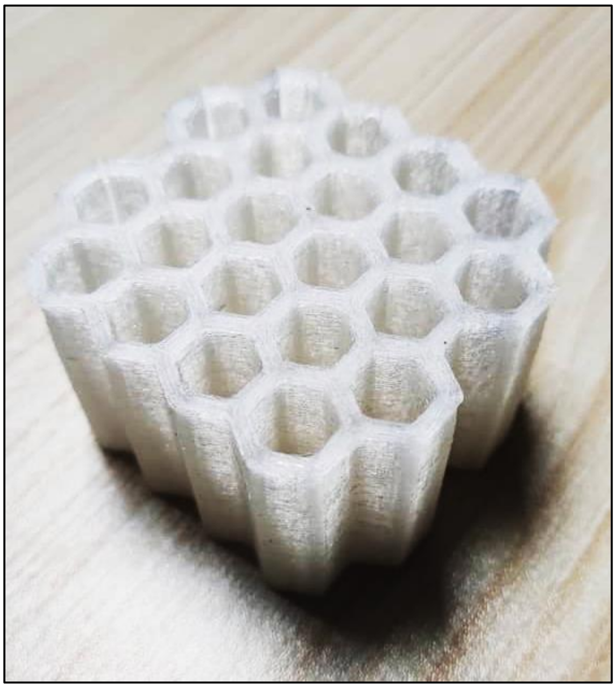


Figure 4.1 HCSS printed by using PLA filamnet

After the confirmation of the printability of the design suing the PLA filament. The fabrication then proceed to print the design by using the bio-composite filament. The bio-composite is a combination of PLA composite with biobased material which is sugar palm fibre (SPF) because it provides unique mechanical properties like lightweight and biodegradable materials. Unfortunately, the bio- composite material is extremely brittle, so the filament often breaks during the printing process, and they are often clogged in the extruder nozzle. The printing process needs to be cautious by paying attention toward all the parameters of 3D printing so that the product can be fabricated flawlessly without any errors of layer of the specimen. An ideal product can give the best mechanical testing results.

Figure 4.2 Fail Printing

Figure 4.3 HCSS printed by using PLA

In Figure 4.2 and Figure 4.3 shows the effect of the degradation of composite filament. The degardation of filament wil cause the extrusion of the FDM printer become inconsistence and most likely the extrusion will not adhere to the 3D printer bed. Other factor that can cause these problem is the inconsistence diameter of the the filament itself. The best way to overcome these problem is to manually insert the filament into the extruder nozzle. Moreover, to overcome the premature termination in the beginning of the printing is to

