ALIGNING NEW PRODUCT DEVELOPMENT WITH REVERSE ENGINEERING METHODOLOGIES FOR HEADLAMP JIG

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Faculty of Industrial and Manufacturing Technology and Engineering

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DEDICATION

"I dedicate this thesis to my loving family, whose unwavering support and encouragement have been the foundation of my academic success. I am grateful for their belief in me and the sacrifices they have made throughout my educational journey. I also extend my heartfelt gratitude to my dedicated supervisor, whose guidance and expertise have shaped my research and intellectual growth. Additionally, I express my appreciation to my friends, research participants, and all those who have touched my life, for their contributions, friendship, and inspiration. This thesis is a testament to their impact and support, without which this achievement would not have been possible."

ABSTRACT

Reverse engineering (RE) is a critical technology, particularly in the geometrically designed and manufactured application areas, where this method is widely recognised as a crucial phase in products and systems.The rapid growth of technology and increasing demand for innovative automotive solutions have driven the need for reverse engineering in the automotive industry. This study focuses on the application of a reverse engineering process for fabricating a composite headlamp jig. In this manufacturing process, the bubble defect are found in the composite headlamp jig. The formation of bubbles in the composite headlamp jig is occur after curing process finish. Repeated exposure to the curing oven, with thermal cycling from low to hight temperature followed by rapid cooling, the formation bubbles has led to that negatively impact the headlamp curing process. The PDCA method are use to construction a new product development (NPD) model. The PDCA method, or Plan-Do-Check-Act, is a systematic problem-solving and continuous improvement method. It helps identify issues, plan solutions, implement changes, assess outcomes, and make adjustments for ongoing enhancement in various processes.

ABSTRAK

Kejuruteraan Terbalik (RE) ialah teknologi kritikal, terutamanya dalam bidang aplikasi yang direka bentuk dan dikilang secara geometri, di mana kaedah ini diiktiraf secara meluas sebagai fasa penting dalam produk dan sistem. Pertumbuhan pesat teknologi dan peningkatan permintaan untuk penyelesaian automotif yang inovatif telah mendorong keperluan untuk kejuruteraan terbalik dalam industri automotif. Kajian ini memberi tumpuan kepada aplikasi proses kejuruteraan terbalik untuk fabrikasi jig komposit lampu depan. Dalam proses pembuatan ini, kecacatan gelembung ditemui pada jig lampu depan komposit. Pembentukan buih dalam lampu depan komposit jig berlaku selepas proses pengawetan selesai. Pendedahan berulang kepada ketuhar pengawetan, dengan kitaran haba dari suhu rendah ke tinggi diikuti dengan penyejukan pantas, pembentukan buih telah membawa kepada kesan negatif kepada proses pengawetan lampu depan. Kaedah PDCA digunakan untuk membina model pembangunan produk (NPD) baharu. Kaedah PDCA, atau Plan-Do-Check-Act, ialah kaedah penyelesaian masalah yang sistematik dan penambahbaikan berterusan. Ia membantu mengenal pasti isu, merancang penyelesaian, melaksanakan perubahan, menilai hasil dan membuat pelarasan untuk peningkatan berterusan dalam pelbagai proses.

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LIST OF SYMBOLS AND ABBREVIATIONS

RE	-	Reverse Engineering
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
PDCA	-	Problem, Do, Check, Act
NPD	-	New Product Development
TQM	-	Total Quality Management
BIM	-	Building Information Modelling
PAN	-	Polyacrylonitrile
GFRP	-	Glass fiber reinforced polymers
MMCs	-	Metal matrix composites
CMCs	-	Ceramic matrix composites
PMCs	-	Polymer matrix composites

