LEARNING FROM THE NATURE: BIO-INSPIRED HOOK DESIGN AND DEVELOPMENT

MUHAMMAD MUSTAQIM BIN MANSOR
B092010399

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MUHAMMAD MUSTAQIM BIN MANSOR

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MUHAMMAD MUSTAQIM BIN MANSOR

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Disahkan oleh:

Alamat Tetap:

K14 Kampung Kuala Jemapoh,72000

Kuala Pilah, Negeri Sembilan Darul Khusus

Cop Rasmi:

DR. MASTURA BINTI MOHAMMAD TAHA
Pensyarah Kanan
Jabatan Teknologi Kejuruteraan Pembuatan
Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan
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DEDICATION

I dedicate this research works and efforts to my beloved family and my fellow friends.A special feeling of appreciation to my loving parents, Mansor bin Abdul Rahman and Roziah bin Abdul Manap whose words of inspiration, encouragement and push for tenacity ring in my ears.

I also dedicate this dissertation to my all of my friends and siblings who have supported me throughout the entire journey. I will always appreciate all they have done, especially my forever mentor, my father, Mansor bin Abdul Rahman for inspiring me developing my engineering skills.

ABSTRACT

Hooks in hoists and cranes play a crucial role in lifting heavy loads across diverse industries, from manufacturing to oil exploration and automotive sectors. Despite their essential function, hook failures can occur due to various factors, including the type of bearing in the hook block, the fastening system securing the hook to hoists or cranes, and the materials used in their construction. Traditional manufacturing processes often yield oversized, expensive hooks lacking flexibility. This study aims to revolutionize hook design by applying bio-inspired principles, specifically drawing inspiration from nature. The design process involves generating CAD models using Solidworks, incorporating insights from muscle fiber patterns, seahorse tail geometry, and Bald Eagle grip strength. The manufacturing phase utilizes Fused Deposition Modeling (FDM) with bio-composite materials, and specific printing parameters, such as a layer height of 0.2mm and 100% infill density, ensure the production of high-quality hooks. Prior to analysis, the hooks undergo a biomimicry design process, emphasizing material strength, integrity, and fracture behavior. Finite Element Analysis (FEA) validation further ensures the reliability of the bio-inspired hook models.

The results showcase the success of Design Concept 1 (Eagle Claw), demonstrating a Factor of Safety (FOS) of 1.3, confirming its robustness and ability to handle forces 1.3 times greater than expected. Mechanical testing, including tensile and flexural tests, along with FEA simulations, highlight the superior performance of Eagle Claw. Tensile testing reveals the design's ductile characteristics, with a maximum force of 561.48 N and stress reaching approximately 4.49 MPa. Flexural testing indicates Eagle Claw's strength, with a peak force of 1544 N and a stress of 115.86 MPa. Simulation results further support the design's reliability, with lower Von Mises stress and resultant displacement compared to alternative designs. This bio-inspired hook model not only addresses manufacturing challenges but also offers a versatile solution for heavy load scenarios, emphasizing strength, flexibility, and efficiency in various applications.

ABSTRAK

Cangkuk dalam lif dan kren memainkan peranan penting dalam mengangkat beban berat di pelbagai industri, dari pembuatan hingga sektor pengeksploran minyak dan automotif. Walaupun fungsi penting mereka, kegagalan cangkuk boleh berlaku disebabkan pelbagai faktor, termasuk jenis galas dalam blok cangkuk, sistem penyekatan yang menyambungkan cangkuk ke lif atau kren, dan bahan yang digunakan dalam pembinaan mereka. Proses pembuatan tradisional sering menghasilkan cangkuk yang terlalu besar, mahal, dan kurang fleksibiliti. Kajian ini bertujuan merevolusikan reka bentuk cangkuk dengan mengaplikasikan prinsip bio-inspirasi, khususnya menarik inspirasi dari alam. Proses reka bentuk melibatkan penghasilan model CAD menggunakan Solidworks, dengan memasukkan pandangan dari corak serat otot, geometri ekor kuda laut, dan kekuatan cengkeram helang botak. Fasa pembuatan melibatkan Teknologi Penyusunan Fusi (FDM) dengan bahan bio-komposit, dan parameter pencetakan tertentu, seperti ketinggian lapisan 0.2mm dan kepadatan infil 100%, memastikan penghasilan cangkuk berkualiti tinggi. Sebelum analisis, cangkuk mengalami proses reka bentuk biomimikri, menitikberatkan kekuatan bahan, integriti, dan tingkah laku patahan. Pengesahan Analisis Elemen Terhingga (FEA) lebih memastikan kebolehpercayaan model cangkuk terinspirasi bio.

Keputusan menunjukkan kejayaan Konsep Reka Bentuk 1 (Eagle Claw), menunjukkan Faktor Keselamatan (FOS) sebanyak 1.3, mengesahkan kekuatan dan keupayaannya untuk menangani daya sebanyak 1.3 kali ganda daripada yang dijangka. Ujian mekanikal, termasuk ujian tarik dan ujian lentur, bersama dengan simulasi FEA, menonjolkan prestasi unggul Eagle Claw. Ujian tarik menunjukkan ciri-ciri daktil reka bentuk ini, dengan daya maksimum 561.48 N dan tekanan mencapai kira-kira 4.49 MPa. Ujian lentur menunjukkan kekuatan Eagle Claw, dengan daya puncak sebanyak 1544 N dan tekanan sebanyak 115.86 MPa. Hasil simulasi lebih menyokong kebolehpercayaan reka bentuk ini, dengan tekanan Von Mises yang lebih rendah dan pergerakan yang dihasilkan berbanding dengan reka bentuk alternatif. Model cangkuk terinspirasi bio ini bukan sahaja menangani cabaran pembuatan, tetapi juga menawarkan penyelesaian serbaguna untuk situasi beban berat, menekankan kekuatan, fleksibiliti, dan kecekapan dalam pelbagai aplikasi.

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CHAPTER 1

INTRODUCTION

1.1 Background

Hooks, indispensable in the field of lifting activities across sectors such as oil and gas platforms, industries, and automotive applications, serve a critical function in supporting and elevating substantial loads. Despite their fundamental importance, traditional hook designs encounter challenges, often leading to potential failure. These challenges encompass the variability in fastening mechanisms, the materials utilized in production, and the structural integrity of the hook block. The inherent requirements of hooks for heavy loads necessitate a design that ensures robustness and strength for optimal performance.

Within the expansive field of hook manufacturing, a cadre of developers is actively engaged in enhancing the cost-effectiveness, size efficiency, and adaptability of hooks designed for larger loads. This research, centered on the development of a hook model, adopts a methodical approach through the incorporation of a bio-inspired design process, specifically embracing the principles of biomimicry. Biomimicry entails the derivation of ideas, designs, and technologies that emulate the efficiency observed in the natural world.The design development in this study employs the Fused Deposition Modeling (FDM) technique and bio-composite materials. FDM, renowned for its precision and customization capabilities, is seamlessly integrated with bio-composite materials to augment the overall structural integrity of the hook model.

While the introduction provides a general background on the challenges and motivations for hook design, the subsequent chapters progressively unveil the specifics of a unique hook model, evolving into a meticulously designed carabiner-type hook. The carabiner, recognized for its versatility as a load-bearing component in applications such as rock climbing and industrial rigging, assumes primacy in this study.The chosen carabiner design harmoniously integrates biomimicry principles with advanced manufacturing techniques—FDM and bio-composite materials. This integration is meticulously engineered to enhance load-bearing capacity, reduce operational costs, and amplify adaptability for heavy loads. Subsequent chapters will systematically delve into the intricacies of biomimicry, FDM, and bio-composite materials, providing a comprehensive exploration of both the broader context and the distinctive attributes of the carabiner-type hook design.

1.2 Problem Statement

The purpose of this research is to address the inherent challenges associated with traditional hook designs, particularly their limitations in size, flexibility, and cost-effectiveness, which hinder their optimal performance in various applications such as industries, oil rigs, and vehicles. Traditional manufacturing processes and metallurgy contribute to the production of oversized hooks that are not only expensive but also lack the necessary flexibility for versatile use. This deficiency increases the risk of hook failures, posing threats to safety and operational efficiency. Motivated by the imperative need for a robust hook design that can effectively prevent potential accidents and operational disruptions, this project aims to optimize the design of a hook model. Currently, traditional hook designs often fall short in meeting the demands of modern applications. One of the major issues with traditional hook designs lies in their reliance on conventional manufacturing processes and metallurgy, resulting in oversized hooks that lack flexibility. The inherent shortcomings in these hooks can lead to failures, impacting safety and operational efficiency.

To address these challenges, this research adopts an innovative approach by incorporating principles of biomimicry into the design process. Drawing inspiration from nature, the aim is to develop a hook model that not only surpasses the limitations of traditional designs but also exhibits superior performance in terms of strength, flexibility, and cost-effectiveness. The utilization of bio-composite materials and additive manufacturing techniques introduces a layer of complexity, demanding a thorough exploration of the mechanical properties associated with these materials. Through the systematic application of biomimicry principles, detailed mechanical testing, and advanced additive manufacturing, the research aims to achieve specific objectives. These include the development of an optimal biomimetic design, a comprehensive investigation into mechanical properties, and the fabrication of the final design using Fused Deposition Modeling and bio-composite materials. By delving into these aspects, the research endeavors to contribute significantly to the advancement of hook design, ultimately leading to safer and more efficient operations across various sectors.

1.3 Research Objective

The main purpose of this research is to be able to run a bio-inspired product design and development of a hook model by going through the biomimicry design process. The objective of this research have been derive and shown as below:

a) To develop the best and optimal design of the hook model inspired by the natures using biomimicry design process.

b) To investigate the mechanical properties of the new design of the 3D printed hook model.

c) To fabricate the final design of a hook model using Fused Deposition Modeling technique and bio- composite materials as its material.

1.4 Scope of Research

The scope of this research are as follows:

- Product Design and Development
- Bio-inspired (Biomimicry) design process
- Bio-composite material (Sugar Palm / PLA composite filament)
- Mechanical testing properties (Tensile Test (ASTM C297)and Flexural Test (ASTM D7250))
- Finite Element Analysis (FEA)

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This research study is about various hook models with several bio-inspired designs that were fabricated using a Fused Deposition Modelling (FDM) technique with bio-composite material and polylactic acid (PLA) material and fixed printing parameters. The purpose of the research is to develop a hook design model inspired by nature. The biomimicry process is the approach to designing three hook design models. The project of developing the hook design model continues by using FDM technique with bio-composite material as its filaments. The study is intended to determine the mechanical properties of the hook design which is the mechanical strength under tensile loading and the fractural behaviors of three different hook models. The scope of the research is to utilize the Finite Element Analysis (FEA) with the experimental outcomes in terms of load capacity, stress strain outcomes, the maximum displacement, and the crack initiation point. The research and analysis for the project summarized below to increase the quality and understanding toward the project.

2.2 Bio-inspired (Biomimicry) design process

The word 'biomimicry' first showed up in scientific publications in 1962 and gained popularity in the 1980s, notably among material scientists. Janine Benyus, Steven Vogel, a biology professor, and Julian Vincent, a biomimetics professor, have all published extensively on this topic. According to Janine Benyus, it is "the conscious emulation of nature's genius," whereas Julian Vincent describes it as "the abstraction of good design from nature." Janine Benyus stated that nature works as a "Model, Measure, and Mentor" and that sustainability is the primary goal of biomimicry. Biomimicry is such a creative and brilliant method for seeking long-term answers to mankind's problems by replicating and emulating nature's resemblance, phenomena, and patterns. The primary goal of biomimicry is to create amazing designs by copying the various biological organisms that have evolved over the last 3.8 billion years. Biomimicry design process is the approuch that have been used as a design concept creation and development since years ago. Leonardo da Vinci attempted to mechanically comprehend the way of birds fly before creating his first áirborne machine during the Renaissance. Bio-inspired design saw a revival in the 1950s, attributable to the aerospace, marine, and automotive industries, as well as, to a lesser extent, cybernetics and complex system modelling.(Benyus, 1997)

2.3 The AskNature Database

Biomimetic design experts indicate a persistent desire for access to essential understanding in science. This information is most valuable when the transferable aspects are separated from biological principles, arranged according to design and engineering purposes, with help from contextual search tools. The minute details of how the information is organized and retrieved, on the other hand, are crucial. As we can see, AskNature.org is the solution for all biological information kept and arranged by search, function, and tri-browse features, with bio-inspired product pages serving as examples of biological strategies in any possible natural environment. AskNature.org was established with the objective of making biological knowledge understandable to individuals who lack expertise in the field, as well as serving as a source of inspiration for biomimetic design. The website is open to the public and provides access to a vast collection of biological information and abstracts, most of which have been published in peer-reviewed publications. The aim is to connect biology with other fields such as engineering, architecture, industrial design, chemistry, and organizational development. Rather than organizing information by taxonomy, the website categorizes biological knowledge based on function and creates "strategy" pages. AskNature.org is available to the public for free (Deldin & Schuknecht, 2014).

The original over 1,300 pages of biological data on AskNature were gathered and generated by trained scientists. These researchers meticulously reviewed scholarly publications, books, and news sources to extract insights on functional biology that would be of interest to entrepreneurs addressing human concerns. The selection of strategies was made subjectively, based on the researchers' opinions regarding the relevance of each strategy in the field of bioinspired design. The initial data collection for AskNature represents a substantial amount of human labor and was only made possible thanks to the generosity of an individual investor.

Years	Page views	Unique visitors
2008	125,568	22,386
2009	1,066,527	208,661
2010	1,195,928	236,117
2011	1,484,148	295,897
2012	1,790,709	478,486

Source Google analytics

Table 1 show the AskNature.org from November 2008 until December 2012

Identifying function is a valuable approach for comprehending biological information and establishing connections between different disciplines. In the context of biomimetic design, determining function can be a crucial factor in addressing design challenges (Helms et al., 2009, 2010; Stone and Wood, 2000; Vattam and Goel, 2011). The AskNature team developed the Biomimicry Taxonomy to structure and present biological facts to design users. This taxonomy serves as the organizational framework for all of the database's biological strategy pages. The details and diagram of the taxonomy will be shown below (Deldin & Schuknecht, 2014).

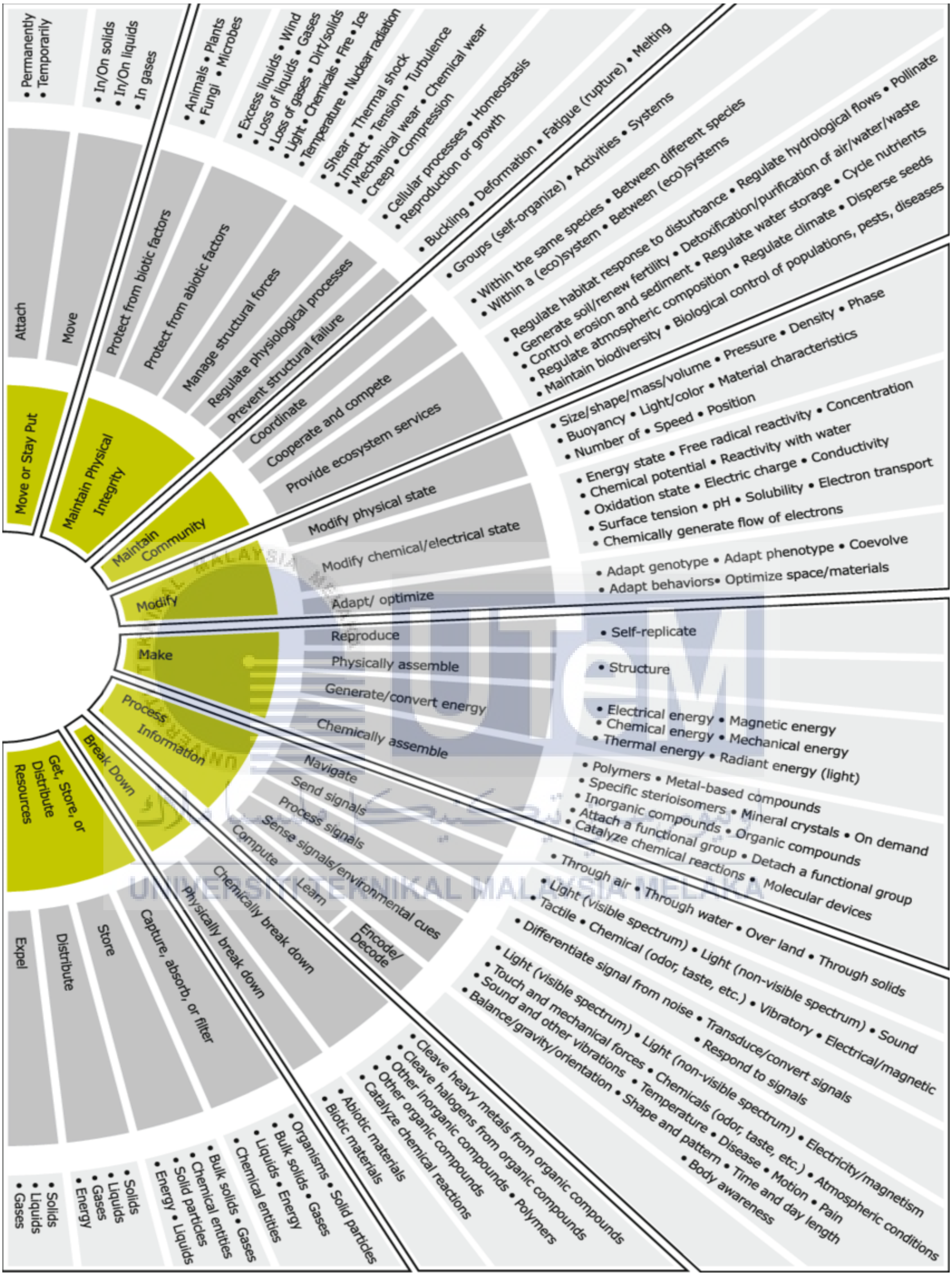


Figure 1 the taxonomy diagram

Following the collection of strategy data, the AskNature team proceeded to search for advancements and classify the data by function. The end result was the Biomimicry Taxonomy, illustrated in Fig. 2. This taxonomy categorizes strategies into three levels: groupings (the highest level), subgroups, and functions. It is further divided into eight classes, 30 subdivisions, and 162 functions. Individual strategies represent the hierarchy's next and most comprehensive level.

As an example, consider an insect tasked with defending itself against other species seeking to devour it. Within the taxonomy, its method for addressing this challenge may be categorized as follows:

GROUP	Maintain physical integrity
SUBGROUP	Protect integrity
FUNCTION	Proctect from animals
STRATEGY	Nanoscale protrusion (AskNature 2008a)

During the development of the taxonomy, AskNature employees collaborated with external design specialists, particularly from the fields of chemistry and materials science. However, it's important to note that this schema is subjective and reflects the perspectives of a limited group of researchers attempting to manage a substantial amount of biological data through function. Unlike previous bio-inspired design schemas (Glier et al., 2011; Vattam et al., 2010; Vincent et al., 2006; Yen et al., 2011), the taxonomy has not undergone systematic evaluation to determine its impact on users.