4.3 3D Printed Sample

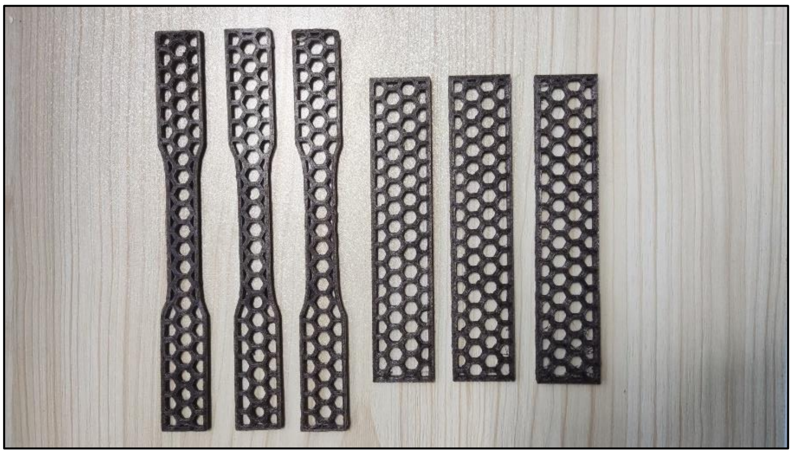


Figure 4.4 Hexagonal sample for Tensile and Fleaxural Test

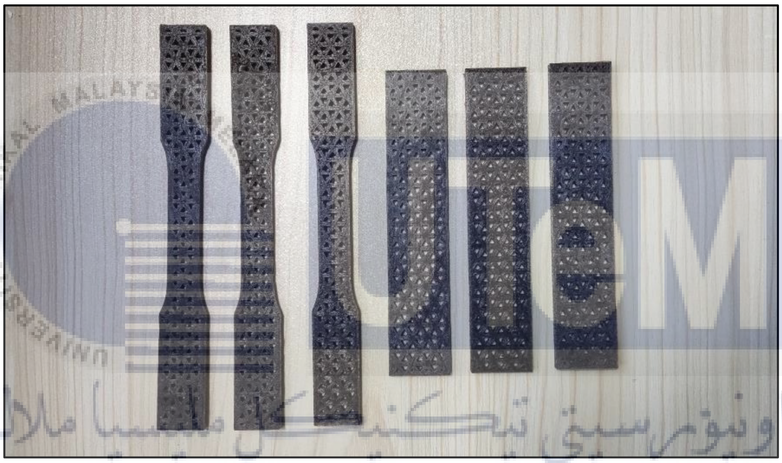


Figure 4.5 Triangular Hexagon sample for Tensile and Flexural Test

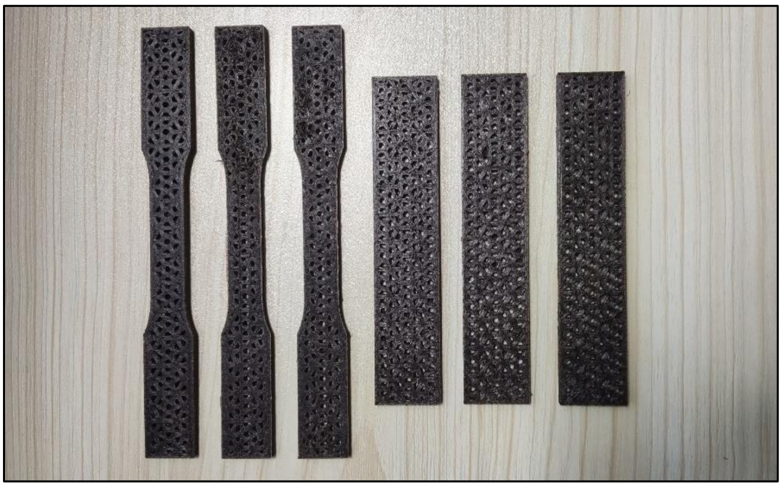


Figure 4.6 Double Hexagonal sample for Tensile and Flexural Test

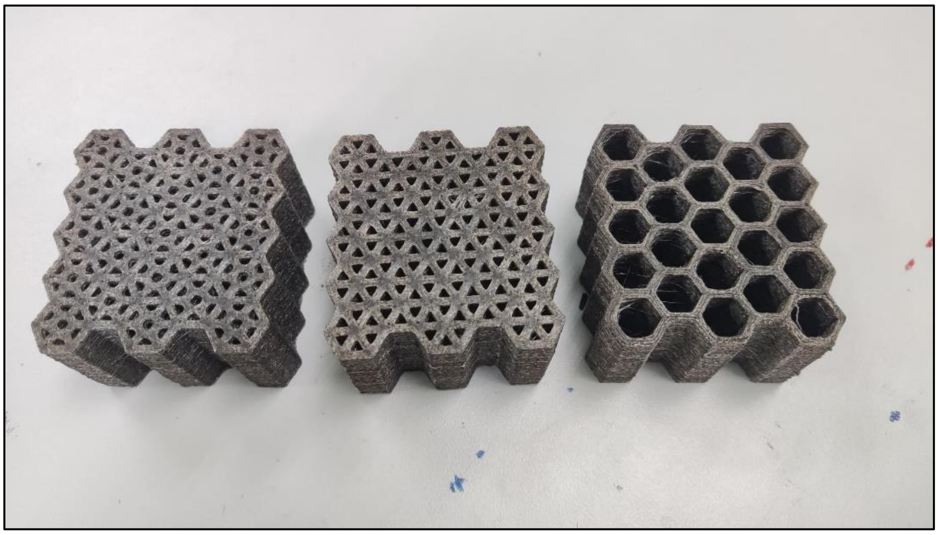


Figure 4.7 Flatwise Tensile sample for Hexagonal, Triangular and Double Hexagon

4.4 Mechanical Testing Result

4.4.1 Tensile Test

The effect of reinforced ribs and additional hexagonal cell on honeycomb sandwich core structure are shown in Table 4.4 and Figure 4.9. It clearly show that when the reinforced rib (Triangular) added to regular hexagonal structure have significant increase in tensile strength. As the additional hexagonal cell to the regular hexagonal structure with reinforce rib (Double Hexagonal), it show slight increase in tensile strength compared to Triangular Hexagonal.

Table 4.1 The result of the tensile strength and modulus elasticity

Pattern	Tensile Strength (MPa)			Average (MPa)	Modulus Elasticity (MPa)			Average (MPa)
	Sample 1	Sample 2	Sample 3		Sample 1	Sample 2	Sample 3	
Hexagon	5.69415	5.81336	5.81680	5.77477	6471.6	10079.6	6194.4	7581.866
Triangular Hexagon	10.5645	9.03431	9.98645	9.86175	24196.1	16673.5	11734.0	17534.533
Double Hexagon	8.81002	13.1069	13.0702	11.66237	13860.1	12676.7	16549.0	14361.933

By referring Table 4.4, the triangular hexagonal pattern is significant higher tensile strength than the regular hexagonal pattern with maxium value of tensile strength, 9.86175 MPa compared to 5.77477 MPa for regular hexagonal structure. But for the double hexagonal pattern, it shown its has higher tensile strength compared to regular hexagonal and triangular pattern with value, 11.66237 MPa.