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CHAPTER 1

INTRODUCTION

1.1 Background

Engineering refers to the process of designing, producing, assembling, and maintaining items and systems. Engineering has two types: forward engineering and backward engineering. Forward engineering is the traditional way for moving from high-level abstractions and logical ideas to the actual implementation of a system. Sometimes a physical component or product exists without any technical information, such as engineering data, bills of materials, or drawings. In contrast, reverse engineering entails replicating an existing component, subassembly, or product without the use of computer models, drawings, or other supporting data (Raja, V., & Fernandes, K. J. (Eds.), 2007). Reverse engineering's main objective was to carry out the conversion of the physical model into a digital one. Reverse engineering has gained new uses outside of the engineering sector as well throughout the years. Possibilities of using reverse engineering:

- Packaging design - When addressing the packaging design, it is possible to use the exact areas and textures obtained by scanning the relevant samples.
- Product ergonomics – enables for the utilisation of data generated from digitising hand-made models and mock-ups in the final product design.
- Digital archiving - With the ability to archive tools, samples, and prototypes in digital form, significant financial resources that would otherwise be required to store these items can be saved.
- Additional production - By obtaining a digital product model, it enables the production of things that their original manufacturer no longer manufactures.

- Spare parts - It permits the manufacturing of a replacement part by scanning a damaged part in the case of a product that is no longer manufactured, no spare parts are created for it, or it is a unique component.
- Digital media, games and animations - From the concept of a designer model, reverse engineering can be utilised to create digital characters and settings for computer games, movies, and animations.
- Cultural and artistic heritage - provides for the high-resolution scanning of a number of works of art and the care of the scanned product for the needs of their restaurant or reconstruction.
- Healthcare - Reverse engineering aids in the replication of organs or bone structures.
- Orthopedic engineering - The scanned data provide extremely important data in the process of manufacturing orthopaedic devices, without which the designers would be unable to build the final product exactly tailored to the user.
- Many other uses - significant assistance in product design, CAD model updates, software analysis of genuine components using various FEM systems, rapid model creation via Rapid prototyping, fabrication of car tuning parts, and much more (Štefan, K., & Janette, B.,2022).

1.2 Problem Statement

The existing headlight production method for cars depends on steel moulds, which presents weight, cost, and design flexibility constraints. To meet the growing need for innovation, there is a pressing need to investigate replacement materials, notably composites, and execute a seamless transition from metal to composite moulds while enhancing manufacturing quality, functionality, and cost.

The formation of bubbles in the composite headlamp jig is occur after curing process finish. Repeated exposure to the curing oven, with thermal cycling from low to hight temperature followed by rapid cooling, the formation bubbles has led to that negatively impact the headlamp curing process. The presence of bubbles can cause a failure of the bond between layers of composite material and will make easy to peeled off. From the impact, the headlamp jig are cannot function as a jig. This will make it affect the headlight curing process.

The construction of a new product development (NPD) model using the PDCA method. The PDCA method, or Plan-Do-Check-Act, is a systematic problem-solving and continuous improvement method. It helps identify issues, plan solutions, implement changes, assess outcomes, and make adjustments for ongoing enhancement in various processes.

1.3 Research Objective

The main aim of this research is changing mold material from metal to composite. Specifically, the objectives are as follows:

a) To identify the mold jig of the headlamp model.

b) To use reverse engineering process to fabricate headlamp composite jig.

c) To develop the new New Product Development (NPD) model from reverse engineering the headlamp jig using PDCA method.

1.4 Scope of Research

The scope of this research are as follows:

- Employing reverse engineering to develop headlamp jigs with composite materials, material selection, precision manufacturing, and integration into production.
- To propose new product development (NPD) Chart in reversed engineering method by incorporate the PDCA methodology to identify every step of development of Headlamp jigs.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reverse engineering is a one type of the engineering. Reverse engineering also knows as backward engineering or back engineering. Reverse engineering is process disassemble or analyze in detail in order to discover concepts involved in manufacture. The process such as re-engineering, re-designing, maintenance and re-manufacturing can be involved in Reverse Engineering depending on their purpose and objective. In other research, Reverse engineering (RE) is an unconventional way of turning physical components into engineering models and concepts. These models provide significant benefits by improving the quality and efficiency of design, analysis, and production. Furthermore, the RE process demonstrates adaptability by being able to propose answers in circumstances when the traditional method does not apply (Chowdary & Jaglal, 2021).