2.4 Hook Design Model

Hooks function in lifting and several types of hooks play an important factor in lifting big loads in a variety of sectors, oil rigs, automobiles, and more. A hoisting tool is a device that is used to lift objects and typically involves engaging a ring or link of a lifting chain or the pin of an anchor or cable socket. It is essential for hoisting tools to comply with health and safety regulations to ensure proper safe and usage. The load rating of the hook determines its performance. Even though the hook has a high load rating, hook failure can occur for any reasons, including the bearing used in the hook block, the kind of fastening operation used to secure the hook to the cranes, the materials used in the hook's manufacture, and furthermore. Hooks for heavy weights must likewise be huge, enormous, massive, and powerful in order to work properly at the specified loads. As a result, Researchers from various fields are engaged in studying hook manufacturing, including the manufacturing process, metallurgy, and other related areas. The objective is to improve the manufacturing process, reduce the size of hooks, lower the cost of production, and enhance their flexibility to withstand high loads. (Bhagyaraj et al., 2017)

One example for a Crane Hook Design Model and Analysis can be shown below. This particular hook design model that been used for today operation sectors such as industries and constructions. The development of a hook is a complex and time-consuming process that involves various tests to validate the design and manufacturing variables. Crane hooks, in particular, are subjected to significant stress during loading. The load is typically delivered at the bottom-most inner curve of the hook, which distributes the created stress across the remaining part of the hook. Therefore, it is essential to ensure that the hook is designed and manufactured to withstand these stresses and provide the necessary safety for lifting heavy loads. Testing is a critical component of the development process to ensure that the hook meets all required safety standards and regulations.(Lakshmana Moorthy & Prakash)

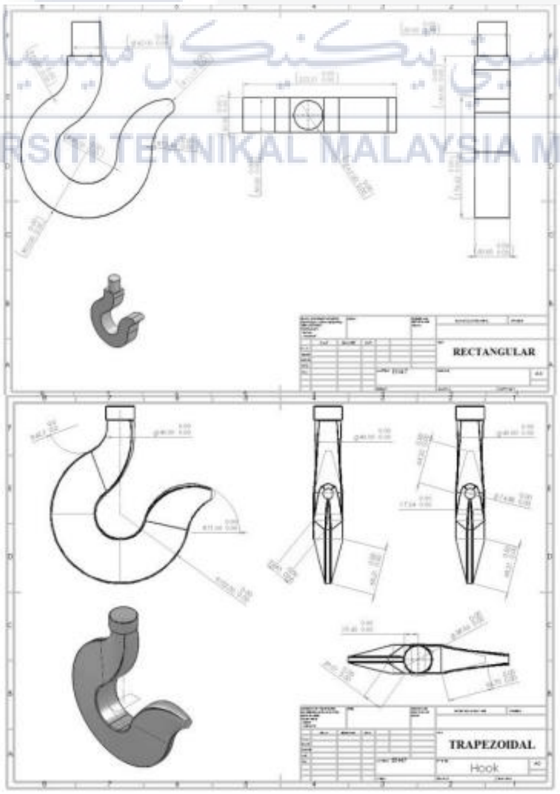


Figure 2 Crane Hook Design Model and Analysis

The analysis in this study is done through modifying the form of the cross sectional of the hook with a constant static load in it. The approuch that is used as a product design's geometric simulations in Solidworks Simulation is the Finite Element Analysis (FEA). Finite Element Analysis, which is commonly used as part of simulation software or solvers, is divided into three stages. The first of the three stages is pre-processing, in which the finite element mesh for the planned model is built with its boundary condition, material characteristics, and loads applied to the model. The following stage is the solution, which will be the Von Mises stress, displacements, and strain as a result of the running simulation. (Bhagyaraj et al., 2017)

Figure 3 3D model of Crane Hook made of circular, rectangular and trapeziodal cross section

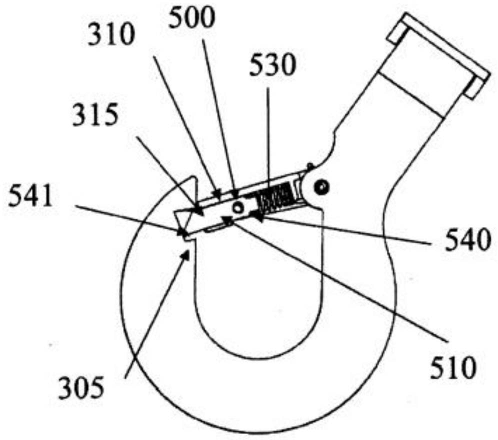


Figure 4 Design concept a hook model

The patent application publication reveals a chain hook design characterized by an elongate body, aiming to mitigate the risk of disengagement of one or more connected chains. While the concept demonstrates a fundamental understanding of the challenges associated with traditional chain hooks, the design reflects a conventional approach prevalent in the industry.(US20130160422A1)

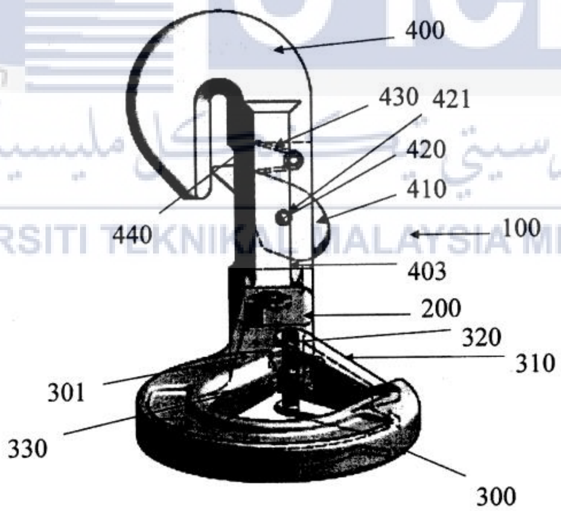


Figure 5 Hook model design

Figure 5 introduces a design concept for a hook model, providing insights into the intricacies of a potential innovative approach. While acknowledging the foundational understanding demonstrated in traditional designs, this concept hints at the need for a departure from conventional methods. The visual representation prompts a critical examination of the inherent limitations in traditional hook designs. (US20130160422A1.)

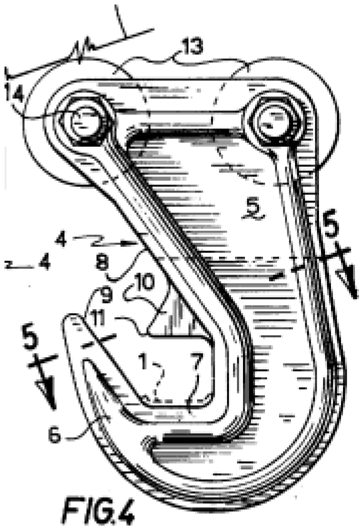


Figure 6 Hook design model

This scrutiny becomes the catalyst for the introduction of an innovative design approach, drawing inspiration from nature through biomimicry. The exploration of biomimicry principles and advanced manufacturing techniques becomes imperative in redefining the future trajectory of chain hook designs in industries where safety and efficiency are paramount.(*US4004770*.)

In summary, our examination of different hook design models highlights the prevalent reliance on conventional methods in the industry. These observations emphasize the need for innovation in chain hook designs. The variations in cross-sections and design concepts encourage us to carefully consider the limitations of traditional hooks. This scrutiny acts as a starting point for our study's main theme an exploration of new methodologies, especially through biomimicry. Looking ahead, we aim to bring about a positive change in hook designs, moving beyond the constraints of tradition to enhance safety, adaptability, and efficiency across various industries.(Bhagyaraj et al., 2017)

2.5 Bio-Composite material

Recent advances in Fused Deposition Modelling (FDM) methods are expanding the use of Additive Manufacturing (AM) technology into new fields of research, including biomedical, aerospace, and marine engineering, in addition to the growing industrial and civil sectors. Complex geometries, lightweight, high strength, breathability, and appealing resemble are all required for components designed for uncommon applications, notably in the biomedical industry. All of these design parameters may be met by manufacturing using 3D printing processes. Furthermore, the creation of purpose-specific filaments may be regarded as a critical aspect in successfully meeting all needs. There are several researches in development and fabrication of five recent thermoplastic materials analysis. They are polylactic acid (PLA) and organic by-products-based organic bio-plastic compounds. The increased interest in these innovative composite materials reinforced with organic by-products stems from lower production management costs and a low environmental effect.(Calì et al., 2020)

Bio-composite filaments are becoming a popular alternative to artificial filaments due to their low cost, availability, and favorable properties. They offer a sustainable and cost-effective option with high strength-to-weight ratio and elasticity modulus, making them suitable for various applications. Therefore, bio-composite filaments are becoming a preferred choice for many industries. Thermoplastic filament is used in the Additive Manufacturing (AM) method commonly referred to as Fused Deposition Modelling (FDM), which builds components layer by layer. The most used thermoplastic is Polylactic Acid (PLA), and natural fibres can be added as filler. (Joseph Arockiam et al., 2022). Nevertheless, one typical limitation of FDM 3D printing for bio-composite material is that the composite materials must be in the form of a filament in order to be extruded. Establishing consistent reinforcement variation in the polymer matrix can be challenging, and it has a significant impact on the printability and physical properties of composite filaments. Uneven distribution of reinforcement can lead to void formation during the FDM 3D printing process, resulting in inferior mechanical characteristics. Therefore, achieving a consistent distribution of reinforcement is critical for producing high-quality 3D printed products. (Wang and Gardner 2017; Tekinalp et al. 2019; Sharma et al. 2020; Wang et al. 2020). Despite the importance of developing polymer composites for FDM printing, there has been limited research conducted in this area, particularly regarding cellulose-based composites. More studies are needed to explore the potential of these composites for FDM printing and to optimize their properties for various applications. (Murphy and Collins 2018; Chang et al. 2019). Cellulose is currently considered the most promising bio-composite material due to its excellent, uniform structure and favorable mechanical properties. It is commonly used as a fiber enhancer or reinforcement in polymer composites, with its enhancing effect influenced by its size, shape, and structure. Smaller cellulose sizes result in higher mechanical characteristics, while larger sizes contribute to better formability, network structure, and entities. Thus, understanding the properties of cellulose and how they affect composite materials is crucial for developing high-quality bio-composite materials for various applications. (Thakur et al. 2014; Gemmeke et al. 2019; Bhasney et al. 2020). Below show the study of kenaf cellulose fiber composite/ PLA comparison with the other material in tensile mechanical testing results.(Aumnate et al., 2021)

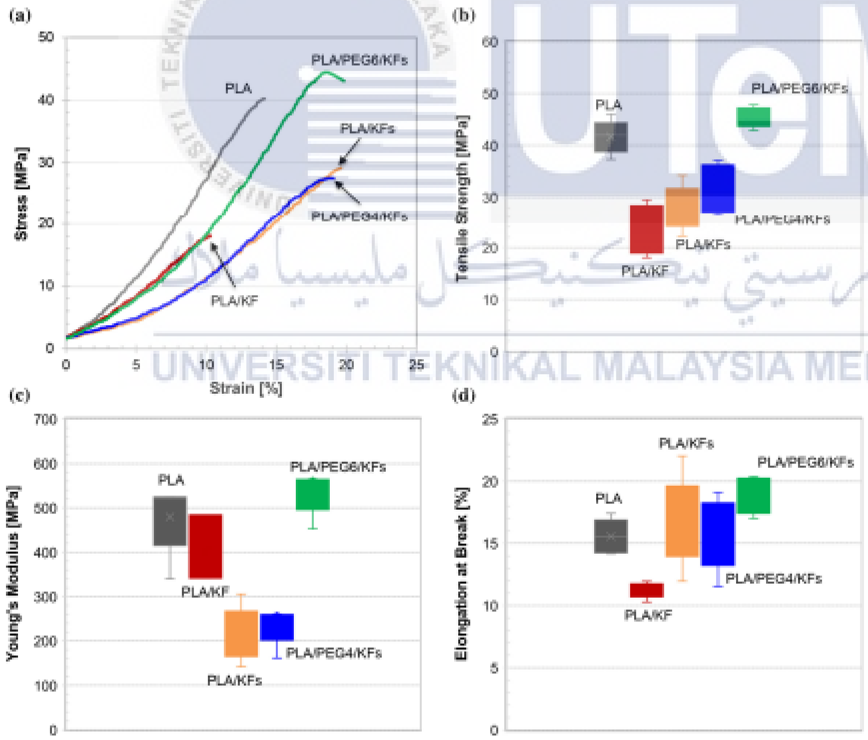


Figure 7 Tensile properties of PLA and PLA/kenaf cellulose fiber composite (Aumnate et al., 2021)

2.6 Fatigue behavior of PLA-wood composite manufactured by fused filament fabrication

The literature study focuses on Fused Filament Fabrication (FFF) and examines Timberfill, a wood-reinforced PLA material. Motivated by sustainability, the study explores how natural fiber additives like Timberfill contribute to extending material lifecycles. Previous literature reveals diverse outcomes in wood-reinforced PLA studies, emphasizing the need for material-specific understanding. The study takes a unique approach by extensively testing Timberfill for fatigue properties using a Taguchi orthogonal array. Unlike traditional research, it evaluates an existing commercial composite, emphasizing less-explored aspects like fatigue properties. The literature review identifies crucial factors in the FFF process affecting mechanical behavior, such as manufacturing orientation, layer height, and infill deposition. The study aims to offer practical insights applicable across industries by providing technological recommendations for Timberfill use through open-source devices.

Table 1 – Reference mechanical properties and recommended manufacturing parameters specified by manufacturer for Timberfill material.

Property	Value	Property	Value
Material density	1.26 g/cm³	Nozzle temperature	170–185 °C
Tensile strength*	39 MPa	Nozzle diameter	Min. 0.4 mm
Tensile modulus*	3200 MPa	Extruder velocity	20–30 mm/s

* Minimum guaranteed by the manufacturer.

Table 2 Mechanical properties and manufacturing parameters

In Table 1, the reference mechanical properties and manufacturer-recommended manufacturing parameters for Timberfill material are outlined. Timberfill, a wood-reinforced PLA material, exhibits a material density of 1.26 g/cm³, a tensile strength of 39 MPa, and a tensile modulus of 3200 MPa. The manufacturer specifies a nozzle temperature range of 170–185°C, emphasizing the importance of maintaining specific thermal conditions during the printing process. Additionally, the recommended nozzle diameter is a minimum of 0.4mm, with an extruder velocity between 20–30 mm/s. These outlined properties and parameters serve as a foundation for understanding Timberfill's characteristics and provide essential guidelines for successful Fused Filament Fabrication (FFF) when utilizing this material.

The experimental phase of the study involved subjecting Timberfill specimens to a single 10-N force to identify optimal manufacturing parameters for maximizing fatigue life. The results, illustrated in Fig. 4, revealed that the combination of a 0.4-mm layer height, 0.7-mm nozzle diameter, 75% infill density, and 35-mm/s printing velocity led to the maximum fatigue life in both honeycomb and rectilinear infill patterns. The absence of a correlation between observed temperatures and manufacturing conditions suggested that extreme temperature changes did not significantly influence fatigue failure.

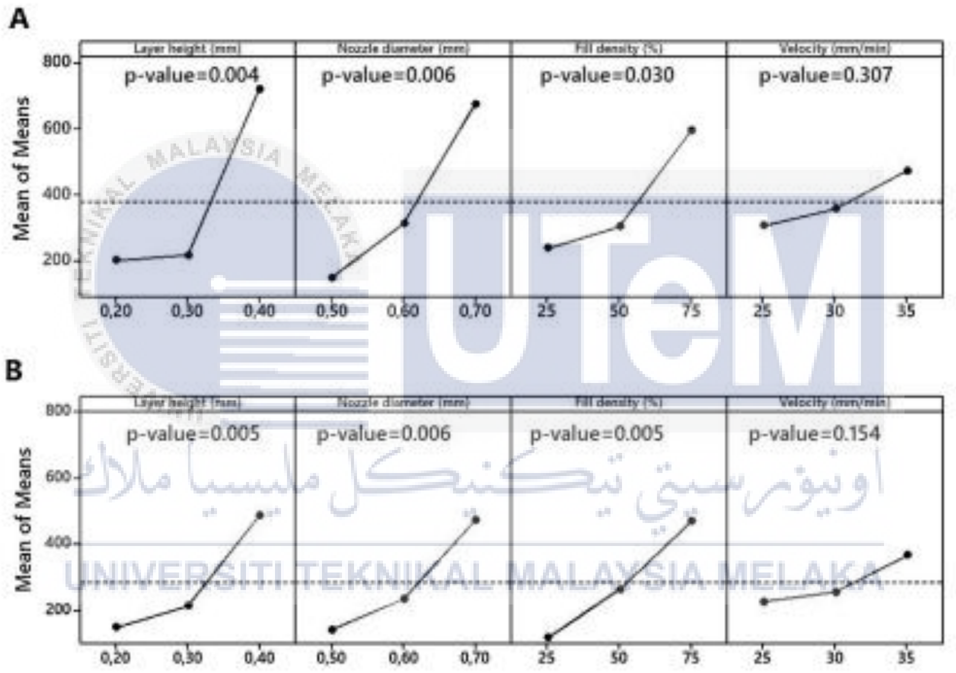


Figure 8 Main effects plot for the response variable number of cycles to failure and p-value associated to the ANOVA tests.

An analysis of variance (ANOVA) was performed to assess the significance of manufacturing parameters on fatigue lifespan. The results, presented in Fig. 8, highlighted layer height, nozzle diameter, and infill density as statistically significant factors. The honeycomb infill pattern exhibited a higher mean result for expected lifespan, aligning with observations in other materials. Layer height had the most significant effect on sample life, indicating that higher layer heights resulted in longer life. Nozzle diameter and infill density also played crucial roles, with the optimal values identified as 0.7mm and 75%, respectively.

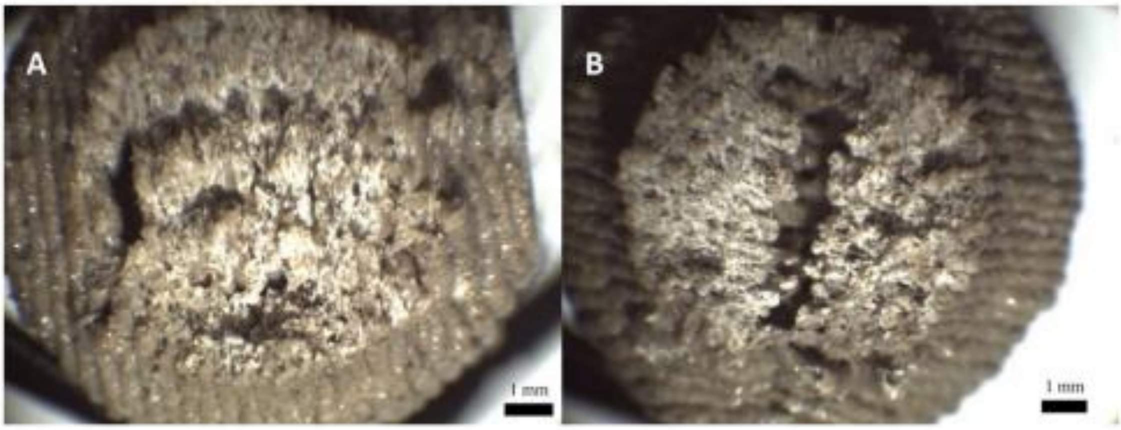


Figure 9 Fractographies of Timberfill specimens printed at 75% with infill pattern.

Fractography provided insights into the failure modes of Timberfill specimens at a 75% infill, revealing ductile behavior with cavities and wooden particles. The results from the optimal printing conditions were used to construct a Wöhler curve, and the specimens subjected to a maximum stress of 17.9 MPa did not experience failure before 10^6 cycles. The S-N curve analysis, comparing Timberfill with non-reinforced PLA, indicated a 40% difference in exponent values, with Timberfill exhibiting a lower expected life. SEM inspection revealed a detrimental adhesion between wood and PLA fibers, leading to stress risers and reduced mechanical properties. The comparison between the failure modes of Timberfill and PLA demonstrated that Timberfill induced a more ductile behavior, attributed to the random distribution of voids and wood fibers acting as stress risers.

In summary, the results of the study underscored the sensitivity of Timberfill's fatigue life to manufacturing parameters, with layer height, nozzle diameter, and infill density playing pivotal roles. The introduction of wood as an additive in Timberfill had both positive and negative effects, influencing fracture modes and diminishing the material's mechanical properties. These findings contribute valuable insights into the behavior of wood-reinforced PLA materials manufactured through Fused Filament Fabrication.