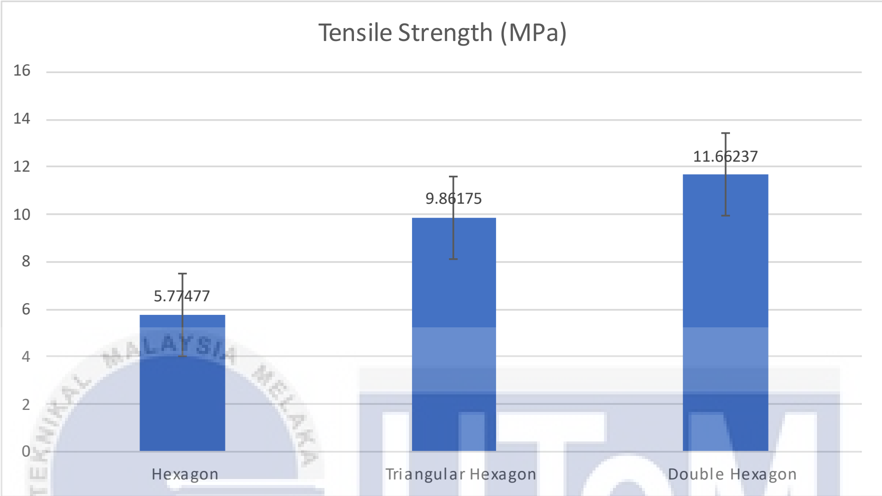


Figure 4.8 Tensile properties of HCSS with different reinforced structure

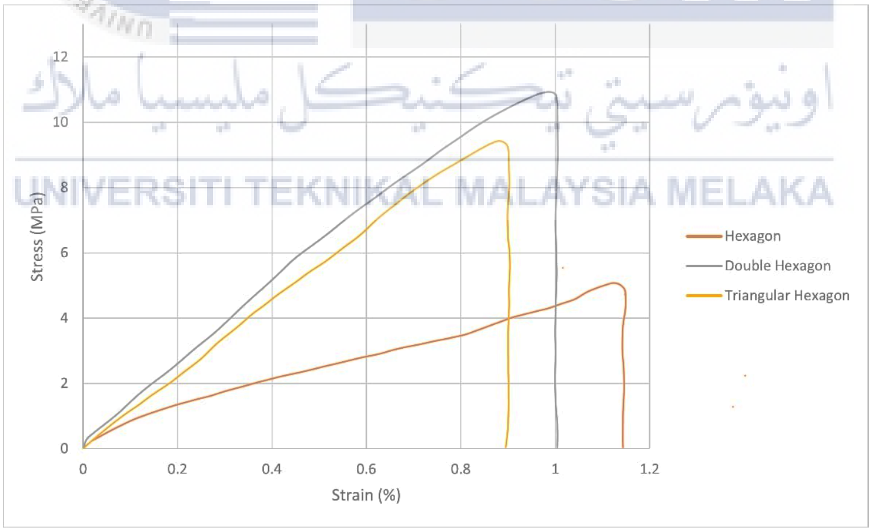


Figure 4.9 Tensile Test Chart

The result can be seen in Figure 4.9, as the reinforced rib and additional hexgonal cell increase respective with tensile strength. As the double hexagonal has both reinforced ribs and additional hexagonal cell, it shows a superior tensile strength compared to regular hexagonal and triangular pattern. Even the double hexagonal provide better tensile strength, it also cost almost double materials consumptions compared to regular hexagonal.

Regarding to Figure 4.8 and Figure 4.11, the fracture area was occured on unusual area. This case can happend due to degradation of the materials, which occur when the materials exposed to open air. The SPF composite element also known to it hydrophobic characteristic, so when it expose to the air, the humidity of the air will absorb by the composite and make it brittle. Other than that, one of the factor that might occur is the uneven force while setting up the sample on the testing machine. When the setting is off from the actual procedure, the force that acting on the sample will distribute unevenly through the whole sample and fracture on other area rather than in fracture area.

Figure 4.10 Fracture area on the tensile sample

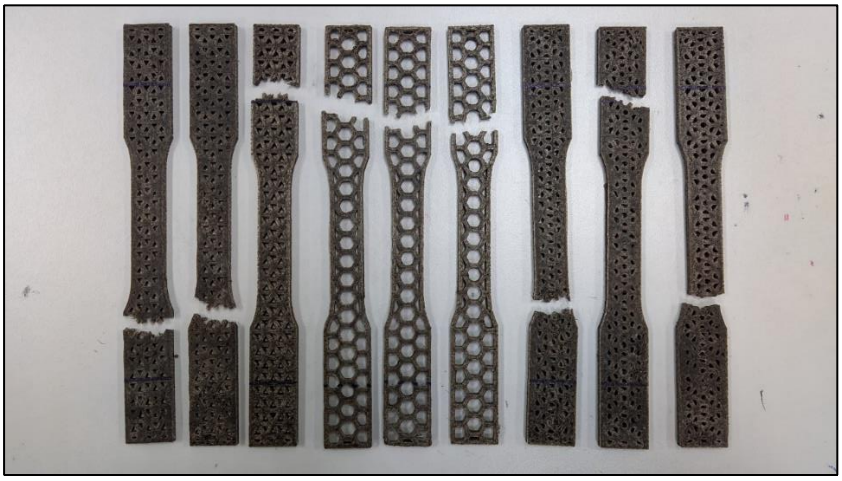


Figure 4.11 Fractured samples

4.4.2 Flexural Test

The effect of the reinforced rib and additional hexagon cell on the flexural properties shown in Figure 4.12, 4.13, 4.14, 4.15 and Table 4.3. Every pattern were tested by using 3 sample of specimens each. Table 4.3 show the total value for 3 sample on the flexural strength and elasticity. Also average of 3 sample each pattern which is regular hexagon, triangular hexagon and double hexagon were shown. The flexural strength show almost double value from the reading on triangular hexagon compared to regular hexagon pattern from average flexural 10.9679 MPa to 22.2835 MPa. The double hexagon pattern has the highest flexural strength with 26.2478 MPa.