There are a few researches about the Reverse Engineering:

- In this work, a unique tool for ultrasonic machining (USM) was conceived and built. The USM tool's CAD model was created using an existing JEDT hemispherical form cavity discovered on a zirconia workpiece. A comparison was made between the newly produced CAD model and the traditional USM tool. The results clearly demonstrated the usefulness of the RE process, particularly in the fabrication of curved part forms (Das et al. 2018).
- This study proposed a new digital construction framework that combines building information modelling (BIM) and the RE approach to improve information utilisation and reduce errors and reworks in rehabilitation

projects. Furthermore, the study used 3D laser scanning to facilitate and demonstrate the benefits of the proposed integrated method, resulting in a significant reduction in errors and rework occurrences throughout the rehabilitation process (Ding et al., 2019).

- This research focused on the application of reverse engineering approaches to a composite material part using imaging technology and machine learning. Using microstructure machine learning approaches, the goal was to precisely record both the geometry and tool path required for 3D printing. When compared to a traditional additive manufacturing (AM) model, which is often linked with issues about part precision, the technique demonstrated remarkable dimensional accuracy (Yanamandra et al.,2020).
- A novel RE model called function-oriented surface reconstruction was devised in this study, allowing for the reconstruction of not just the underlying component but also the surface function. The usefulness of this novel approach was proved by the use of a gearbox reconstruction model, which validated its effectiveness and future applications (Qie et al., 2021).
- A case study was undertaken in this study to investigate the application of RE using a handheld 3D laser scanner, with a special emphasis on parts with sophisticated geometry, such as free-form surfaces. According to the research findings, using a handheld 3D laser scanner is the best approach for accurately collecting complicated geometry. The investigation also investigated and identified dimensional flaws in the 3D CAD model, demonstrating the efficiency of the RE procedure. Furthermore, the study emphasised the potential of 3D laser scanning in the RE area. It did, however, identify substantial hurdles in constructing reliable surface reconstruction

models that can effectively handle typical point cloud concerns like noise and holes (Helle and Lemu, 2021).

- The RE method, product innovation design, and 3D printing technology were used to create a helmet in this project. The study demonstrated the effectiveness of RE's integrated strategy in lowering product development time, increasing production efficiency, and achieving customised helmet designs to improve employee comfort. The findings revealed the approach's potential to streamline the manufacturing process and optimise product outcomes (Wang et al., 2021).
- Figure 2.1 show the reverse engineering process connection with the product development cycle.
- Figure 2.2 show the basic phase in Reverse Engineering occur.
- Figure 2.3 show the flowchart of the Reverse Engineering from data acquisition until 3D printing.