2.7 Fused Deposition Modelling (FDM) process

Fused deposition modelling (FDM) 3D printing, also known as fused filament fabrication (FFF), is an additive manufacturing (AM) technology that uses material extrusion to produce parts layer by layer. In FDM, melted material is deposited in a predetermined path to create the final physical product. The material used in FDM is typically thermoplastic polymers in the form of filaments. FDM is the most widely used 3D printing technology across various industries and has the largest installed base of 3D printers globally. It is often the first technique that comes to mind when people think of 3D printing due to its popularity and versatility. (Popescu et al., 2018)

FDM 3D printing involves depositing melted filament material layer by layer to create a finished product. To begin, a digital design file is submitted to the printer and converted into physical dimensions. The printer uses thermoplastic polymers such as ABS, PLA, PETG, and PEI, which are fed through a heated nozzle as threads. The filament is first loaded onto a spool and then fed through the extrusion head and nozzle once the nozzle reaches the required temperature. The extrusion head is connected to a three-axis system that moves along the X, Y, and Z axes. The printer extrudes the heated material in thin strands and places it layer by layer along a predetermined design path. The material cools and solidifies after being placed, and fans can be used to speed up the cooling process. FDM 3D printing is widely used in various industries for its versatility and ability to rapidly prototype and manufacture parts.(Popescu et al., 2018)

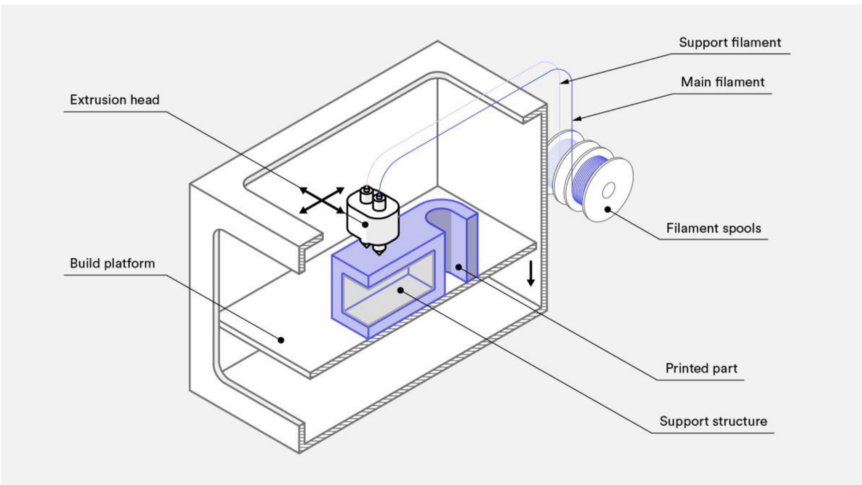


Figure 10 The 3D Printing component

There are a few parameters needed to be focalise on from the FDM process. The FDM system needed its users to adjust the several process parameters. These include the nozzle and build platform temperatures, build speed, layer height and cooling fan speed. The sizing of our hook design model needed to consider a few guidelines to develop the best prototypes of Hook design model using FDM process. The size of our Hook model needed to be mainly consider first because the common build size of the desktop 3d Printer is 200 x 200 x 200 mm, while industrial machines can reach sizes of 1,000 x 1,000 x 1,000 mm. Our product need to be sized in that range of dimensions.(Popescu et al., 2018)

2.8 Mechanical testing properties (Tensile Test (ASTM C297) and Flexural Test (ASTM D7250))

The approuch of the study on investigating an effect to a printed parts via Fused Deposition Modelling (FDM) of the the filling patttern is a few mechanical properties testing which is tensile strength test and flexural strength testing. Mechanical testing is a set of tests that have been standardized to evaluate the physical and mechanical qualities of a material, as well as whether it is suitable for the intended applications. Mechanical testing is required in product design and part manufacture to meet the standards set by organisations such as ASTM and ISO. These tests enable producers to differentiate low-quality components and select the best material for their goods. Mechanical testing to is appropiate for this research is Tensile Test (ASTM C297) and Flexural Test (ASTM D7250) to ensure the hook design model capable to lift a better load capacity.(Mechanical_Testing_of_Advanced_Fibre_Com)

Tensile testing is a basic mechanical strength test that determines a material's properties such as stress, strain, and yield deformation. The material is subjected to opposite forces and pulled until it breaks. This test is conducted using a tensile testing machine, which can be either hydraulic or electric. The experimental method produces a stress-strain curve on a graph and can also determine the yield strength, modulus of elasticity, and ductility or brittleness of the material. Additionally, the test provides information how of the material fractures. (Mechanical_Testing_of_Advanced_Fibre_Com)

Flexural testing measures a material's stiffness and resistance to bending by determining the force required to bend a plastic beam. The flex modulus of a material indicates its ability to flex before experiencing permanent deformation. In snap fit assemblies or plastic lock arms, the arm must flex to allow proper seating of the connection and then flex back into place to lock the connection. If the locking mechanism is made of brittle material, it is more likely to break when flexed, compromising the assembly's integrity.(Mechanical_Testing_of_Advanced_Fibre_Com)

Mechanical testing produces outcomes that provide information on the properties of a material. In the case of samples manufactured using Fused Deposition Modeling, the mechanical properties are affected by process parameters such as orientation, layer thickness, and filling rate. The results of the mechanical testing will show how these parameters have impacted the mechanical properties of the PLA samples, including their tensile strength, yield strength, modulus of elasticity, and elongation at break. These results can be used to optimize process parameters and improve the mechanical properties of future PLA samples manufactured using Fused Deposition Modeling.(Danut Mazurchevici et al., 2020)

Table 3 — Mechanical properties of PLA material obtained by FDM method[18,19].

PLA properties	Values
Tensile strength	(15.5–72.2)MPa
Flexural strength	(52–115.1) MPa
Tensile modulus	(2.020–3.550)GPa
Flexural modulus	(2.392–4.930)GPa
Elongation at break	(0.5–9.2) %

Table 3 shows the results of mechanical testing towards PLA material by FDM technique

The mechanical testing study is the best approuch for determining the strength point of the Hook Design model fabrication via Fused Deposition Modelling with bio-composite material. The results from the testing will ensure the product safety despite through the limitation of the selected fabrication process and the selected material of the product. (Danut Mazurchevici et al., 2020)

2.9 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) is a computer-aided engineering tool that predicts how an object will behave under various physical conditions. FEA is used to analyze structures, vibrations, and thermal properties and is widely used in the automotive industry. It is used by design engineers as a tool during the product development process to quickly analyze their designs while they are still easily modifiable CAD models. Proper use of FEA requires an understanding of FEA basics, modeling techniques, and potential errors that may affect the quality of results. When used correctly, FEA is a valuable tool that reduces product development time and cost. However, misapplication of FEA may result in erroneous design decisions that are expensive to correct later in the design process. (Finite_Element_Analysis)

Boundary conditions are fundamental constraints applied to structures in mechanical engineering and structural analysis, dictating their behavior within specific environments. In the realm of finite element analysis (FEA), these conditions are crucial for simulating how structures respond to external forces and loads. They define the limits of displacement, rotation, and forces that a structure can undergo. Common types of boundary conditions include fixed (zero displacement), pinned (zero rotation), and roller (zero horizontal and vertical force) conditions. The accuracy of simulations and analyses heavily relies on precisely defining these boundary conditions to mimic real-world scenarios. However, the challenge lies in translating complex, real-world conditions into accurate boundary conditions for simulation purposes. (*Finite_Element_Analysis*, n.d.)

The FEA simulation can be done in CAD Software which is SolidWorks. The outcomes that can be obtained from the simulation are the meshing detail, a discretization of a geometric domain into small triangle shapes or quadrilateral. The mesh is about the representation of the terrain data.(Handbook_of_Computational_Geometry). Below shows the standard design of crane hook (Isometric view) and the details.(Bhagyaraj et al., 2017)

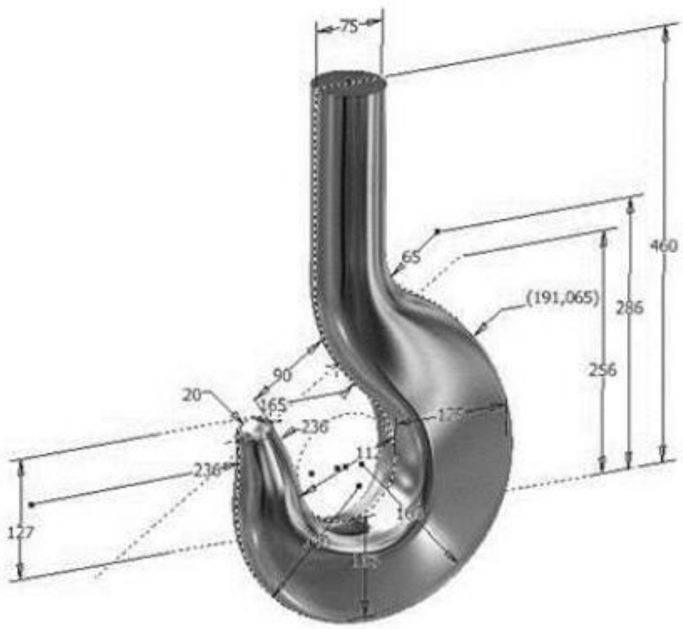


Figure 11 Hook Isometric view

Design With Alloy	Mass	Volume	Density	Weight
Alloy 1.2367 (X38CrMoV5-3)	9.0659 1 kg	0.0011548 9 m^3	7850 kg/m^3	88.8459 N

Table 4 the product details

Mesh Details	Alloy 1.2367
Type of Mesh	Solid mesh
Type of Mesh Element	Tetrahedron
Jacobian points	4
Size of Element	5.24417 mm
Tolerance	0.262208 mm
Total Nodes	68096
Total Elements	45438
Maximum Aspect Ratio	26.378

Table 5 The meshing details

Simulation studies have been conducted on a crane hook using Alloy 1.2367 (X38CrMoV5-3) to evaluate its sustainability against loading. The results of the simulation studies include Von Mises stress, Factor of Safety (FOS), strain, and displacements.The test conditions and the results are as follows: (Bhagyaraj et al., 2017)

Design With Alloy	**Von Mises Stress (min)**	**Von Mises Stress (max)**
Alloy 1.2367	1.41561e+05 N/m^2	2.04796e+07 N/m^2

Design With Alloy	**Displacement (min)**	**Displacement (max)**
Alloy 1.2367	2.98539e+080 mm	1.94566e+010 mm

Design With Alloy	**Strain (min)**	**Strain (max)**
Alloy 1.2367	0.037966	311.928

Table 6 show the reult of the simulation of the crane hook

From the simulation help the users to determine the capability of the product with the physical testing. The Finite Element Analysis simulation helps the strength point of the hook by calculating the Von Mises Stress value. (Bhagyaraj et al., 2017)

2.10 Biomimetic Design Concept Generation Methodology.

Biomimetics, an expanding design discipline in engineering and a burgeoning field in architecture, involves deriving solutions by imitating strategies, mechanisms, and principles found in nature. Beyond its recognized creative potential (Benyus 2002), biomimetics holds promise for future environmentally responsive developments. While various biomimetic design strategies have emerged in recent years, applying biomimetics in architecture remains a significant challenge.(Badarnah & Kadri, 2015)

In attempting to transfer adaptation strategies from nature to design, common traits like morphology and form are often incorporated into architecture. However, these traits frequently lack the functionality of the imitated natural systems, posing challenges for successful biomimetic design. Limitations in achieving successful design concepts may stem from difficulties in selecting appropriate strategies from the vast natural database, scaling issues, and conflicts between integrated parts of the design concept.(Badarnah & Kadri, 2015)

Within architecture, numerous explorations in the past decade have sought to enhance biomimetic developments. These explorations encompass investigations into life sciences terminologies for potential use in built environments, understanding ecosystem interactions for sustainable developments, drawing inspiration from nature, and identifying strategies from animal skins for performative constructions. Despite revealing unique aspects from nature to inform built environments, biomimetics remains a challenging design tool due to the absence of a systematic selective design methodology, particularly for designers with limited biophysical backgrounds(Badarnah & Kadri, 2015)

	Group 1	Group 2	Group 3	Group 4	Group 5
Problem and definition	• Identify function • Define context • Integrate Life''s principles into brief design	• Define problem • Analyse and Understand problem	• Problem Definition	• Problem Definition • Reframe problem	• Formulate the techincal problem

Exploration and investigation	• discoverNatural models • Abstract biological strategies into design principles	• Find Functional analogy in biology • Compare solution from biology and TRIZ	• Search for biological solution search • Assessing biological analogies	• Biological solution search • Define the biological solution • Principles extraction	• Seek for analogies in biology • Identify corresponding principles • Abstract from biological model
Solution and developmetn	• Braimstorm bio-inspired ideas • Emulate design prinsiples • Measure using Life's principles	• List principles from both biological and technical domains • Develop Idea	• Applying biological analogies	• Principles Applicat ion	• Implement technology through prototyping and testing

Table 2 encapsulates a problem-based biomimetic design approach, delineating the strategic steps across three pivotal phases: problem definition, exploration and investigation, and solution development The problem definition phase involves activities such as identifying functions, framing challenges, and formulating technical problems. The exploration and investigation phase delves into discovering natural models, assessing biological analogies, and extracting principles for design. Finally, the solution development phase emphasizes translating biological insights into tangible solutions through activities like brainstorming, applying analogies, and prototyping. This comprehensive overview guides the biomimetic design process, providing a structured pathway for designers to navigate from initial problem identification to the implementation of bio-inspired solutions.

2.11 Market Survey

A market survey on an existing product gathers all the information about how well the product is performing in the market and identifies any areas for improvement. This survey helps to gain insights into the needs, preferences, and pain points of potential users. Understanding what users are looking for in a hook design can guide the development process to create a product that truly addresses their requirements. Throughout this market survey, there are various types of hook design model that accommodate various purposes while originating from a common foundational principle. The purposes of a hook are in various application like household appliance, hardcore outdoor activities, and industrial operation. There are four products of hook model have been surveyed through e-commerce platform listed in the table below. The product specifications such as design, cost, material, weight, length, capacity, and purposes.

Specification	Product A	Product B	Product C	Product D
Brand	XINDA	LONLYEAGLE	DINGEE	LRSNINE
Type	Screwgate Carabiner	S carabiner hook	S hook	Swivel Eye Hook
Design				
Cost	$8.49	$0.29	$1.50	$27.99
Material	Aluminium	Metal	Vinyl, metal	Alloy steel
Weight	59.5g	3.2 g	250g	1.2kg

Length	66cm	41mm	6 inches	7.2 inches
Capacity	5500lbs	-	70lbs	3 ton
Purpose	Mountain climbing	Accessories	Household	Industrial operation

Product A is a screwgate carabiner hook from XINDA. This hook model designed for hardcore outdoor activities such as mountain climbing, hiking, and camping. The durability of the product to withstand a bigger load is the better the rest of the products due to priority of the product which is to ensure the safety to its user while doing the risky outdoor activities. To achieve this, its cost more than the rest of the product as it has an additional features like screw lock system and use aluminium alloy as its material. (Amazon 2019)

Product B is a S shaped carabiner hook from LONLYEAGLE. This product cost the cheapest among the other products due to its purpose is mainly for accessories and merchandises. It initially purposes are to hold together the user's belonging that is small like a key and can also use as a zipper replacement. (Amazon 2022)

Product C is a S shaped hook from DINGEE, this hook is designed to withstand a regular load for household appliances such as to hang a kitchen utensil or toiletries. The design is very practical and use vinyl metal as its material. The cost of this product is cheap despite having a non-slip feature which is rubber coated surfaces. This product is very convenient for user to make their household appliances tidier and can save more space. (Amazon 2021)

Product D is Swivel Eye Sling Hook from LRSNINE. This hook is designed for heavy duty operation like industrial or construction. This product must be to most durable product to withstand the huge load to ensure the safety of the load lifting. The cost of this product is the most expensive among other due to the capacity, sizes, and weight of the product. (Amazon 2020)

This market survey provides valuable data for informing the design specifications, considering cost, material, weight, length, capacity, and intended purposes of the surveyed hook models. Integrating these insights into the product design specification will facilitate the development of a hook model that aligns with user expectations and market demands. (Amazon 2022)

PDS Element	Description
Materials	• The material used for the product is from bio-composite which is wood pla.
Performance	• Able to withstand a huge amount of force around 30kg to 100kg
Weight	• The weight must below 1kg
Size	• 45mm x 115mm • Compact infill of density to make it more durable
Aesthetics	• The surface has a smooth finish. • The product must be inspired by nature.
Cost	• The cost must be affordable and less than the metallic product.
Manufacturing	• Low-cost and low complexity for the manufacturing

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research required the best methodology to keep the project flow systematically. This helps to reduce the difficulties and changes in any process or situation. The methodology for this research started with a planning phase and ended up with mechanical testing and simulation. The research is the development of a product which hook model. Hooks are a components that are very reliable for lifting activities and its commonly utilised in industrial settings. As a result, such a critical component in an industry must be built and developed in a way that ensures it delivers maximum performance without failure. Therefore, the objective of the research is to investigate the stress distribution pattern of a crane hook using the finite element method. The greater hook model is based on its strength in handling tensile stresss and bending stress so that it can be reliable for most sector like construction, offshore platform and industries. The purpose of designing the best hook model inspired by nature need to ensure the the strength point of the hook model in fatigueness and continous loading.

This thesis presents an integrated analytical approach to develop a bio-inspired hook model. The essence of the approach used in this project is centered on the concept of the nature toward our designs . The selected approach is to for the development of design of hook design model with bio-composite material consists of Idea generation, PDS, conceptual design, detailed design, production, and mechanical testing.

3.2 Project Planning

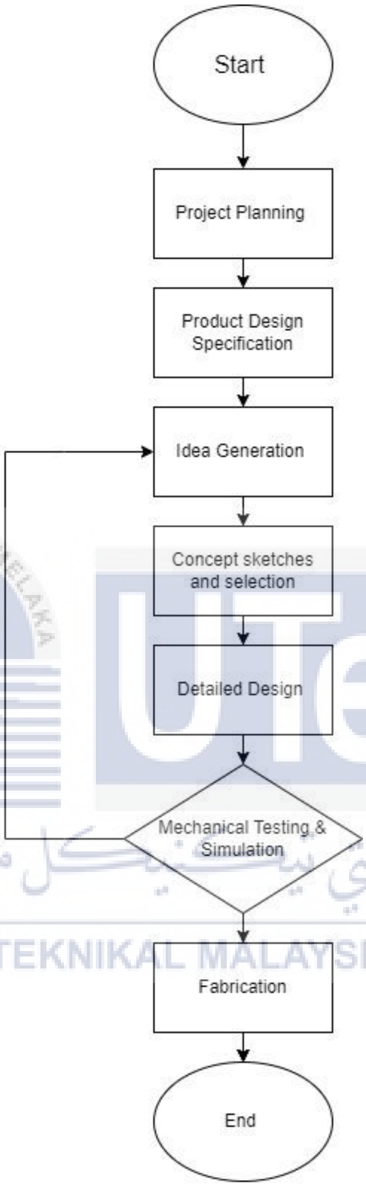


Figure 12 The flowchart

The flowchart is the way this project provides a breakdown of the essential steps of well-orgnized process flow. Flowcharts helps the research project identifying the key components of a process while also providing a larger view of the process while developing and planning it. It classifies tasks chronologically and categorises them by category, such as procedure, decision, data, and so on.

The project is visually represented through a flowchart, offering an organized breakdown of essential steps, and aiding in task identification. A detailed Product Design Specification (PDS) serves as a guide for subsequent design phases, outlining critical elements such as materials, performance criteria, weight, size, aesthetics, cost, and manufacturing considerations.

The idea generation phase involves research and analysis, leading to the development of a bio-inspired hook design model. Biomimicry principles, inspired by nature, are adopted, and design concepts draw inspiration from the strength of Bald Eagles, muscle fiber patterns, and the square tail of seahorses. Conceptualization involves generating and evaluating potential solutions based on the Product Design Specification. Concept sketches and detailed drawings capture the essence of the bio-inspired hook design, incorporating biomimicry principles. A morphological chart categorizes design elements, aiding in navigating choices. Concept selection is facilitated through the Pugh matrix evaluation method, guiding the choice of the most promising design based on criteria such as complexity, weight, ergonomics, and manufacturing ease.