Table 4.2 The result of the flexural strength and elasticity

Pattern	Flexural Strength (MPa)			Average (MPa)	Elasticity (MPa)			Average (MPa)
	Sample 1	Sample 2	Sample 3		Sample 1	Sample 2	Sample 3	
Hexagon (A)	11.7021	9.35048	11.8511	10.9679	4661.3	4192.6	4533.6	4462.5
Triangular Hexagon (B)	21.8954	21.7883	23.1667	22.2835	8641.4	7415.6	11545.6	9200.9

Double Hexagon (C)	26.3285	27.6789	24.7359	26.2478	9823.9	11661.0	10612.0	10699

The result can be seen in Figure 4.13, as the reinforced rib and additional hexgonal cell increase respective with tensile strength. As the double hexagonal has both reinforced ribs and additional hexagonal cell, it shows a superior flexural strength compared to regular hexagonal and triangular pattern. Even the double hexagonal provide better flexural strength, it also cost almost double materials consumptions compared to regular hexagonal.

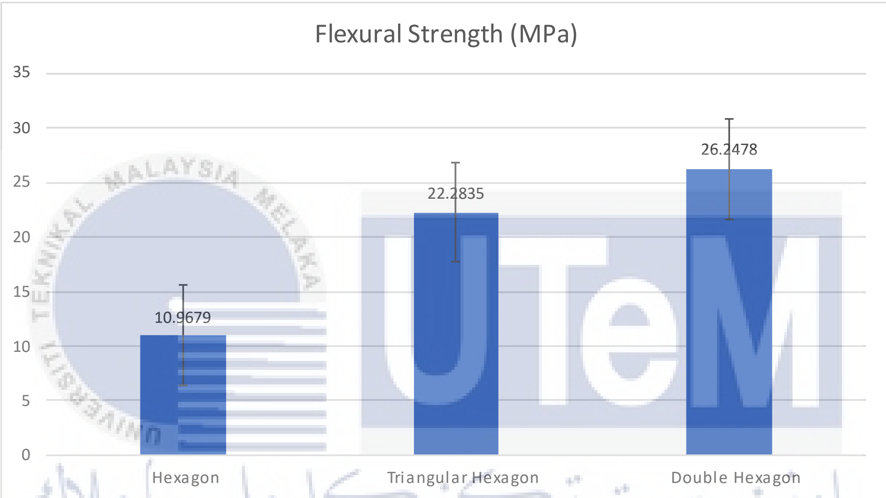


Figure 4.12 Flexural Strength of HCSS with different reinforced structure

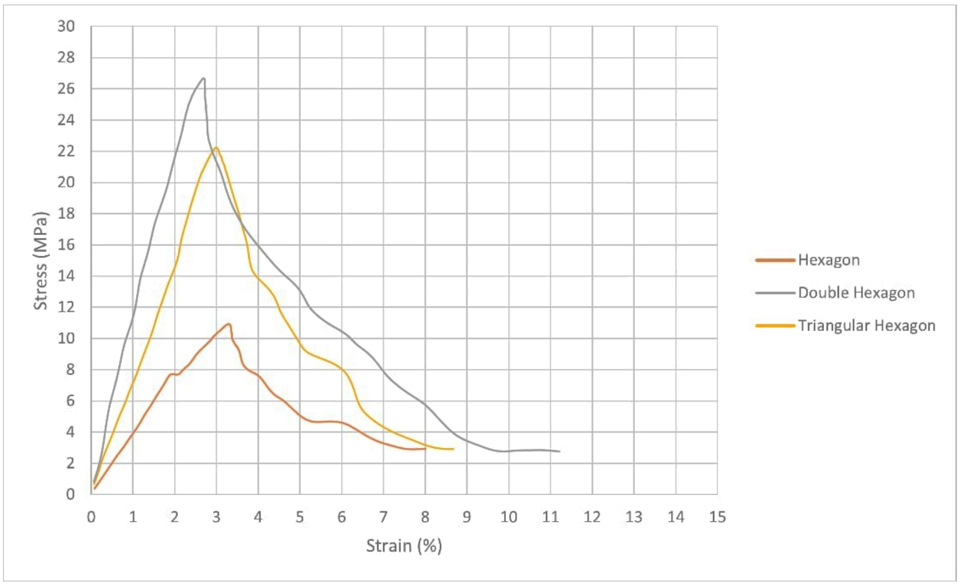


Figure 4.13 Flexural Test Chart

Figure 4.14 3-Point Bending Testing on sample

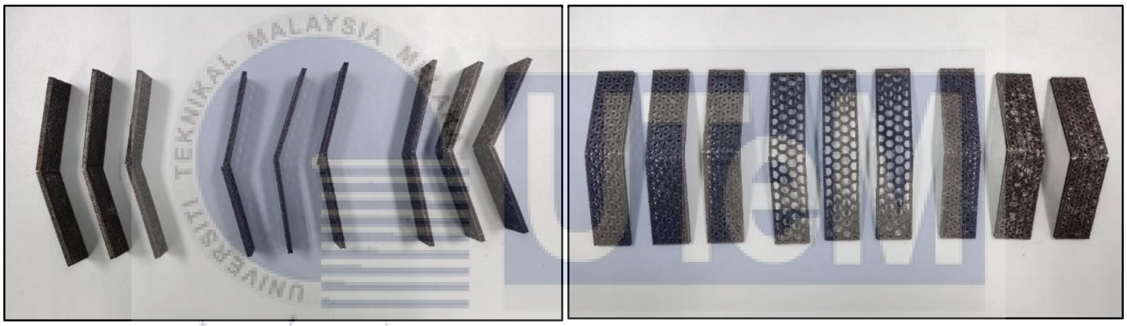


Figure 4.15 Fractured flexural samples

4.4.3 Flatwise Tensile Test