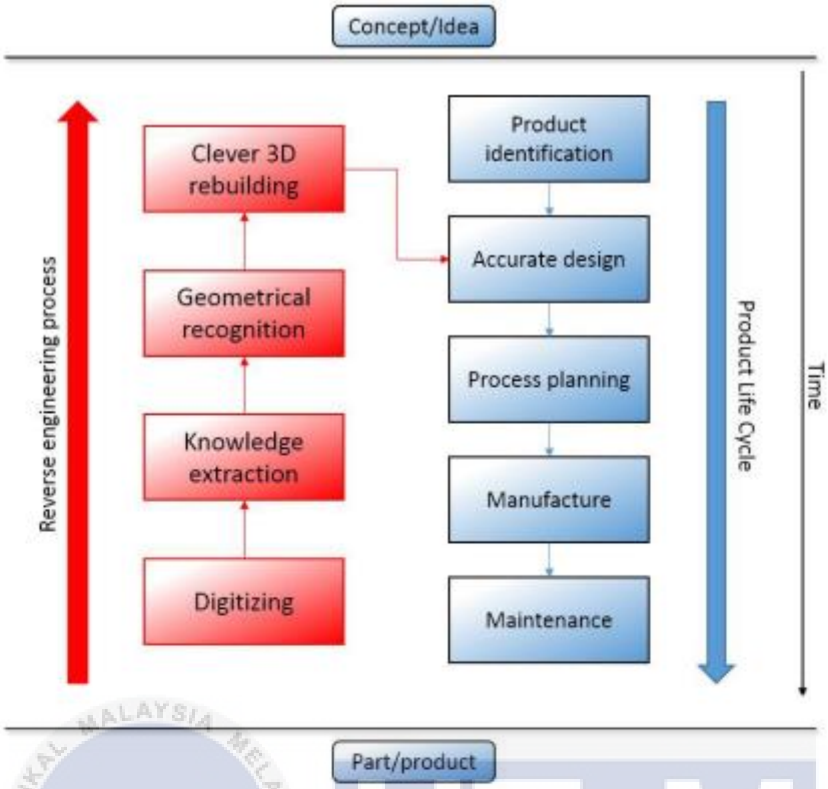

Figure 2.1: The RE process connection with the product live cycle (Ouamer-Ali et al., 2014).

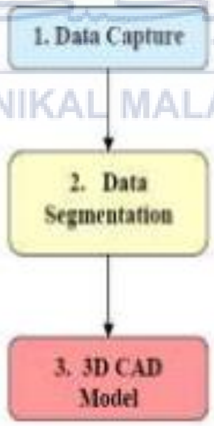

Figure 2.1: Basic Phase in Reverse Engineering(Adate & Pandhare, 2017).

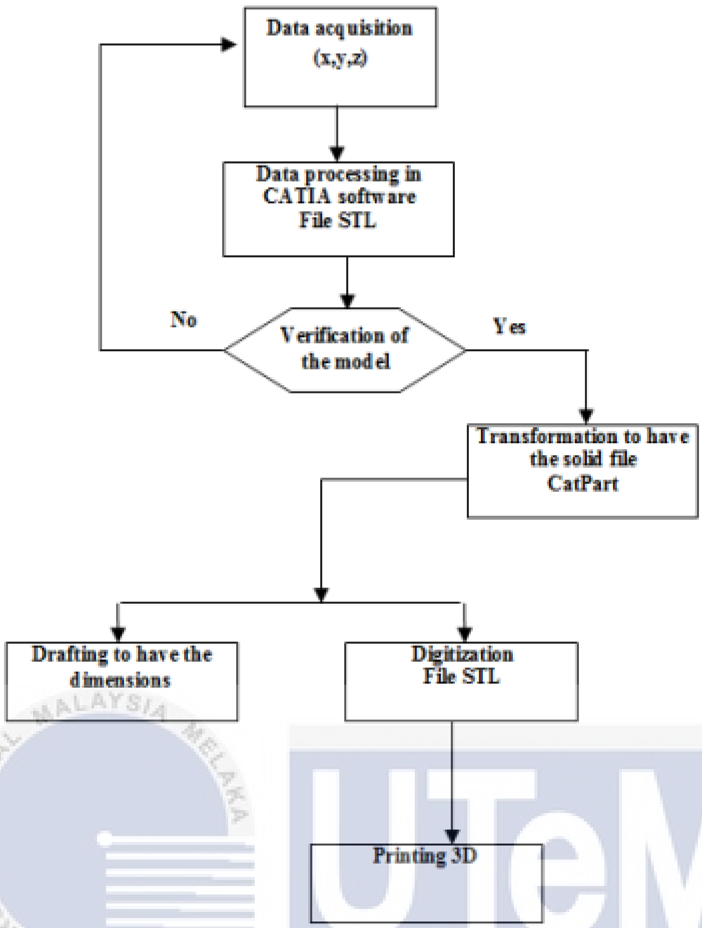

Figure 2.2: Flow Chart of the Reverse Engineering (Amroune et al., 2021).