Detailed designs are executed using SolidWorks, providing dimensional views, isometric views, orthographic views, and rendering views. This detailed design is crucial for accurately representing the hook design model.

Mechanical testing, including Tensile and Flexural tests, ensures the hook's physical and mechanical properties. Finite Element Analysis (FEA) simulation predicts the model's performance under various conditions, revealing stress, strain, and displacement outcomes.

Fabrication employs Fused Deposition Modeling (FDM) technology with Ulti maker Cura, utilizing bio-composite material. The chosen parameters ensure uniformity, structural integrity, and environmentally conscious manufacturing, contributing to high-quality, mechanically stable objects. The project planning integrates creativity, research, and engineering principles to systematically develop a bio-inspired hook model with a focus on performance, durability, and cost-effectiveness.

3.3 Product Design Specification (PDS)

A Product Design Specification (PDS) is a document that is created during the problem definition phase of the design process. It is created after a market investigation has been conducted and includes all the details and requirements necessary for the product or process to be successful. The PDS acts as a guide for the design process and sets boundaries for subsequent designs. In the case of the bio-inspired hook design, the following elements were considered in the PDS: performance issues, market issues, capability issues, materials used, size and dimensions, ergonomics, and cost. These elements were used to guide the conceptual design process and ensure that the design is optimized to meet all the necessary requirements.

PDS Element	Description
Materials	• The material used for the product is from bio-composite which is wood pla.
Performance	• Able to withstand a huge amount of force around 30kg to 100kg
Weight	• The weight must below 1kg
Size	• 45mm x 115mm • Compact infill of density to make it more durable
Aesthetics	• The surface has a smooth finish. • The product must be inspired by nature.
Cost	The cost must be affordable and less than the metallic product.
Manufacturing	Low-cost and low complexity for the manufacturing

Table 7 Product Design Specification

3.4 Idea Generation

For the early stage to the project, idea generation is one of the crucial processes in developing the bio-inspired hook design model. Research and analysis are the early tasks for the phase, the research about the existing and common hook design model is where the guidelines are produced. The Hook comes with a few designs which are chain link, S hook, C Hook and carabiner improved. Bio-inspired hook design model approximately looks like in this particular shape due to the functionality of the hook is to be able to sustain in continuous force loading in tensile type of stress. Below shows the guidelines from the outcomes of this project's research and analysis.

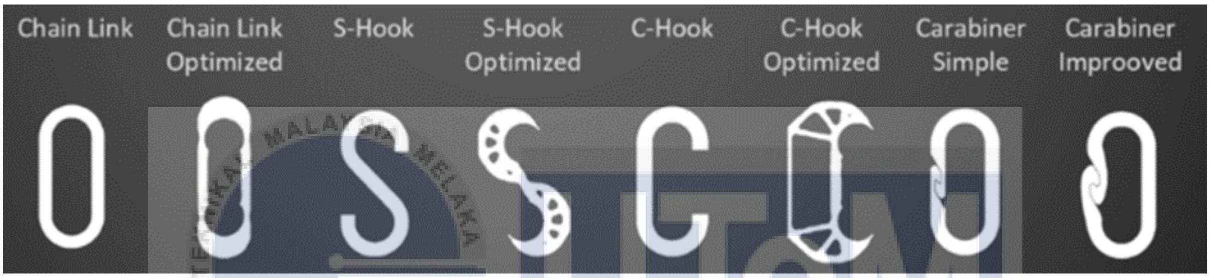


Figure 13 the types of hooks design model

Not to forget that this research's main priority is to develop a hook design model inspired by nature. The design development of the hook design model is to be mimicking the nature by using the biomimicry design process. Biomimicry is the most creative and brilliant technique to find sustainable solutions to human problems by replicating and emulating nature's analogies, phenomena, and patterns. The primary goal of biomimicry is to create amazing designs by copying the various biological organisms that have evolved over the last 3.8 billion years. Biomimicry design process is the approach that has been used as a design concept creation and development since years ago.

By implementing the biomimicry design process in this research is to utilize AskNature.org as the tool to go through a study about Nature. AskNature.org is a website of a thousand biological knowledge collections for non-biologists and to act as a source of inspiration for biomimetic design. AskNature.org is a free, public database of biological information and abstracts, the majority of which come from peer-reviewed publications to bridge the gap between biology and areas such as engineering, architecture, industrial design, chemistry, organizational development, and others, the website catalogues biological knowledge by function in "strategy" pages. From the AskNature.org analysis, we come out with the Nature environment that gives an inspiration towards this hook design and development. The idea for this bio-inspired hook design model comes with these three Nature biological information.

Figure 14 Design Concept 1 Inspiration

Bald Eagles are said to have a grip 10 times stronger than a human’s. This comes in handy when they use their talons to pick up fish from a lake.

Figure 15 Design Concept 2 Inspiration

Three muscle fiber patterns inside trunks work together to provide the strength, support, and resistance needed to bend and twist with extreme agility.

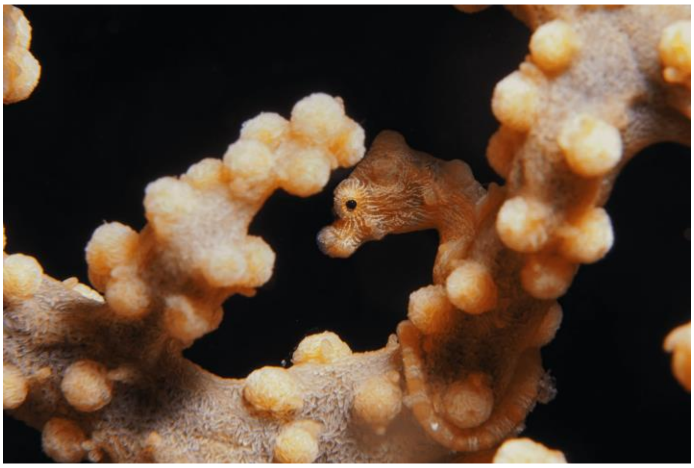


Figure 16 Design Concept 3 Inspiration

The square tail of the seahorse helps give it extra grip when hunting for prey.

From this phase of Idea Generation, a thorough exploration has been conducted to dissect the intricate biological features exhibited by three distinct entities in nature. The synergistic interplay of muscle fiber patterns within trunks, the seahorse's square tail augmenting its prey-grasping capabilities, and the remarkable grip strength of Bald Eagles, surpassing human capability tenfold, have all served as profound sources of inspiration.

These biological revelations have not only ignited creative insights but have also been translated into tangible design development ideas. The culmination of these concepts is encapsulated in the form of bio-inspired hook design models, meticulously depicted in detailed drawings. These renderings capture the essence of our biomimicry journey, reflecting the convergence of nature's ingenious designs with innovative human engineering.

3.5 Concept Sketches

A concept design might be just apart from a collection of sketches, ideas, and explorations. It can also go into enormous detail, including design sketches, preliminary plans, sections and elevations, and 3D models of a development method. The conceptual design phase is about generating and evaluating potential solutions to meet the requirements of the Product Design Specification (PDS). This phase involves creating the initial design using drawings or models and using various methods like brainstorming and research studies to develop potential solutions. The two stages of this phase are concept generation and concept selection, where potential solutions are evaluated based on criteria such as cost, functionality, usability, and manufacturability. The most suitable solution is selected for further development in subsequent phases. In this stage is where all the possible sketches provided indicating all the detail of the product design based on nature below show the conceptual sketches that have been developed for this project.

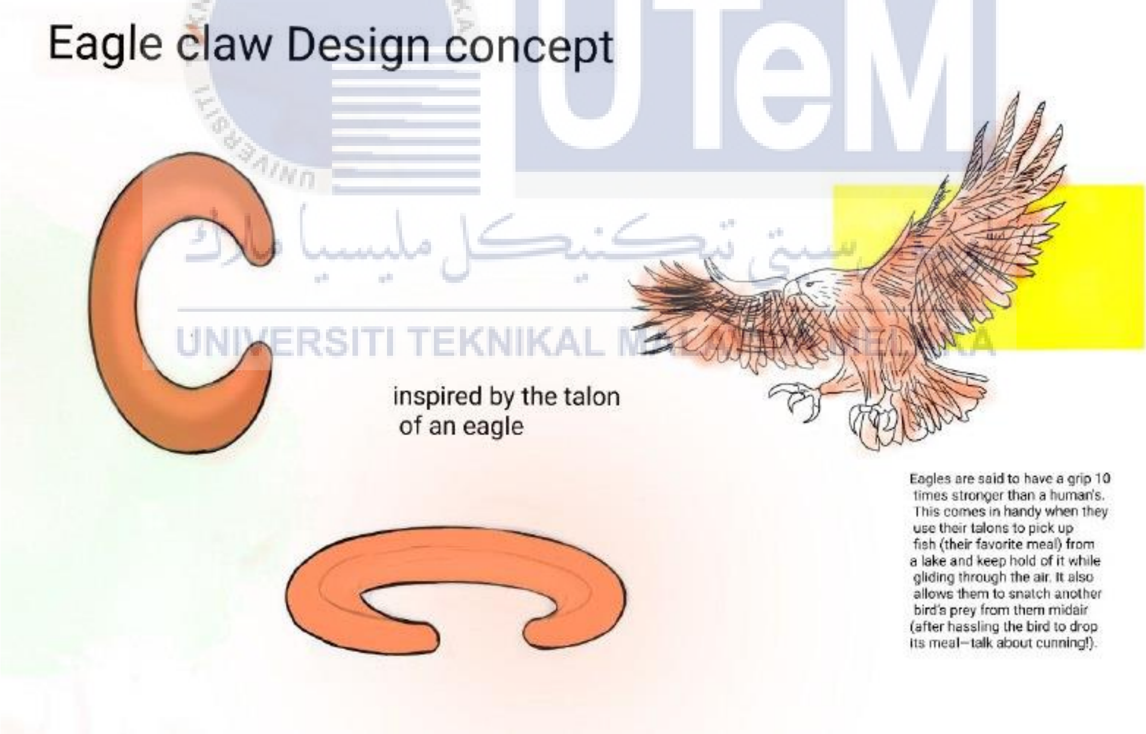


Figure 17 The design sketches for eagle claw concept

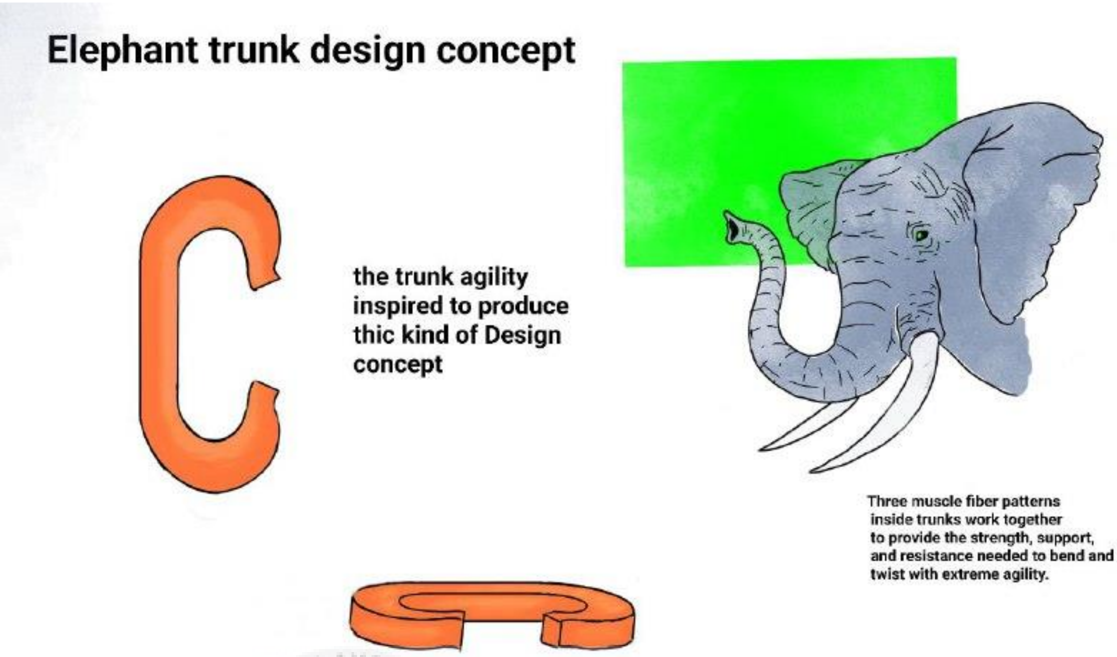


Figure 19 design sketches for elephant trunk concept

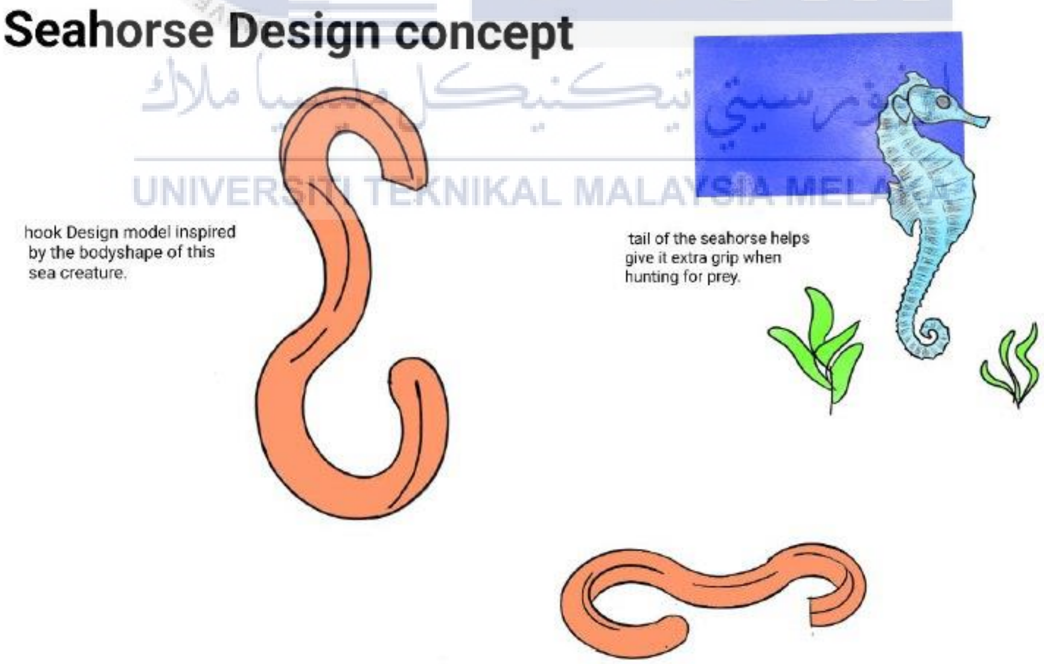


Figure 18 Design sketches for seahorse concept

3.6 Morphological Chart Generation

In the quest to develop an optimal and innovative hook design model, a comprehensive exploration of the design space becomes paramount. The morphological chart serves as a structured framework, allowing us to dissect and categorize the diverse design elements essential to this project. This tool becomes instrumental in navigating the intricate choices that define the form and functionality of the hook. By systematically breaking down the design into distinct criteria, we gain clarity on the variations and possibilities that may shape our final product.

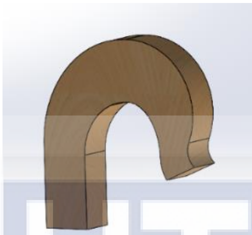
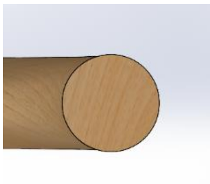
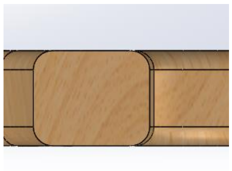
Function	1	2	3
A			
B			
C			

Table 8 Morphological Chart

3.7 Concept Selection

After the development of several designs, few designs were selected by using the Pugh selection method. The selected design was evaluated in detail based on criteria that were deduced from PDS. The best design will be picked as the final design hook model. The scoring in the Pugh matrix was based on a thorough assessment of each design alternative against crucial criteria. For design complexity, a positive score indicated lower complexity compared to the baseline, while a negative score denoted higher complexity. Lightweight design was scored positively for reduced weight and negatively for increased weight. Ergonomics were evaluated with positive, zero, or negative scores for superior, similar, or inferior features. Ease of manufacturing received a positive score for simplicity, zero for similarity, and a negative score for complexity. This methodical scoring ensured an objective evaluation, guiding the selection of the most promising design for further development as the final hook model. Below show the table of Pugh matrix evaluation method for the project.

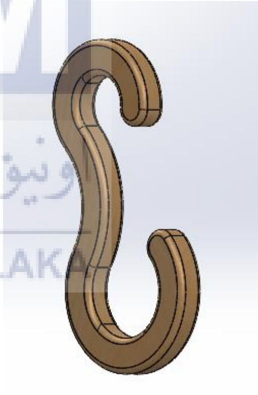
Criteria Selection	**A1,B1 and C1** 	**A2, B2 and C2** 	**A3,B3 and C3** 
Design complexity	+	+	+
Lightweight	+	+	+
Ergonomic	+	0	_
Ease manufacturing	+	0	_
Total pluses	4	2	2
Total minuses	0	0	2
Total zeros	0	2	0
Net score	4	2	0
Rank	**1**	**2**	**3**

Table 9 Pugh matrix evaluation diagram

3.8 Detailed Design In CAD Software

The detailed of the design of the hook models will be executed in CAD software which is Solidwork. The detailed of the design must be exhibited to show the dimensional view such as isometric view, ortographic view and rendering view. The detailed design is very important to show the actual sizing of the hook design model. The Solidwork software is very essential tools to exhibit the detailed design because it enables the users to import and translate the details of our design into other form of data. Solidwork can be used to extruded our design model and convert into Stereolithography (STL) file. STL is a file format commonly used for 3D printing. STL also means as Standard Triangle Language or Standard Tessellation Language. The files of our design can used in the Fabrication phase using 3D printiing machine. Below shows the detailed design the hook design model.