The effect of the reinforced rib and additional hexagon cell on the flatwise tensile properties shown in Figure 4.16 and Table 4.5. Every pattern were tested by using 1 specimen only, due to insufficient of SPF filament. Table 4.5 show the total value for 3 sample on the flatwise tensile strength and elasticity. Also single sample result for each pattern which is regular hexagon, triangular hexagon and double hexagon were shown. The flatwise tensile strength show the highest reading on triangular hexagon with reading 32.0027 MPa followed by double hexagon pattern with slight below from that reading which is 32.0024 MPa. The regular hexagon pattern has the lowest flexural strength with 18.0476 MPa. The overall reading shown the lack of accuracy in finding the average flatwise tensile strength. As result, the different outcome came out the triangular hexagonal pattern have better flatwise tensile strength compared to double hexagonal pattern which have reinforced ribs and additional hexagonal core.

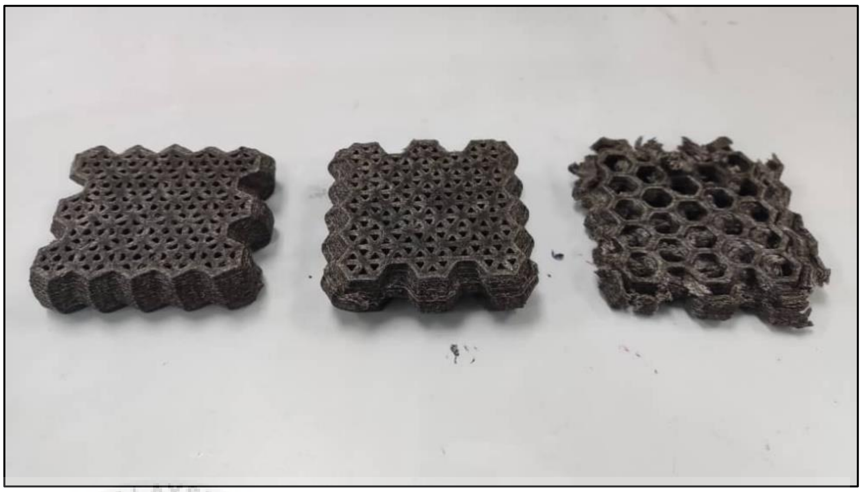


Figure 4.16 Compressed flatwise tensile samples

Table 4.3 The result of the flatwise tensile strength and elasticity

Pattern	Flatwise Tensile Strength (MPa)	Elasticity (MPa)
Hexagon	18.0476	378.7
Triangular Hexagon	32.0027	1737.7
Double Hexagon	32.0024	1486.2