From research, Figure 2.4 show the input and output of Reverse Engineering in a product/system. When compared to the typical manufacturing method (forward engineering), reverse engineering begins with an actual part to obtain the geometric model. Because neither forward nor reverse engineering can be totally automated, various CAD software and hardware are used to complete the process. The RE process is divided into specific actions that require the designer's talent and knowledge, such as data for valid translation and physical and virtual analytical techniques required to analyze the product and provide know-how and new ideas for production processes. The RE process entails more than just recording the geometric model (Joshi, M. M, et. al.,2021).

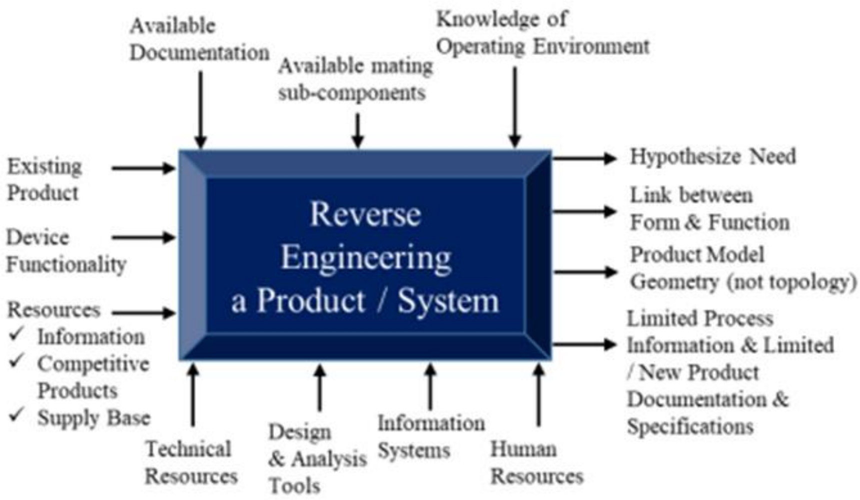

Figure 2.3: Reverse Engineering For A Product (Joshi, M. M, et. al.,2021).

2.2 Forward Engineering

Forward engineering is also known as Traditional Engineering. In manufacturing, Forward Engineering is the process of designing and developing a new product from scratch, starting with a conceptual idea and proceeding through various stages of design, prototyping, testing, and production. It was opposite with the Reverse Engineering. Table 2.1 show the basic comparison between Forward engineering and Reverse Engineering.

Table 2.1: Basic comparison between Forward engineering and Reverse Engineering

Basic for Comparison	Forward Engineering	Reverse Engineering
Basic	Development of the application with provided requirements.	The requirements are deduced from the given application.
Certainty	Always produces an application implementing the requirements.	One can yield several ideas about the requirement from an implementation.
Nature	Prescriptive	Adaptive
Needed skills	High proficiency	Low-level expertise
Time required	More	Less
Accuracy	Model must be precise and complete.	Inexact model can also provide partial information.

2.3 Function of Reverse Engineering

Reasons for using reverse engineering are listed below:

- When the original manufacturer is no longer operational, but customers require additional parts for a product.
- In instances where long-life products have faulty or non-functional parts that need replacement, and both the product and spare parts are no longer accessible in the market.
- When the original product has become obsolete, and alternatives using that technology are unavailable.
- In cases where the original design documentation (blueprints) for the product is lost or never existed.
- To generate data for repairing or producing a part lacking CAD data, or when the existing data is outdated or deleted.
- Disassembling competitors' products to understand their construction and functionality, and for inspection and quality control by comparing fabricated parts to CAD descriptions or standard items.
- When certain negative aspects of a product need to be eliminated.
- To enhance positive qualities of a product through prolonged use.
- Examining both positive and negative aspects of competitors' products.
- Seeking new ways to enhance the performance and functionality of products.
- Creating 3-D data from a model or sculpture for use in game and film animation.
- Generating 3-D data from a person, model, or sculpture for making, scaling, or duplicating artwork.

- Measurement and documentation for architectural and construction projects.
- Fitting clothing or footwear to individuals and determining population anthropometry.
- Generating data for dental or surgical prostheses, tissue-created body parts, or surgical (Raja, V., & Fernandes, K. J. (Eds.), 2007).