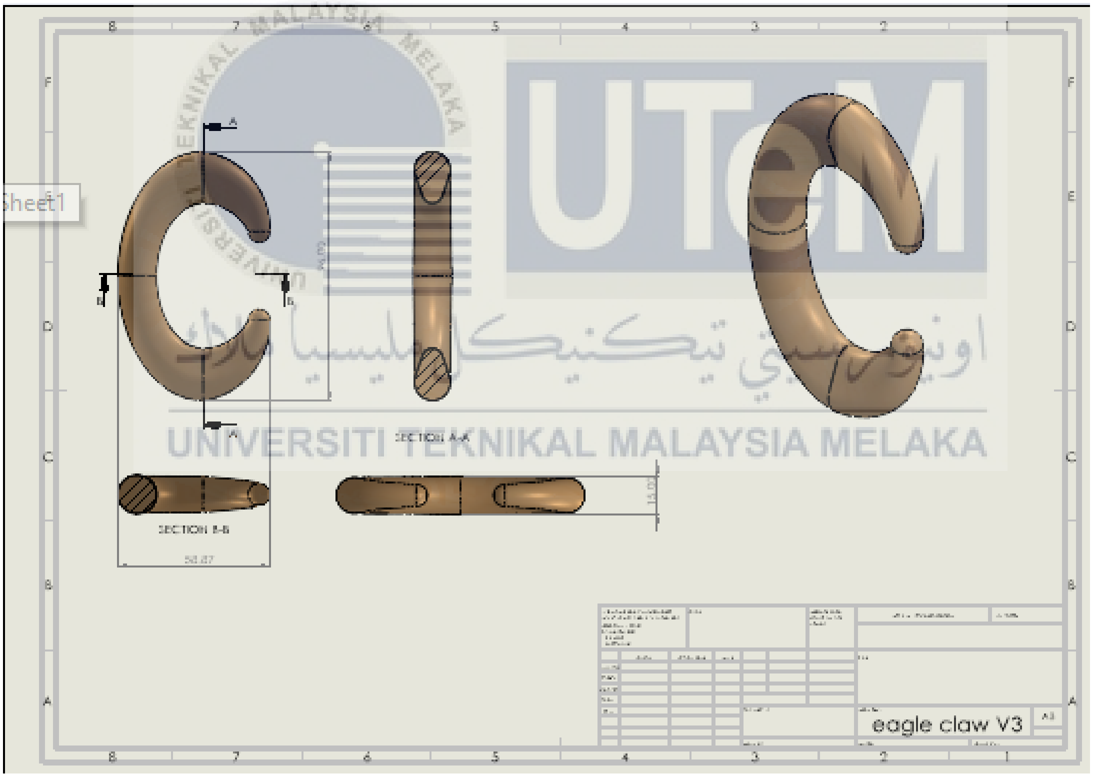


Figure 20 CAD Drawing for Eagle claw concept

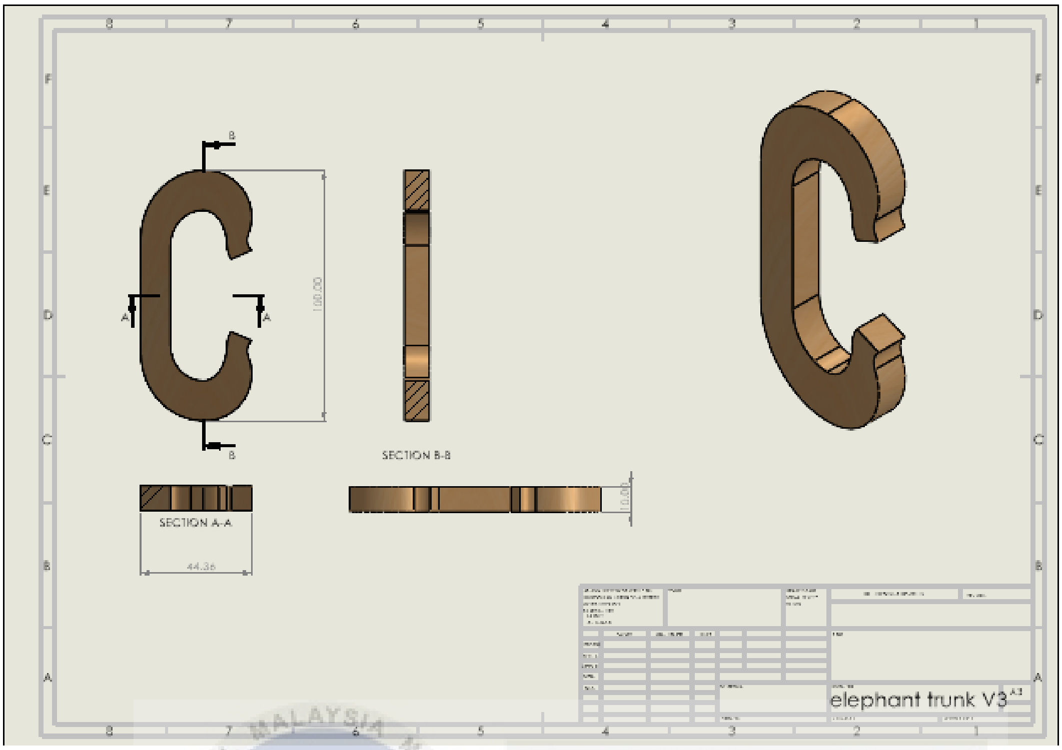


Figure 21 CAD Drawing for Elephant trunk concept

Figure 22 CAD Drawing for Seahorse concept

3.9 Mechanical Testing

Mechanical testing is a set of tests that have been standardized to determine a material's physical and mechanical properties and suitability for its proposed applications. Mechanical testing is one of necessities in product design and part manufacturing due to the need by organizations such as ASTM and ISO to achieve their standards set. These tests enable producers to differentiate low-quality components and select the best material for their goods. Mechanical testing to is appropiate for this research is Tensile Test (ASTM C297) and Flexural Test (ASTM D7250) to ensure the hook design model capable to lift a better load capacity.

Figure 23 Tensile testing (ASTM C297)

Tensile testing is a mechanical strength test that determines material properties such as stress, strain, and yield deformation. It involves pulling a material with force until it breaks, using a tensile testing machine that can be hydraulic or electric. This test produces a stress-strain curve on a graph and shows the manner in which the material fractures. It can also determine the yield strength, modulus of elasticity, and ductility or brittleness of the material. Tensile testing is a fundamental test used in material science and engineering to assess the strength and durability of materials.

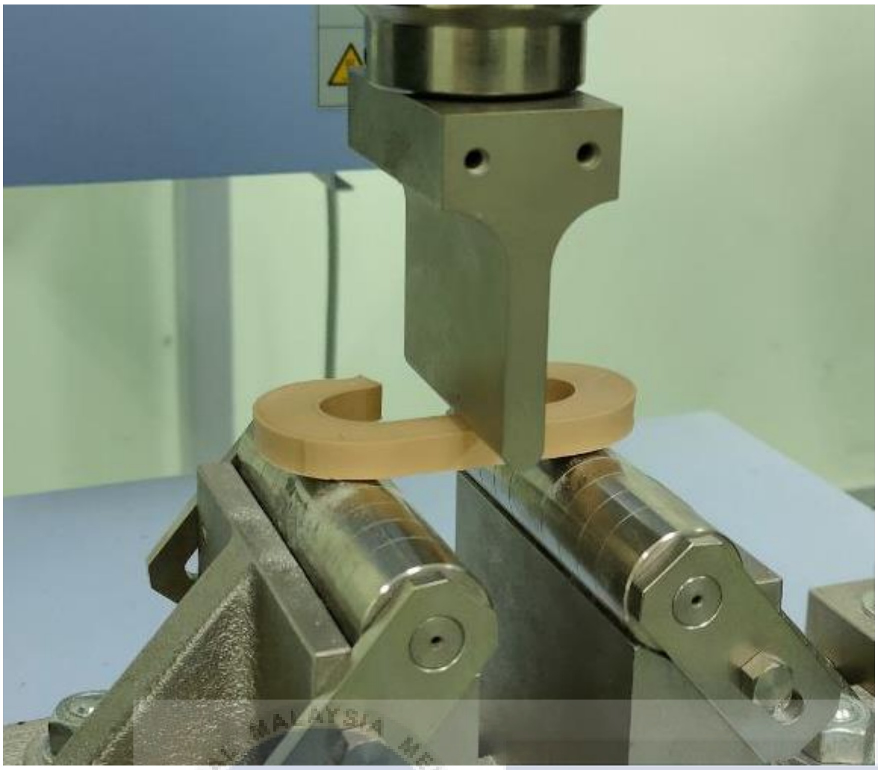


Figure 24 Flexural Testing (ASTM D7250)

Flexural testing is a method for determining a material's resistance to flexing or stiffness by measuring the force required to bend a plastic beam. The flex modulus of a material indicates how much it can flex before experiencing permanent deformation. In the case of plastic lock arms or snap-fit assemblies, the arm needs to flex to allow proper seating of the connection and then flex back into position to lock the connection in place. If the locking mechanism is made of brittle material, it will have a higher tendency to break when flexed. Flexural testing is critical in determining the durability and reliability of plastic components in various applications.

3.10 Simulation

Finite element analysis (FEA) is a technique that involves predicting and comprehending how an object would perform under different physical scenarios through the use of calculations, simulations, and models. The primary objective of FEA is to identify design flaws in prototypes. It is a computer-aided engineering (CAE) tool that is utilized to examine how designs react in real-world conditions. The following example exhibits a simulation test conducted on the hook design model using FEA analysis, which reveals the stress, strain, and displacement outcomes.

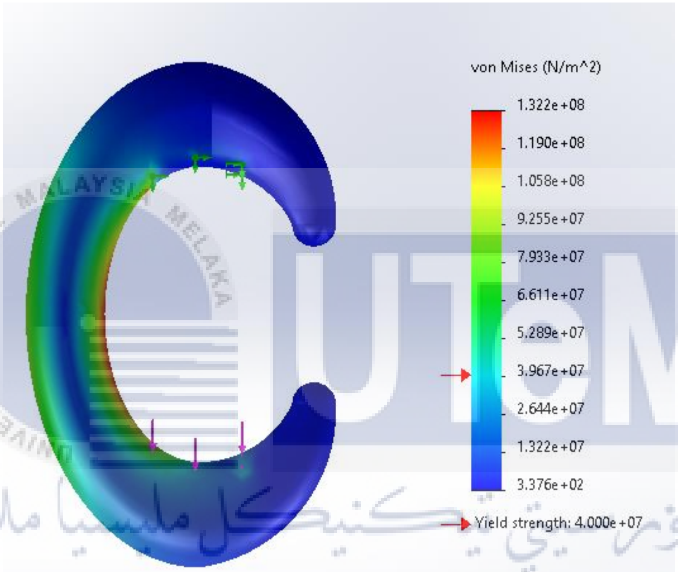


Figure 25 simulation testing towards loading

Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.376e+02N/m^2 Node: 11378	1.322e+08N/m^2 Node: 537

Table 10 the results from simulation

3.11 Fabrication

FDM technology is a technique used to create physical objects by adding successive layers of material. The process involves pushing a thermoplastic filament through an extruder and depositing it layer by layer to form the desired object. This approach is an additive manufacturing (AM) method, which is the opposite of traditional manufacturing, where material is cut away from a block to create the object. 3D printing using FDM technology is user-friendly, easy to use, and produces minimal waste. This is due to the use of production-grade materials that are both mechanically and environmentally stable. These materials are often the same thermoplastics used in traditional manufacturing methods such as injection molding. The following example depicts an ongoing FDM fabrication of our hook design model, which uses bio-composite material.

Figure 26 on-going fabrication process using 3D printer Ender 5

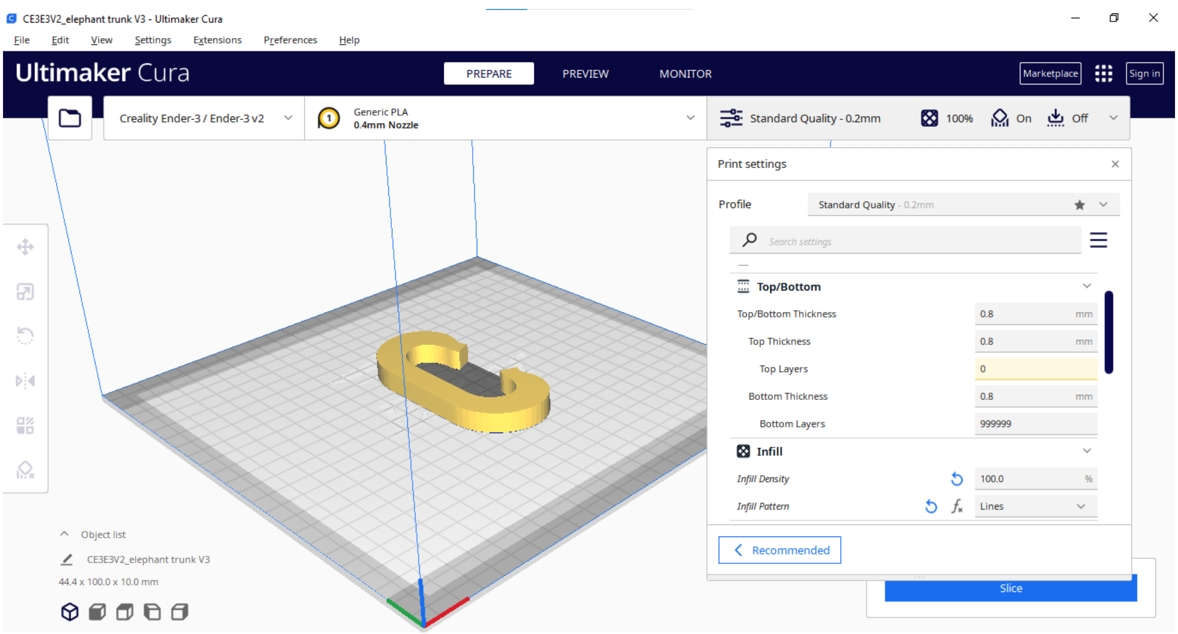


Figure 27 Ultimaker Cura and the parameter settting

Fused Deposition Modeling (FDM) technology is employed for the fabrication process, utilizing Ultimaker Cura as the slicing software. Ultimaker Cura allows for precise control over various printing parameters, ensuring the successful realization of the designed objects. The chosen parameter settings remain consistent across all three design concepts to maintain uniformity and standardize the fabrication process. The key parameter settings for the fabrication process include a layer height of 0.2mm, resulting in finer details on the printed object. The infill density is set to 100%, enhancing the structural integrity of the objects, with the infill pattern configured as a line for optimal strength. These settings contribute to the overall quality and strength of the fabricated objects.

Moreover, considering the use of wood PLA as the filament material, a printing temperature of 200°C is selected. This temperature ensures proper material flow and adhesion during the printing process, optimizing the performance of the wood PLA. The build plate is set to 50°C, promoting better bed adhesion for the first few layers and reducing the likelihood of warping. These parameter settings are meticulously chosen to suit the characteristics of wood PLA and are applied consistently across the ongoing FDM fabrication of the hook design model, which utilizes a bio-composite material. This approach aims to produce high-quality, mechanically stable objects with minimal waste, aligning with the user-friendly and environmentally conscious nature of FDM technology.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Chapter 4 details the results and analyses of the bio-inspired hook design model's design development, mechanical testing, and simulation outcomes for the fabricated product. The primary aim is to create an optimal hook design inspired by nature, considering fabrication limitations such as printability with bio-composite material and the product's ability to endure specific tensile forces during continuous loading. The following sections explore design development intricacies, scrutinize empirical findings from mechanical testing, and reveal outcomes from simulation studies. This structured exploration offers a comprehensive understanding of achieved results and their implications, emphasizing the importance of a bio-inspired design meeting fabrication constraints and excelling in continuous loading scenarios.

4.2 Results of Printability of the Fabricated product.

Figure 28 outcomes from hook model fabrication

This section examines the critical aspects of the product's printability, a central theme in our research study. Employing 3D printing or additive manufacturing, our fabrication process relies on a layer-by-layer build approach, with wood PLA chosen as the biobased material. Wood PLA imparts distinctive mechanical properties such as lightweight and biodegradability. However, the bio-composite material's inherent brittleness poses challenges, leading to filament breakage and nozzle clogging during the printing process. Careful consideration of 3D printing parameters is essential to ensure flawless fabrication, minimizing errors in layer formation. The precision of the printing process directly correlates with achieving optimal mechanical testing results, making it a pivotal focus of our study.

4.3 Result for SolidWorks Simulation

This section presents the outcomes derived from the SolidWorks simulation, a pivotal aspect of our study. SolidWorks, a powerful tool in engineering simulation, offers insights into the structural behavior and performance of our bio-inspired hook design model under specified conditions. The results from this simulation provide a nuanced understanding of stress distribution, deformation, and other critical factors that contribute to the overall evaluation of the design's robustness.

Name	Type	Min	Max
Eagle Claw (Stress)	VON: von Mises Stress	3.376e+02N/m^2 Node: 11378	1.322e+08N/m^2 Node: 537

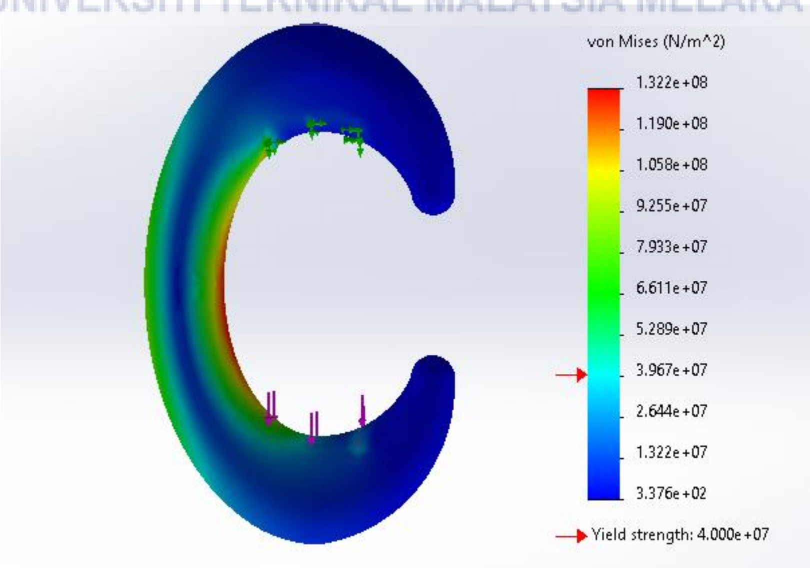


Figure 29 Von Mises Stress for Eagle Claw

Name	Type	Min	Max
Eagle Claw(Displacement)	URES: Resultant Displacement	0.000e+00mm Node: 23	1.238e+01mm Node: 649

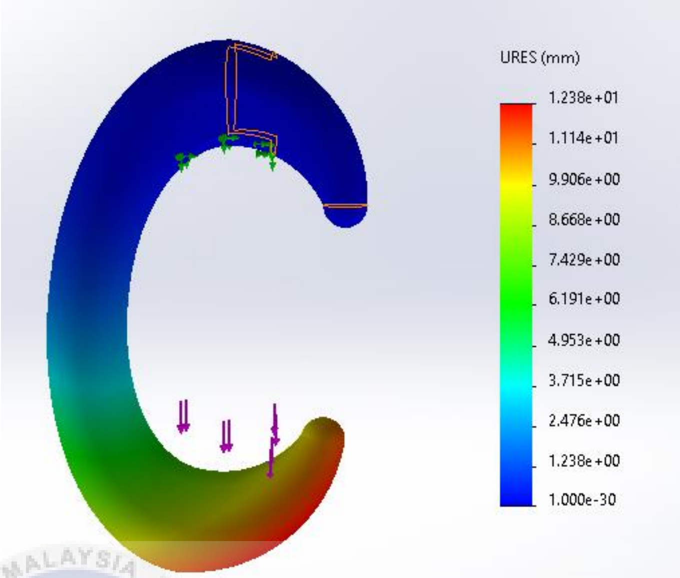


Figure 30 URES Resultant Displacement for Eagle Claw

Name	Type	Min	Max
Eagle claw(Strain)	ESTRN: Equivalent Strain	1.048e-07 Element: 673	2.958e-02 Element: 1984

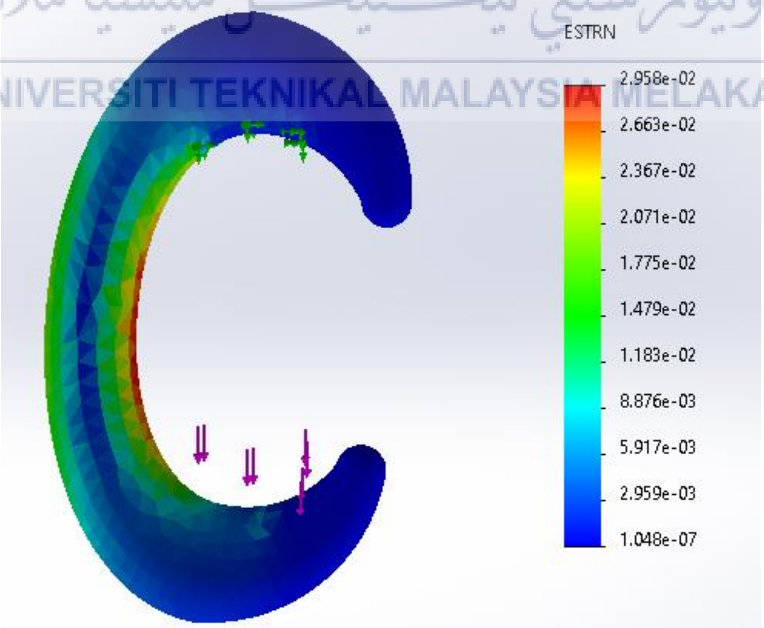


Figure 31 ESTRN Equivalent Strain for Eagle Claw

Name	Type	Min	Max
Elephant Trunk (Stress)	VON: von Mises Stress	6.171e+01N/m^2 Node: 737	9.447e+07N/m^2 Node: 12777