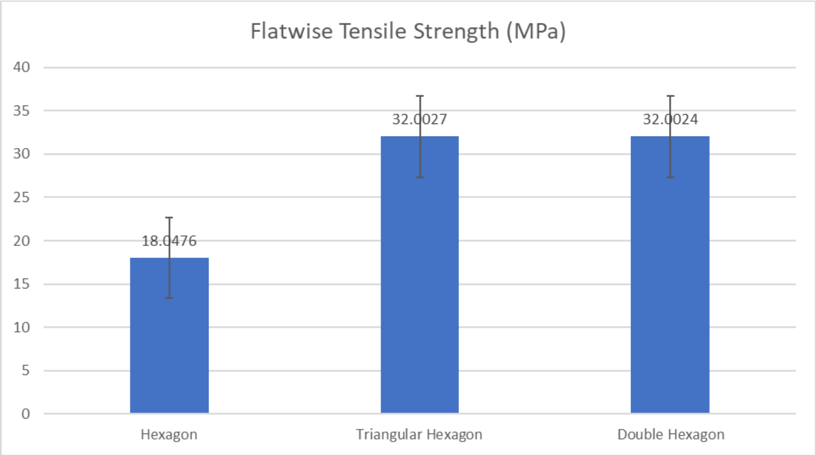


Figure 4.17 Flatwise Tensile Strength of HCSS with different reinforced structure

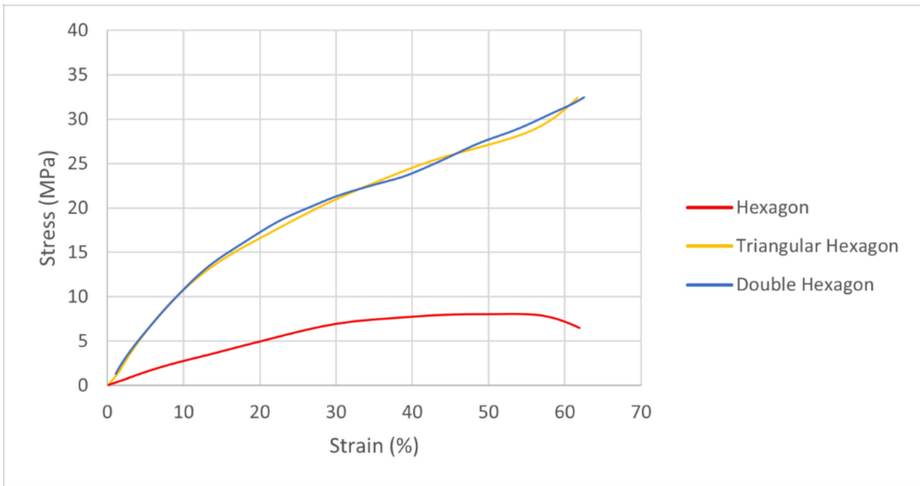


Figure 4.18 Flatwise Tensile Test Chart

For the weight comparison, it is clear that regular hexagonal pattern have the lowest weight with only 17.509 g. On the other hand, the double hexagonal pattern have the highest weight with 44.459 g due to its additional hexagonal core and reinforced ribs. Followed by double hexagonal pattern, triangular hexagonal pattern with slight below to double hexagonal pattern with only 0.323 g different from it actual weight, 44.136 g.