2.4 Classification of data acquisition methods

Physical considerations limit data acquisition systems to acquiring data from a limited section of an object's surface. As a result, many scans are required to thoroughly measure a portion. See the section on merging several views for further information. Depending on the 3D acquisition methodology and technology used, RE approaches are classed as touch or non-contact (usually optical). Figure 2.5 show the Classification of data acquisition methods.

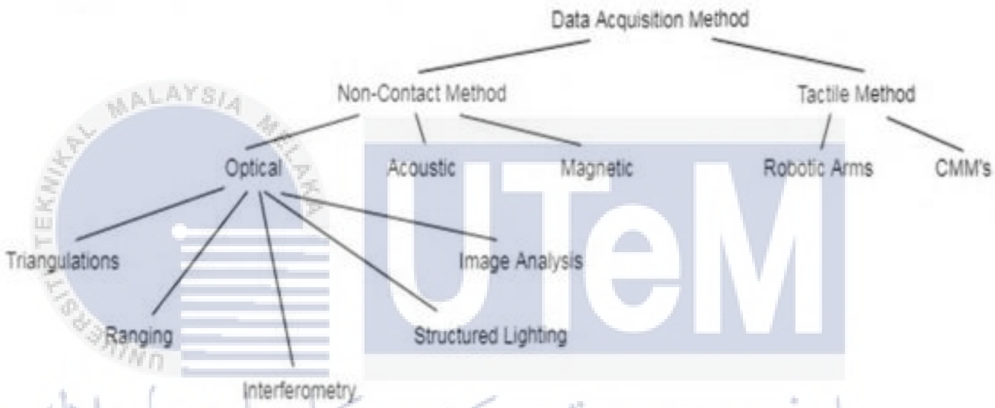

Figure 2.4: Classification of data acquisition methods (Channa, G. S. ,2021).

2.4.1 Non-Contact Methods

In the non-contact method, the scanned part is seen from the orthogonal direction to create the image. It generates 2D projections and sends the data set to the CAD/CAM program, where it is further digitized using contact probe guiding and the surface is formed since orthogonal perspectives are taken into account while making the component. It entails edge detection and vectorization techniques. A theoretical description of the edges may be communicated to the CAD system after the initial phase identifies probable edge locations and the subsequent procedure fits the suitable curve from these boundaries. There are 3 method under non-contact method it is Optical System, Acoustic System, and Magnetic System (Channa, G. S. ,2021).

a) Optical System

The optical approach includes creating a light source with a flash tube, which is then collected, focussed, and directed to produce a concentrated strip of light on the component. A concave reflective mirror that uses the upward light beam, optical condensers, sharp edge band slits, adjustment mechanisms, and a pair of projection lenses all help to ease this operation. To attain the best results with this data collecting approach, many setups are required (Channa, G. S. ,2021).

b) Acoustic System

This design offers a significant benefit compared to other existing designs by functioning as a system synchronizer, ensuring a continuous signal is provided to each sub-system. When all sub-systems are prepared and the image is focused, it commands other systems and captures pictures to gather data sets. This is achieved by detecting reflected sound waves from surfaces. The distance is subsequently calculated using the known speed of sound from the source to the surface (Channa, G. S. ,2021).

c) Magnetic System

This approach includes measuring the source's magnetic field strength. Magnetic touch probes are used in this data collecting method to determine the orientation and location of the probe inside the field. Furthermore, a trigger is built into the systems to let the user capture precise data points near the place of interest (Channa, G. S. ,2021).