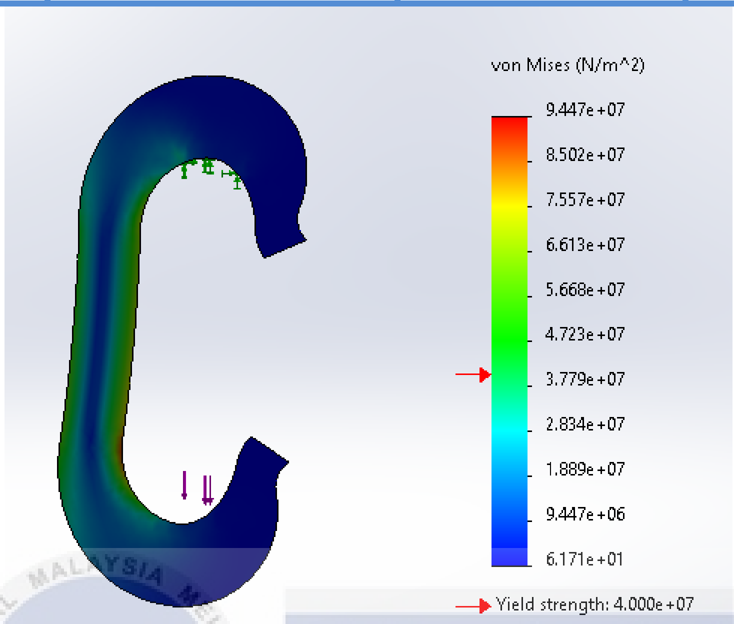


Figure 32 Von Mises Stress for Elephant Trunk

Name	Type	Min	Max
Elephant Trunk(Displacement)	URES: Resultant Displacement	0.000e+00mm Node: 65	1.040e+01mm Node: 1049

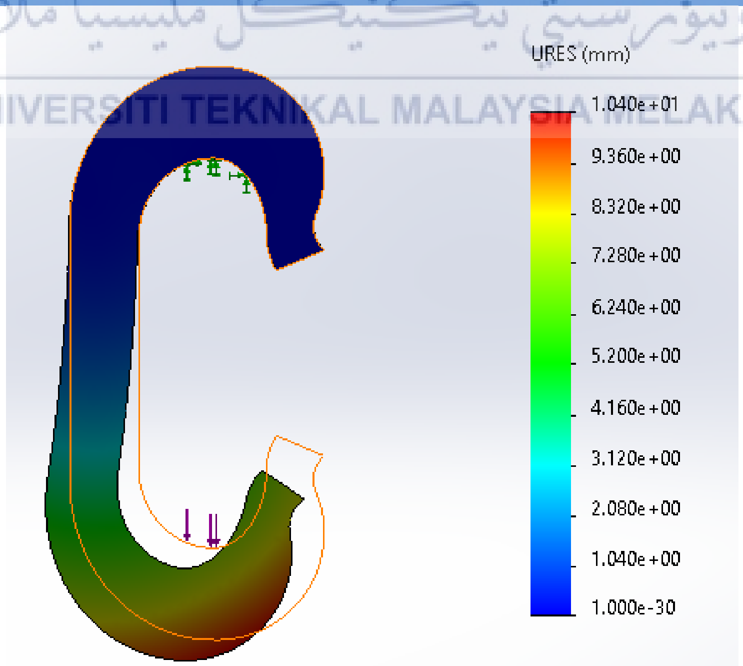


Figure 33 URES Resultant Displacement for Elephant Trunk

Name	Type	Min	Max
Elephant Trunk (Strain)	ESTRN: Equivalent Strain	1.240e-07 Element: 2937	2.143e-02 Element: 5906

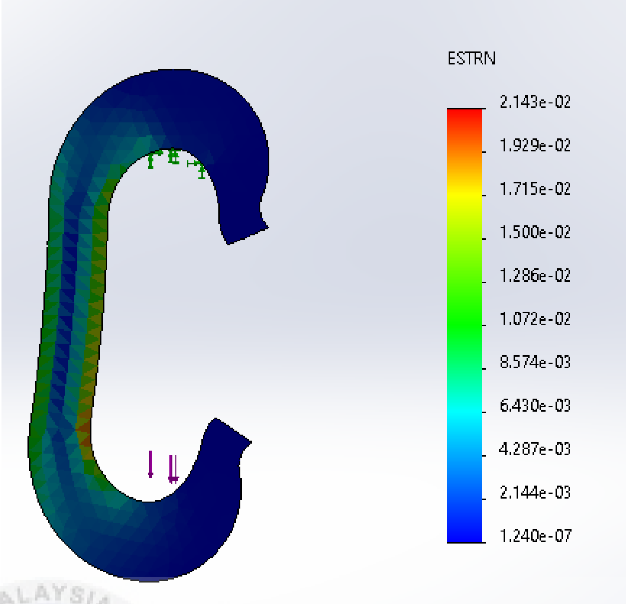


Figure 34 ESTRN Equivalent Strain for Elephant Trunk

Name	Type	Min	Max
Seahorse (Stress)	VON: von Mises Stress	1.453e+00N/m^2 Node: 2762	1.576e+08N/m^2 Node: 518

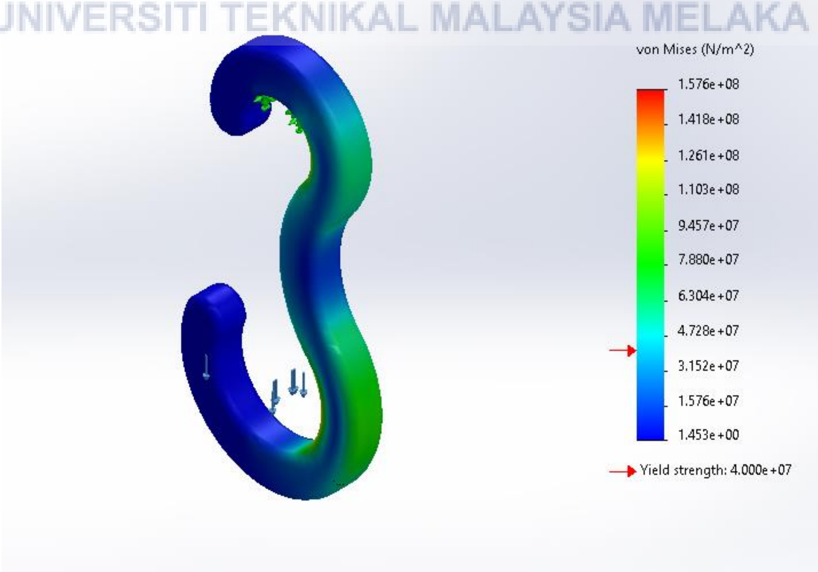


Figure 35 Von Mises Stress for Seahorse

Name	Type	Min	Max
Elephant Trunk (Displacement)	URES: Resultant Displacement	0.000e+00mm Node: 371	2.149e+01mm Node: 11500

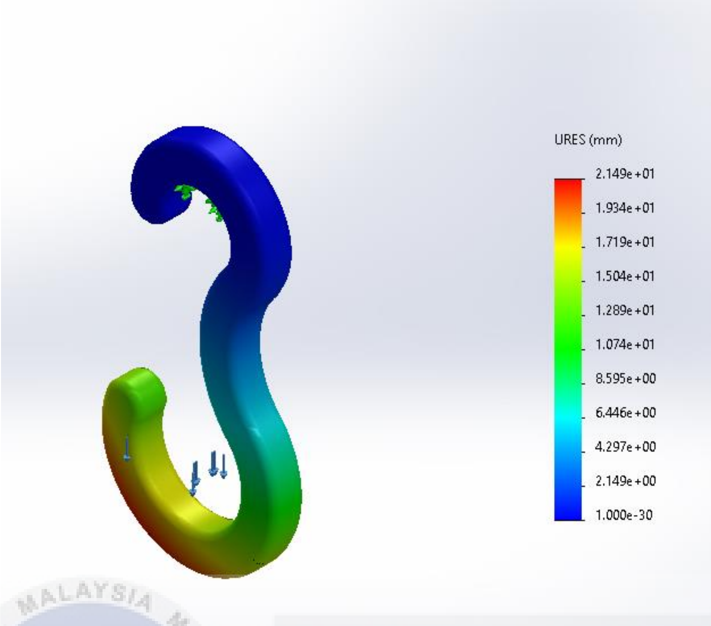


Figure 36 URES Resultant Displacement for Seahorse

Name	Type	Min	Max
Elephant Trunk (Strain)	ESTRN: Equivalent Strain	3.931e-10 Element: 5897	3.486e-02 Element: 7369

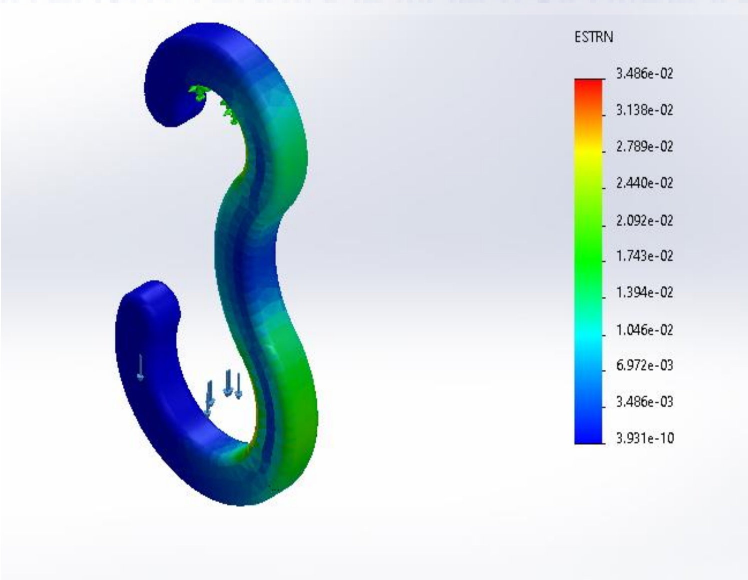


Figure 37 ESTRN Equivalent Strain for Seahorse

	Eagle Claw	Elephant Trunk	Seahorse
Von Mises Stress (N/m^2)	1.322e+08	9.447e+07	1.576e+08
Yield Strength (N/m^2)	4.000e+07	4.000e+07	4.000e+07
Resultant Replacement (mm)	1.238e+01	1.040e+01	2.149e+01
Equivalent Strain	2.958e-02	2.143e-02	3.486e-02

Table 11 Simulation Results from SolidWorks

The Von Mises Stress, representing the material's strength under various loads, is highest for Seahorse with a value of 1.576e+08 N/m^2, suggesting that it might be subjected to higher forces compared to Eagle Claw (1.322e+08 N/m^2) and Elephant Trunk (9.447e+07 N/m^2). Despite the elevated stress levels, all three designs have Yield Strength values (4.000e+07 N/m^2) higher than their respective Von Mises Stress, indicating that they are within the material's elastic range and are not surpassing the yield point.

Regarding displacement, Seahorse exhibits the highest Resultant Replacement at 2.149e+01 mm, implying that it undergoes more deformation compared to Eagle Claw (1.238e+01 mm) and Elephant Trunk (1.040e+01 mm). Additionally, Seahorse shows the highest Equivalent Strain at 3.486e-02, indicating more significant overall deformation compared to Eagle Claw (2.958e-02) and Elephant Trunk (2.143e-02).

In summary, Seahorse experiences the highest Von Mises Stress, Resultant Replacement, and Equivalent Strain, suggesting that it undergoes more deformation and might be subjected to higher loads. Eagle Claw and Elephant Trunk perform relatively better in terms of stress, displacement, and strain. However, further analysis, considering specific design requirements and constraints, is crucial for a comprehensive interpretation.o

4.4 Result for mechanical testing (Tensile and Flexural)

The mechanical testing, comprising the tensile test and flexural testing, aimed to experimentally assess the hook design model's ability to endure tensile stress under continuous loading. In the Tensile test (ASTM C297), the obtained data includes max stress, max force, and other mechanical properties. Analysis of these parameters helps determine the product's behavior, indicating whether it exhibits ductile or brittle characteristics. This information is derived from the stress-strain curve graph and the observed condition of the product during post-testing experiments.

4.4.1 Tensile Test (ASTM C297)

Tensile test results (ASTM C297) encompass max stress, max force, and essential mechanical properties. This data is pivotal for evaluating the hook design model's response to continuous tensile stress. The stress-strain curve graph sheds light on material performance, helping determine whether Design 1 displays ductile or brittle characteristics. Observations from post-testing experiments further enhance the comprehensive analysis.

4.4.1.1 Design Concept 1 (Eagle Claw)

Key Word		Product Name	
Test File Name	Tensile_20231103_0936.xtak	Method File Name	Tensile.xmak
Report Date	11/3/2023	Test Date	11/3/2023
Test Mode	Single	Test Type	Tensile
Speed	5mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

Name	Max_Force	Tensile Strength	Elastic	Break_Disp.
Parameters	Calc. at Entire Areas	Calc. at Entire Areas	Force 0.001 - 10 N	Sensitivity: 10
Unit	N	MPa	GPa	mm
sample 1	561.476	4.48853	0.10106	-.-

Figure 38 Tensile Test; Force (N) vs Displacement (mm) graph for Eagle Claw

In the force vs displacement curve for Design Concept 1 (Eagle Claw), the maximum force recorded is approximately 561.48 N. This force corresponds to a displacement of around 7.3 mm. The curve demonstrates a gradual decrease in force with increasing displacement, suggesting that the material undergoes plastic deformation rather than an abrupt failure. The data indicates that the material exhibits some level of ductility, allowing it to deform before reaching its maximum force. This behavior provides insights into the material's response under load, showcasing a post-peak behavior where the force decreases as the displacement continues.

Figure 39 Tensile Test; Stress (MPa) vs Strain (%) graph for Eagle Claw

In the stress vs strain graph for Design Concept 1 (Eagle Claw), the stress values reach a maximum of approximately 4.48853 MPa, and the material undergoes significant plastic deformation, collapsing at a strain of around 7%. This indicates that the material experiences substantial deformation before potential failure, showcasing its ductility and ability to withstand high strains. The stress vs strain curve provides a clear representation of the material's behavior under increasing loads, with the peak stress indicating the maximum stress the material can endure before reaching its limits. The observed collapse at 7% strain suggests a point of critical plastic deformation, offering insights into the material's mechanical properties and its performance under various stress levels.

4.4.1.2 Design Concept 2 (Elephant Trunk)

Key Word		Product Name	
Test File Name	Tensile_20231103_0942.xtak	Method File Name	Tensile.xmak
Report Date	11/3/2023	Test Date	11/3/2023
Test Mode	Single	Test Type	Tensile
Speed	5mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

Name	Max_Force	Tensile Strength	Elastic	Break_Disp.
Parameters	Calc. at Entire Areas	Calc. at Entire Areas	Force 0.001 - 10 N	Sensitivity: 10
Unit	N	MPa	GPa	mm
sample 1	563.177	4.50213	0.01378	10.1273

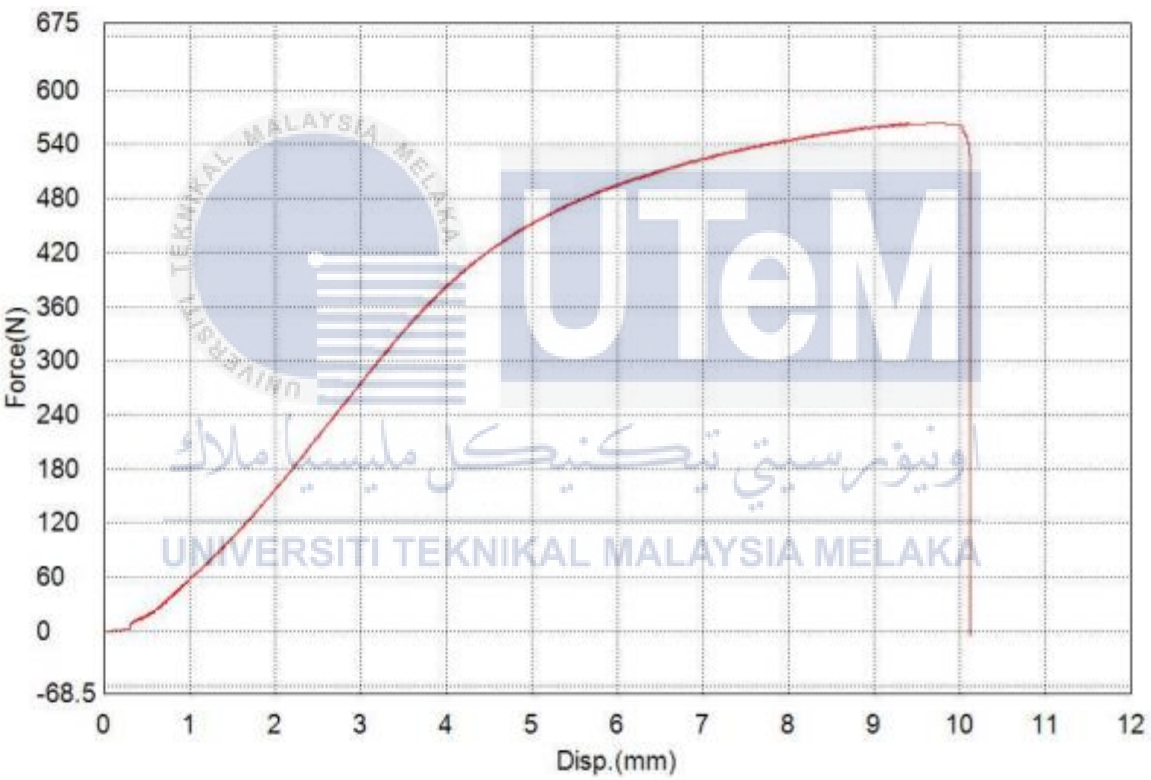


Figure 40 Tensile Test; Force (N) vs Displacement (mm) graph for Elephant Trunk

In the force vs displacement graph for Design Concept 2 (Elephant Trunk), a noteworthy finding emerges as the data reveals a peak force of around 563.177 N occurring at a displacement of 9.7 mm. This specific point signifies the threshold at which the material experiences its highest applied load, shedding light on the structural response to external forces. The graph, by capturing this critical data, contributes to a comprehensive understanding of the design's behavior under various loads, providing essential information for evaluating its robustness and performance in practical applications.