Figure 4.19 Weight of flatwise tensile samples for each pattern

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Several studies have been conducted to achive the research objective of (1) to design and fabricated honeycomb sandwich structure (HCSS) using bio composite filament through fused deposition modelling (FDM) printing technique and (2) to analyse the effect of bio composite on different type of honeycomb core sandwich structure through mechanical testing. Therefore, from all the analysis, there are few important conclusions were draw as follow:

a) The tensile properties of reinforced hexagon pattern increased as the reinforced ribs and additional core hexagon. The main reason to addition reinforced ribs feature was to improve the mechanical properties in the honeycomb core sandwich structure (HCSS). The hexagon pattern that has reinforced ribs and additional hexagonal core presented increased tensile strength starting with double hexagon pattern with 11.66237 MPa, followed by triangular hexagon, 9.86175 MPa and regular hexagon, 5.77477 MPa.

b) The flexural strength significantly increased as the reinforced ribs and additional hexagonal core added to the regular hexagon which is the double hexagon pattern. The flexural strength show almost double value from the reading on triangular hexagon compared to regular hexagon pattern from average flexural 10.9679 MPa to 22.2835 MPa. The double hexagon pattern has the highest flexural strength with 26.2478 MPa. It shown that the addition

c) The reinforced rib and hexagon cell affect flexural characteristics. Due to SPF filament shortages, each design was evaluated with one specimen. Single sample results for normal hexagon, triangular hexagon, and double hexagon patterns were displayed. Flatwise tensile strength is greatest on triangular hexagon at 32.0027 MPa, followed by double hexagon at 32.0024 MPa. With 18.0476 MPa, the regular hexagon design has the lowest flatwise tensile strength. Overall, the average flatwise tensile strength was inaccurately calculated due to lack of sample. The triangular hexagonal design has superior flatwise tensile strength than the double hexagonal pattern with reinforced ribs and a hexagonal core.

5.2 Recommendations

Further work that can be extended in this study is to investigate more reinforced pattern of honeycomb core sandwich structure (HCSS). The pattern can be test on different type of composite with different type mechanical testing. The properties of the composites filament also can extend the testing on morphological and thermogravimetric analysis (TGA).

5.3 Project Potential

The research of this study has a strong potential for being commercialization in industry as one of the optional reinforced honeycomb core strcuture. This reinforced honeycomb core structure also potentially can be used in any type of application in aerospace industry.

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APPENDICES

APPENDIX A Gantt Chart PSM 1

Gantt Chart for PSM 1																	
No	Task Project	Plan/Actual	Week														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Registration of PSM title	Plan														
		Actual														
2	Briefing of PSM and project explanation by supervisor	Plan														
		Actual														
3	Drafting and writing of Chapter 2 Literature Review	Plan														
		Actual														
4	Presentation of draft Chapter 2 with supervisor	Plan														
		Actual														
5	Submission of Chapter 2	Plan														
		Actual														
6	Briefing of Chapter 1 with supervisor	Plan														
		Actual														
7	Writing of Chapter 1	Plan														
		Actual														
8	Submission of Chapter 1	Plan														
		Actual														

9	Discussion of Chapter 3 with supervisor	Plan														
		Actual														
10	Draft and writing of Chapter 3	Plan														
		Actual														
11	Submission of Chapter 3	Plan														
		Actual														
12	Writing Chapter 4 and Chapter 5, expected outcome and conclusion, abstract	Plan														
		Actual														
13	Submission of report PSM 1 first draft	Plan														
		Actual														
14	Last correction of the report	Plan														
		Actual														
15	Submission of report to supervisor and panels	Plan														
		Actual														
16	Preparation slides and presentation PSM 1	Plan														
		Actual														

APPENDIX B Gantt Chart PSM 2

Gantt Chart for PSM 2																
NO.	**TASK NAME**	**STATUS**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**
1	Prepare of specimen	Plan														
		Actual														
2	Mechanical testing - Tensile - Flexural - compression	Plan														
		Actual														
3	Result preparation	Plan														
		Actual														
4	Report writing	Plan														
		Actual														
5	Psm-2 presentation preparation PowerPoint preparing	Plan														
		Actual														
6	Psm-2 draft submission	Plan														
		Actual														
7	Psm-2 presentation	Plan														
		Actual														