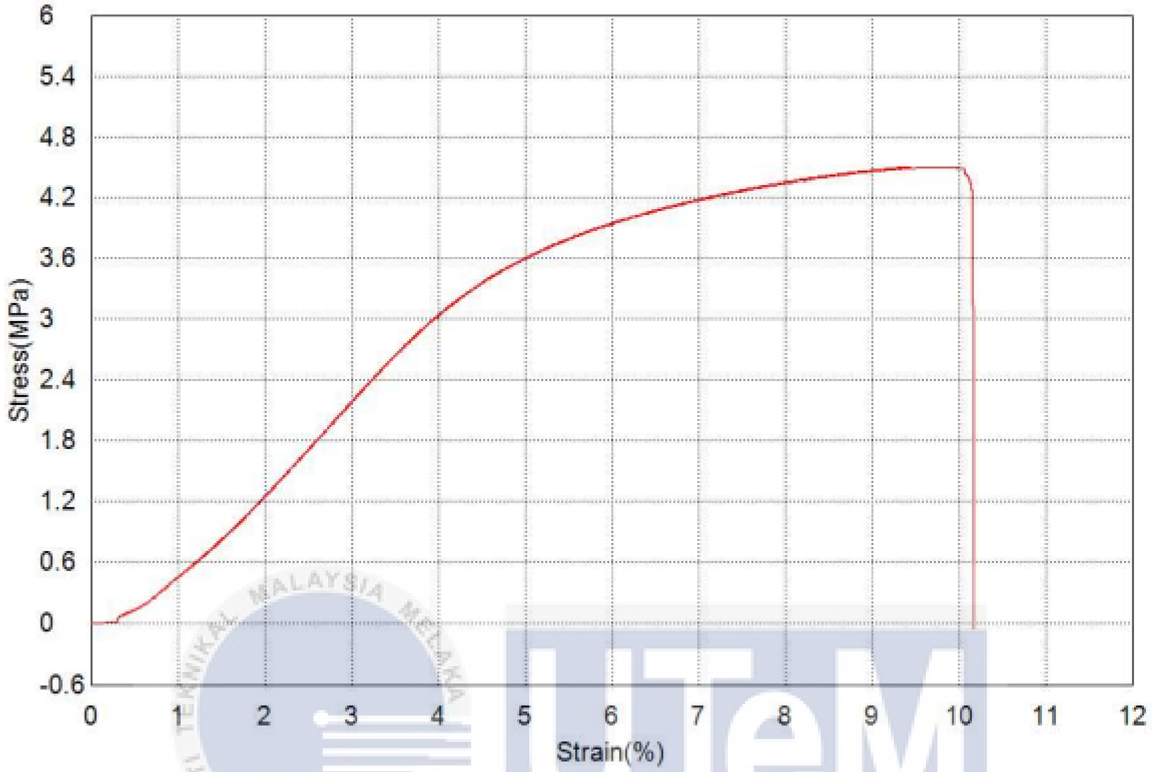


Figure 41 Tensile Test; Stress (MPa) vs Strain (%) graph for Elepahnt trunk

In the stress vs strain graph for Design Concept 2 (Elephant Trunk), the stress reaches a maximum value of approximately 4.50213 MPa, corresponding to a strain of 10%. This signifies the point at which the material experiences its highest stress level before potential yielding or failure. The stress vs strain curve captures this critical data, providing valuable information about the material's mechanical properties and performance under varying loads.

4.4.1.3 Design Concept 3 (Seahorse)

Key Word		Product Name	
Test File Name	Tensile_20231103_0949.xtak	Method File Name	Tensile.xmak
Report Date	11/3/2023	Test Date	11/3/2023
Test Mode	Single	Test Type	Tensile
Speed	5mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

Name	Max_Force	Tensile Strength	Elastic	Break_Disp.
Parameters	Calc. at Entire Areas	Calc. at Entire Areas	Force 0.001 − 10 N	Sensitivity: 10
Unit	N	MPa	GPa	mm
sample 1	293.636	2.34738	0.01294	-.-

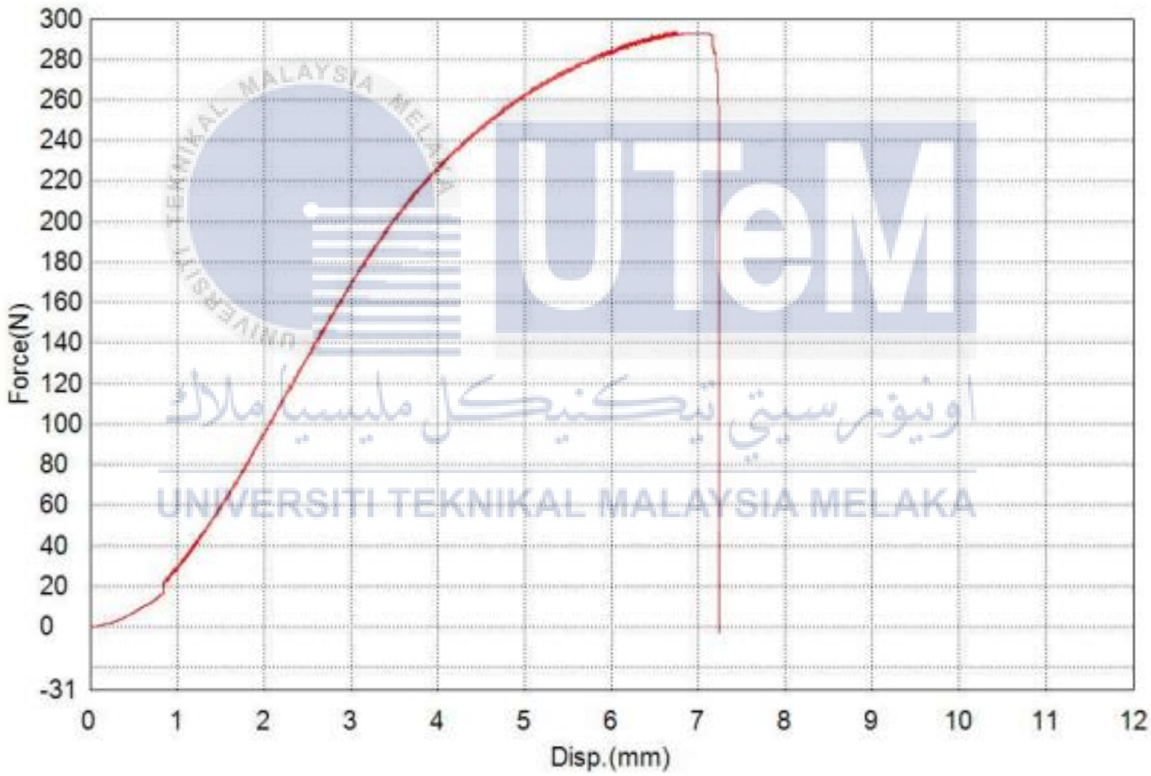


Figure 42 Tensile Test; Force (N) vs Displacement (mm) graph for Seahorse

In the force vs displacement graph for Design Concept 3 (Seahorse), we observe a peak force of approximately 293.636 N at a displacement of 6.7 mm. This pivotal point signifies the Seahorse design's maximal load-bearing capacity, portraying the threshold at which the material experiences its highest applied load before undergoing significant deformation or potential failure. Understanding such critical data from the force vs displacement curve provides valuable insights into the Seahorse design's structural integrity and performance characteristics under varying loads.

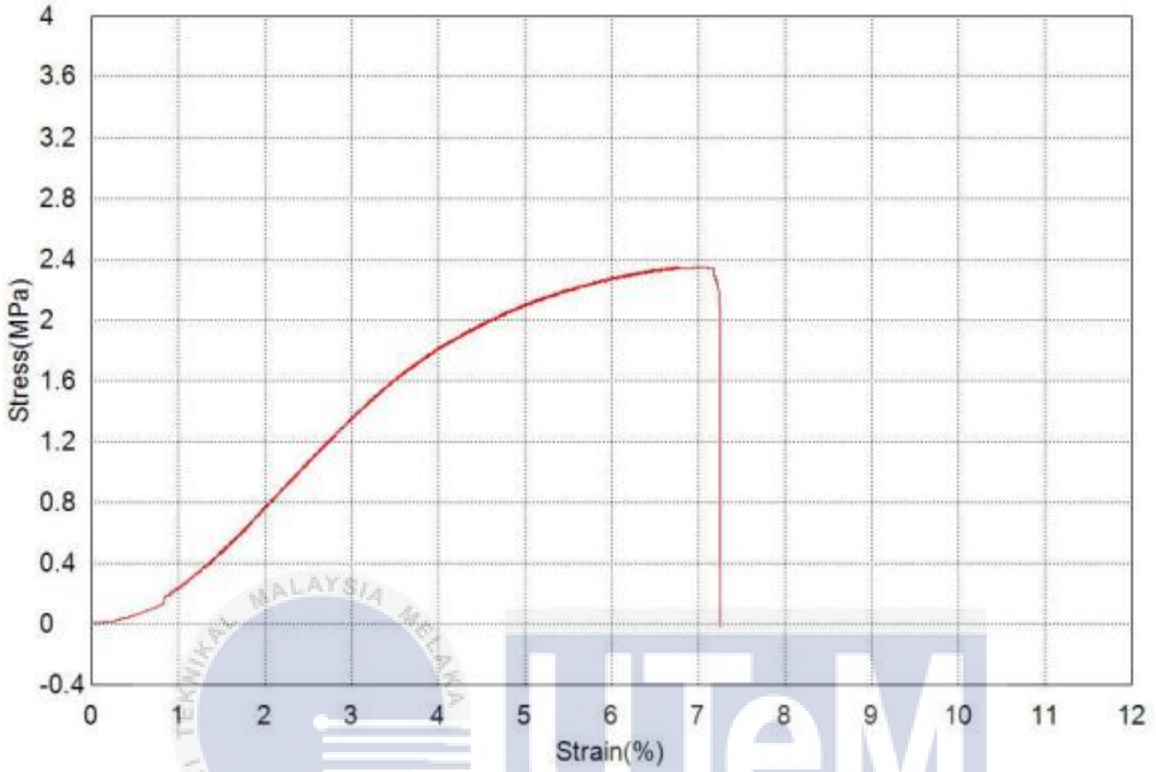


Figure 43 Tensile Test; Stress (MPa) vs Strain (%) graph for Seahorse

In the stress vs strain graph for Design Concept 3 (Seahorse), the stress reaches a peak value of approximately 2.347 MPa at a strain of 7%. This specific point represents the Seahorse design's highest stress level before potential yielding or failure, offering crucial insights into its mechanical properties and load-bearing capabilities. The stress vs strain curve captures this critical data, contributing to a comprehensive understanding of the Seahorse design's behavior under varying loads.

4.4.2 Flexural Test (ASTM D7250)

The Flexural test, vital data, including max stress, max force, and relevant mechanical properties, is considered. This information is essential for understanding how the hook design model withstands bending stress. The flexural test results, combined with observations from post-testing experiments, contribute to a thorough analysis of all hook model performance in flexural conditions.

4.4.2.1 Design Concept 1 (Eagle Claw)

Key Word		Product Name	
Test File Name	Flexural_20231103_1029.xtak	Method File Name	Flexural.xmak
Report Date	11/3/2023	Test Date	11/3/2023
Test Mode	Single	Test Type	3 Point Bend
Speed	5mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

Name	Max_Force	Max_Stress	Elastic
Parameters	Calc. at Entire Areas	Calc. at Entire Areas	Force 0.001 - 10 N
Unit	N	MPa	GPa
sample 1	1544.78	115.858	0.00147

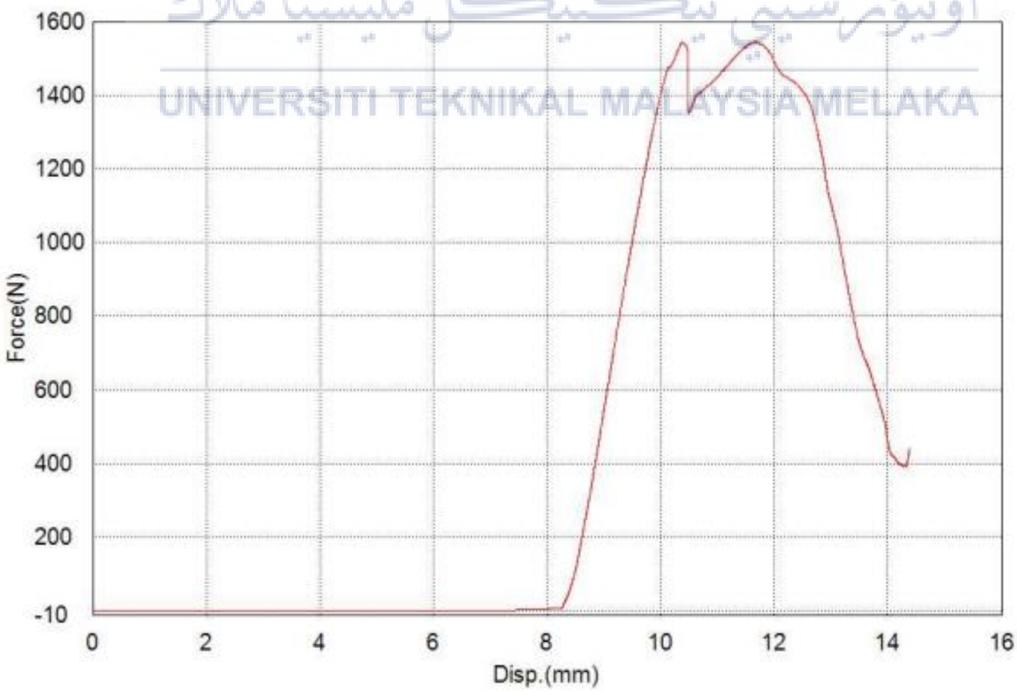


Figure 44 Flexural Test; Force (N) vs Displacement (mm) graph for Eagle Claw

In the flexural analysis of Design Concept 1 (Eagle Claw), the stress-strain graph reveals key characteristics of the material's response to bending. The initial linear region depicts the material's stiffness, while the yield point and ultimate stress provide insights into its ductility and maximum load-bearing capacity. The force-displacement graph complements this by showcasing Eagle Claw's strength, evident in the peak force of 1544 N, and the displacement at failure, indicating the extent of bending sustained before potential collapse. Together, these results offer a comprehensive understanding of Eagle Claw's flexural behavior, essential for assessing its structural integrity and performance in applications subject to bending forces.

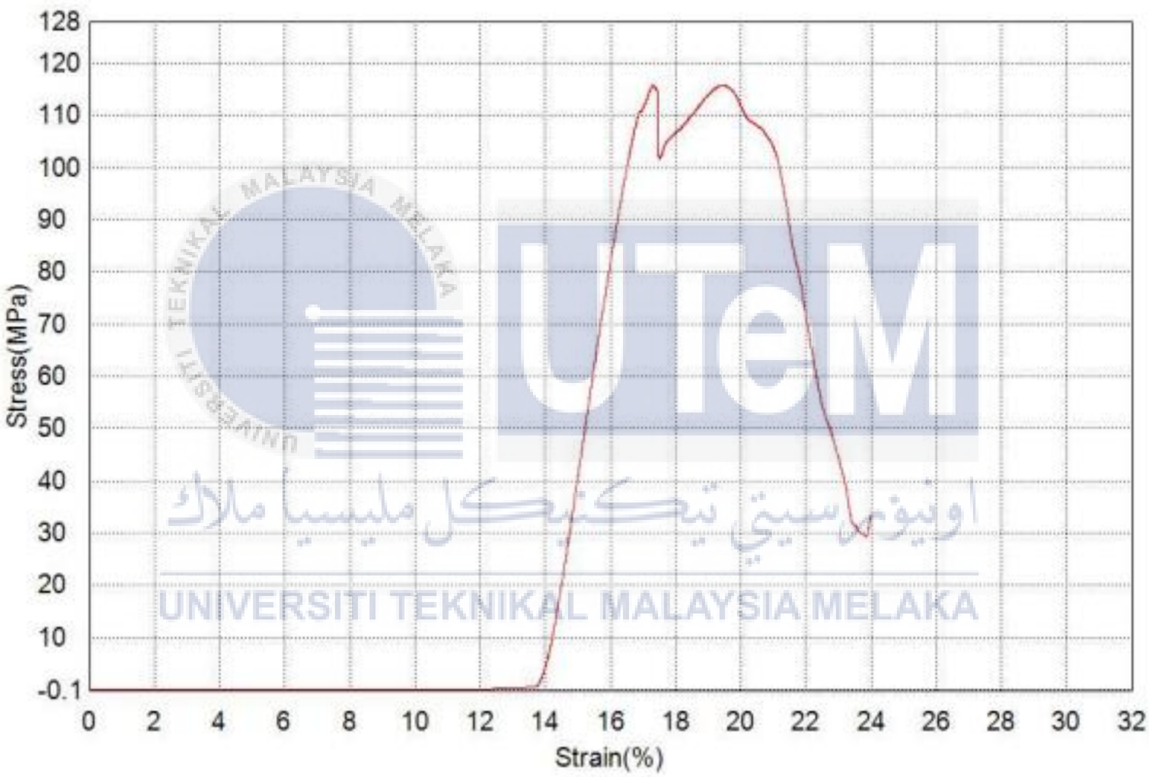


Figure 45 Flexural Test; Stress (MPa) vs Strain (%) graph for Eagle Claw

In the stress-strain analysis for Design Concept 1 (Eagle Claw), the material exhibits a peak stress of 115.858 MPa at a strain of 19%. This data point signifies the design's ability to withstand significant deformation under bending forces, providing crucial insights into its ductility and load-bearing capabilities in flexural scenarios. The stress-strain curve captures the material's response to increasing loads, with the recorded values aiding in a detailed assessment of Eagle Claw's mechanical behavior and performance, particularly in applications where bending stresses are a critical consideration.

4.4.2.2 Design Concept 2 (Elephant Trunk)

Key Word		Product Name	
Test File Name	Flexural_20231103_1023.xtak	Method File Name	Flexural.xmak
Report Date	11/3/2023	Test Date	11/3/2023
Test Mode	Single	Test Type	3 Point Bend
Speed	5mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

Name	Max_Force	Max_Stress	Elastic
Parameters	Calc. at Entire Areas	Calc. at Entire Areas	Force 0.001 - 10 N
Unit	N	MPa	GPa
sample 1	663.710	49.7782	0.31789

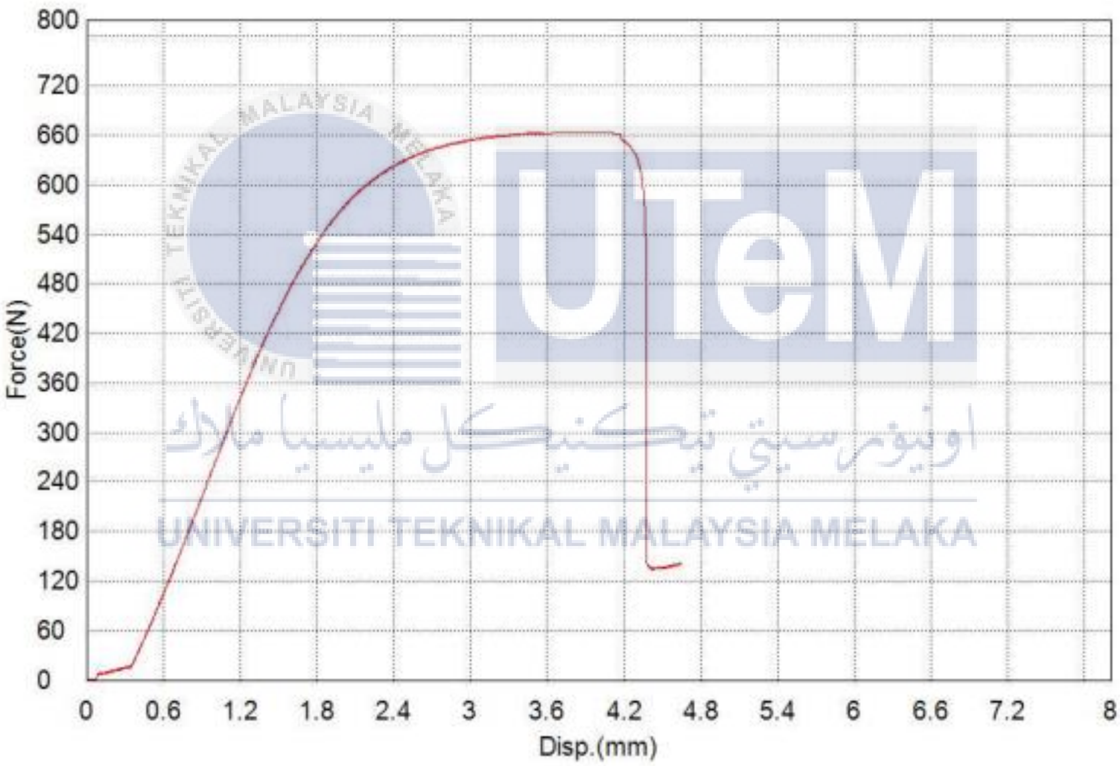


Figure 46 Flexural Test; Force (N) vs Displacement (mm) graph for Elephant trunk

In the flexural analysis of Design Concept 2 (Elephant Trunk), the force-displacement graph reveals a maximum force of 663.710 N at a displacement of 4.2 mm. This significant force denotes the design's ability to withstand bending loads, showcasing its strength and load-bearing capacity under flexural stress. The force-displacement curve provides valuable insights into the material's behavior, offering a clear indication of its flexibility and resistance to deformation. These results contribute to a comprehensive understanding of Elephant Trunk's performance in applications where bending forces are a critical consideration.

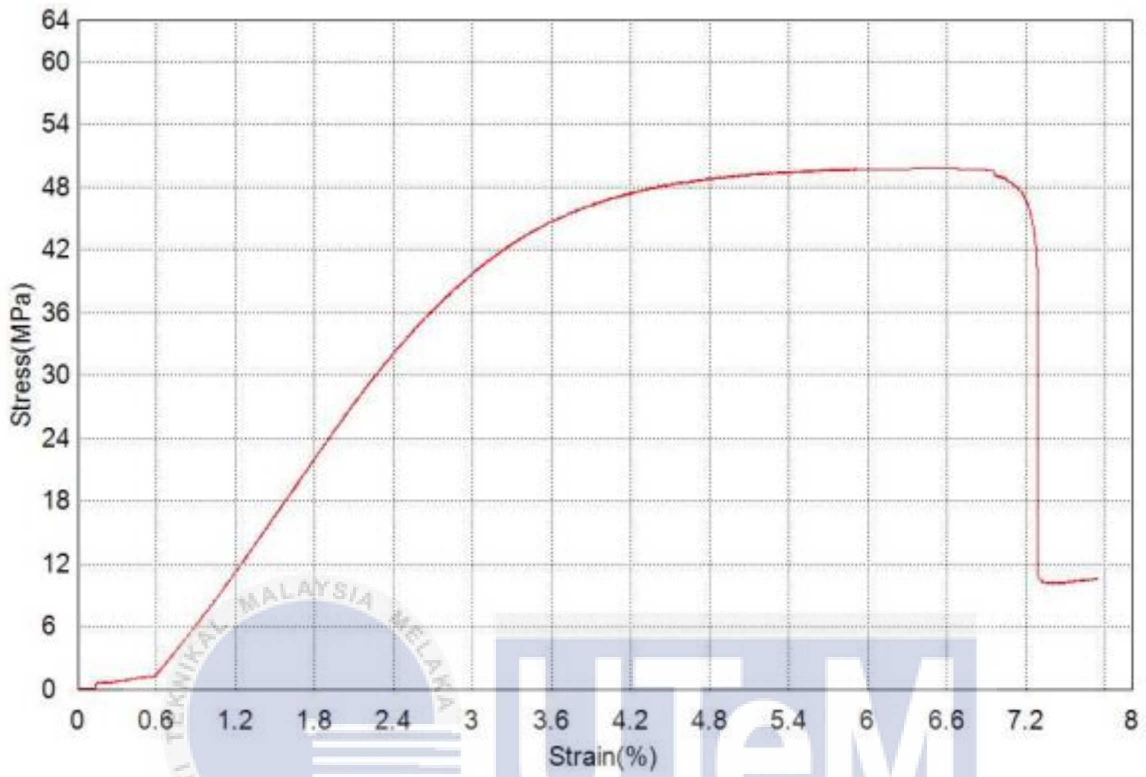


Figure 47 Flexural Test; Stress (MPa) vs Strain (%) graph for Elephant Trunk

In the stress-strain analysis for Design Concept 2 (Elephant Trunk), the material reaches a stress of 49.7782 MPa at a strain of 7%. This specific data point highlights the design's behavior under bending forces, showcasing its stress-resisting capabilities and deformation characteristics. The stress-strain curve captures the material's response to increasing loads, providing crucial insights into Elephant Trunk's mechanical properties in flexural scenarios. This information aids in the assessment of the design's overall performance and suitability for applications where bending stresses are a key consideration.

4.4.2.3 Design Concept 3 (Seahorse)

Key Word		Product Name	
Test File Name	Flexural_20231103_1017.xtak	Method File Name	Flexural.xmak
Report Date	11/3/2023	Test Date	11/3/2023
Test Mode	Single	Test Type	3 Point Bend
Speed	5mm/min	Shape	Plate
No of Batches:	1	Qty/Batch:	1

Name	Max_Force	Max_Stress	Elastic
Parameters	Calc. at Entire Areas	Calc. at Entire Areas	Force 0.001 − 10 N
Unit	N	MPa	GPa
sample 1	388.463	29.1348	0.12936

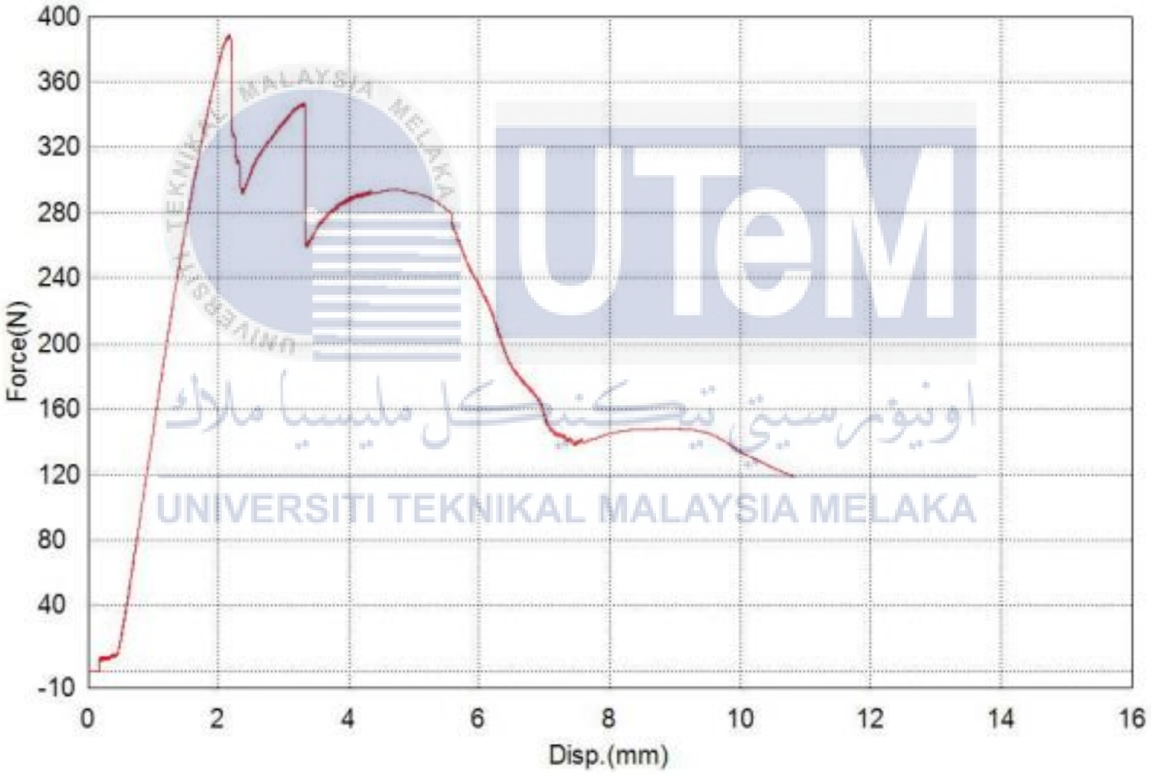


Figure 48 Flexural Test; Force (N) vs Displacement (mm) graph for Seahorse

In the flexural analysis of Design Concept 3 (Seahorse), the force-displacement graph reveals a maximum force of 388.463 N at a displacement of 3 mm. This significant force indicates the Seahorse design's ability to withstand bending loads, showcasing its strength and load-bearing capacity under flexural stress. The force-displacement curve provides valuable insights into the material's behavior, offering a clear indication of its flexibility and resistance to deformation. These results contribute to a comprehensive understanding of Seahorse's performance in applications where bending forces are a critical consideration.

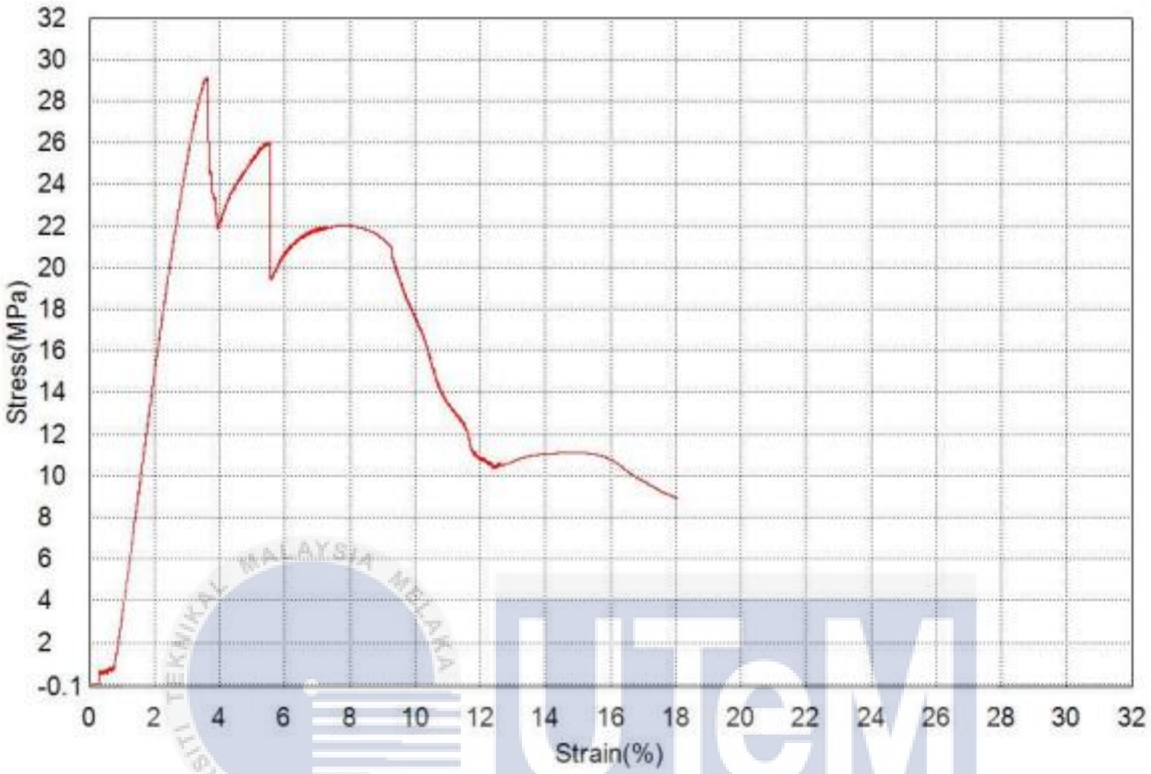


Figure 49 Flexural Test; Stress (MPa) vs Strain (%) graph for Seahorse

In the stress-strain analysis for Design Concept 3 (Seahorse), the material exhibits a stress of 29.1348 MPa at a strain of 5%. This specific data point provides insights into Seahorse's response to bending forces, highlighting its stress-resisting capabilities and deformation characteristics. The stress-strain curve captures the material's behavior under increasing loads, offering crucial information for understanding Seahorse's mechanical properties in flexural scenarios. This data contributes to the assessment of the design's overall performance and its suitability for applications where bending stresses play a significant role.

4.5 Comparative Analysis of Biomimetic Hook Designs: Eagle Claw, Elephant Trunk, and Seahorse

This section presents a comparative analysis of three distinct hook design concepts: Eagle Claw (Design Concept 1), Elephant Trunk (Design Concept 2), and Seahorse (Design Concept 3). The comparison involves evaluating the performance of each design through mechanical testing (tensile and flexural) and finite element analysis (FEA) simulations. By examining key parameters such as strength, durability, and resistance to deformation, this analysis aims to identify the strengths and weaknesses of each design. The ensuing discussion will focus on numerical results and qualitative observations, providing insights into the relative merits of the three design concepts.

Design Parameter	*Design Concept 1 (Eagle Claw)*	*Design Concept 2 (Elephant Trunk)*	*Design Concept 3 (Seahorse)*
*Tensile Test Result**			
Max Force (N)	561.476	563.177	293.636
Tensile Strength (MPa)	4.48853	4.50213	2.34738
Elastic Modulus (GPa)	0.10106	0.01378	0.01294
*Flexural Test Result**			
Max Force (N)	1544.78	663.710	388.463
Flexural Strength (MPa)	115.858	49.7783	29.1348
Elastic Modulus (GPa)	0.00147	0.31789	0.12936

*Simulation Test Result**			
Von Mises Stress (N/m^2)	1.322e+08	9.447e+07	1.576e+08
Yield Strength (N/m^2)	4.000e+07	4.000e+07	4.000e+07
Resultant Replacement (mm)	1.238e+01	1.040e+01	2.149e+01
Equivalent Strain	2.958e-02	2.143e-02	3.486e-02

Table 12 Numerical Results from Mechanical Testing and Simulation

In the evaluation of three different hook design concepts—Eagle Claw (Design Concept 1), Elephant Trunk (Design Concept 2), and Seahorse (Design Concept 3)—across tensile tests, flexural tests, and simulation results, each design exhibited unique strengths. Design Concept 2 (Elephant Trunk) demonstrated superior tensile strength, displaying the highest force resistance among the designs. Conversely, Design Concept 1 (Eagle Claw) showed the best performance in flexural strength, exhibiting the highest resistance to forces causing bending. Design Concept 3 (Seahorse) displayed notable results in certain aspects but encountered challenges, particularly in simulation outcomes, where it showed higher Von Mises stress and resultant displacement.

Considering the overall assessment, Design Concept 1 (Eagle Claw) emerges as the preferred choice. It not only demonstrated competitive tensile strength but also exhibited the highest flexural strength, indicating robustness under bending forces. Additionally, in simulation analysis, Design Concept 1 displayed lower Von Mises stress and resultant displacement compared to the other designs, suggesting a more structurally sound response to loading conditions. This combination of superior tensile and flexural strength, along with favorable simulation outcomes, positions Design Concept 1 as the preferred choice for applications that require a balanced performance under various loading scenarios.

4.5.1 Unveiling Eagle Claw's Strength: An In-depth FOS Analysis

Within the exploration of Eagle Claw's design lies a crucial examination of its equilibrium between strength and practical utility. This section systematically dissects the Factor of Safety (FOS) analysis, offering insights into the foundation of Eagle Claw's robustness. As we progress through safety considerations, we'll uncover the correlation between numerical precision and tangible real-world applications. This segment will perform a formal analysis of Eagle Claw's design, where the intricate dance between strength and practicality takes center stage.

Figure 50 FOS Analysis for choosen Design Concept; Eagle Claw

The analysis of Factor of Safety (FOS) plays a crucial role in assessing the strength of the Eagle Claw hook design. With an FOS of 1.3, this numerical value indicates that the hook is well-equipped to handle forces. Simply put, it means the hook can endure loads 1.3 times greater than expected, showing a significant safety margin. This extra capacity is a result of careful engineering, ensuring not only compliance with industry standards but also exceeding them. The accompanying figure visually illustrates stress distribution and safety factors throughout the hook's intricate structure. Exploring the importance of this analysis provides a better understanding of the impressive strength inherent in the Eagle Claw hook.

4.5.2 Practical Implementation: Real-world Application of Eagle Claw's Performance

The versatility of the hook design model extends across diverse applications, catering to the distinct needs of users in various scenarios. Embodying robustness and adaptability, this hook seamlessly transitions from the rugged outdoors to everyday household utility. In outdoor adventures such as camping, hiking, or mountaineering, the hook proves indispensable for securing essential items, be it lanterns, cooking utensils, or bags, ensuring a hassle-free and organized experience in the wilderness.

Within the confines of a home, the hook transforms into a household organizational ally, providing an elegant solution for hanging keys, hats, or small bags near entrances. Its non-slip surface guarantees items stay firmly in place, making it a practical addition to kitchens for organizing lightweight utensils or contributing to bathroom tidiness by managing towels and toiletries efficiently.

In industrial settings, the hook's heavy-duty design comes to the forefront, offering secure storage for tools and equipment. With a high load capacity, it aids in the systematic organization of wrenches, pliers, or safety gear in workshops, construction sites, or factory floors, streamlining access and enhancing efficiency in professional environments.

For sports enthusiasts, the hook adapts to the unique demands of organizing and storing sports gear. Whether in gyms, home workout areas, or sports facilities, it maintains a perfect balance of style and functionality. From holding gym bags and towels to facilitating the storage of sports equipment like basketballs, tennis rackets, or yoga mats, the hook design model seamlessly integrates into the world of sports, combining practicality with a sporty aesthetic.

Figure 51 Render View of Final Hook Design Model

Figure 52 Render View with enviromental scene

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this research has successfully achieved its objectives, providing a detailed evaluation of bio-inspired hook models fabricated using Fused Deposition Modeling (FDM) with bio-composite materials. The numerical outcomes from mechanical testing and simulation offer critical insights into the performance of each design concept – Eagle Claw, Elephant Trunk, and Seahorse. Eagle Claw exhibited remarkable tensile strength (4.49 MPa) and an elastic modulus of 0.10 GPa, enduring a maximum force of 561.48 N. Elephant Trunk demonstrated comparable strength, with a tensile strength of 4.50 MPa, elastic modulus of 0.01 GPa, and a maximum force tolerance of 563.18 N. Seahorse, with a distinctive profile, displayed a tensile strength of 2.35 MPa, elastic modulus of 0.01 GPa, and a maximum force tolerance of 293.64 N. In flexural testing, Eagle Claw excelled with a maximum force of 1544.78 N, flexural strength of 115.86 MPa, and elastic modulus of 0.00147 GPa. Elephant Trunk achieved a balanced approach with a maximum force of 663.71 N, flexural strength of 49.78 MPa, and elastic modulus of 0.32 GPa. Seahorse excelled in specific applications with a maximum force of 388.46 N, flexural strength of 29.13 MPa, and elastic modulus of 0.13 GPa.

Simulation results further validated mechanical testing, providing insights into Von Mises stress, yield strength, resultant displacement, and equivalent strain. These collective findings underscore the structural integrity and performance of each design concept, forming a quantitative foundation for selecting and optimizing the final hook model. The amalgamation of biomimicry principles, advanced manufacturing techniques, and innovative materials in this research not only advances the field of bio-inspired design but also contributes significantly to engineering, particularly in the domains of additive manufacturing and biomimetic applications. Moving forward, this study serves as a catalyst for future innovations, inspiring the development of advanced, environmentally conscious solutions in hook design and beyond.

5.2 Recommendations

For future advancements, Im envision this research on bio-inspired hook design models using bio-composite materials to evolve into a transformative initiative with broader applications and heightened goals. The potential of this project extends beyond its current scope, offering possibilities fordd the development of various hook types using alternative materials, steering away from conventional metallic choices. The ongoing efforts in refining bio-inspired hook design and development hold the promise of ushering in a new era in hook manufacturing.

This research lays the groundwork for a paradigm shift, aiming to redefine ordinary hooks by introducing bio-composite materials. The use of biodegradable materials not only aligns with eco-friendly principles but also addresses concerns about the environmental impact of traditional metallic hooks. Moreover, the safety aspect of bio-composite hooks, characterized by an enhanced weight-to-strength ratio, stands out as a notable improvement. These features collectively position bio-composite hooks as a safer and more sustainable alternative.

Looking ahead, the outcomes of this research study have the potential to catalyze innovation in the realm of long-standing, commonly used products. The improvements stemming from this project can transcend individual use cases, benefiting various sectors such as industries and construction. As we continue to explore and refine bio-composite hook designs, the positive impact on safety, sustainability, and overall product performance may extend to diverse applications, fostering positive change in multiple industries. This research serves as a catalyst for future innovation, inspiring the development of advanced, environmentally conscious solutions in hook design.

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