2.4.2 Tactile Method

The tactile approach includes collecting data with the use of a probe. A force-sensitive tactile sensor and proprietary software are used to create a 3D model that assists in the merging of data sets acquired from various angles. To determine surface area, the computational model of visual attention makes use of geometrical information. The tactile approach requires local contact with the component, therefore moving and setting the sensor might be time-consuming (Channa, G. S. ,2021).

a) Robotic arm

This method uses a probe attached to a robotic arm. The probe moves across the surface of the component, gathering data points together with their x, y, and z coordinates. Maintaining contact with the surface during the scanning process is critical for accurate findings. This tactile approach is often used for scanning components (Channa, G. S. ,2021).

b) CMM

The coordinate measuring machine is a preprogrammed machine that follows the course of a surface while gathering exact data sets free of noise. This method is more exact than the robotic arm, which uses a probe to determine the coordinates of the data collection (Channa, G. S. ,2021).

2.5 Additive Manufacturing

Additive Manufacturing (AM) is a production process that constructs physical objects by sequentially building layers of material. It involves the exact positioning, joining, and modification of volumetric pieces to produce the finished item. The material used, the manufacturing equipment's specifications (such as build platform precision and nozzle geometry), and the process variables (such as nozzle temperature, light or beam intensity, and traverse speed) all have an impact on the shape, size, and strength of the bond between the layers. Along with these elements, the tool paths and projection patterns (digital masks) used throughout the manufacturing process also affect the part's overall shape (Thompson, et. al, 2016). Based on the type of material used as a feedstock, the energy source used, and the build volume supported, AM systems can be categorised. Understanding the capabilities and restrictions of various AM methods is aided by these classifications.

The manufacturing systems can be divided into three broad categories, which are briefly described as follows:

- Powder bed systems

A common build volume for powder bed systems used in additive manufacturing is less than 0.03 m3. These technologies involve uniformly distributing a coating of powder across the work surface to create a component. To create the required form for that layer, the energy source, which is frequently programmable, selectively sinters or fuses the powder particles together. Then, until the entire 3D component is created, this process is repeated, with each layer of powder being swept across the work bed and selectively sintered.

The capacity of powder bed methods to create highly detailed features and complicated interior pathways is one of their significant benefits. These systems enable complicated shapes and fine features that may be difficult to fabricate using conventional approaches by selectively fusing the powder particles. Powder bed methods also provide superior dimensional control, enabling accurate reproduction of the specified part dimensions

- Powder feed systems

In additive manufacturing, greater build volumes often reaching 1.2 m3 are frequently provided by powder feed systems. Compared to powder bed units, this technology is more simply scalable in terms of construction volume. The powder material is transported through a nozzle in powder feed systems and deposited onto the build surface. The powder is then melted using a laser to create the appropriate shape and a sizable 3D component. The two most common arrangements for powder feed systems are. In the initial arrangement, the workpiece stays still while the deposition head moves to apply the laser melting and deposit the powder. In the second arrangement, the workpiece is moved while the deposition head stays still to apply powder deposition and laser treatment.

One of the key advantages of powder feed systems is their ability to produce larger build volume components. The increased build volume allows for the production of larger and more complex parts compared to powder bed systems. This makes powder feed systems suitable for applications that require the manufacturing of sizable components (Channa, G. S. 2021).

- Wire feed system

Wire feed systems in Additive Manufacturing use wire as the material source. They can work with electron beams, laser beams, or plasma arcs. The process involves depositing layers of material to gradually build a solid 3D structure. These systems are good for fast production rates but may require additional machining for smoother surfaces and higher accuracy (Channa, G. S. 2021).

- Fused Deposition Modeling

This system is called Fused Filament Fabrication (FFF) and belongs to the extrusion family. It works by melting the material to a semi-liquid state and then depositing it layer by layer along a specific path defined by slicer software. The material used is usually in the form of a thin filament and is commonly thermoplastic polymers (Channa, G. S. 2021).

2.5.1 The basics of additive manufacturing

i) The process

The basic concept of additive manufacturing is to produce 3D geometries by material addition, often layer by layer. The following qualities are shared by additive manufacturing processes: a computer to store data, process geometric information, and advise the user, and a deposition material that is treated by points, lines, or regions to make parts. The ISO/ASTM 52900 standard defines additive manufacturing as "the process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive and formative manufacturing methodologies." Additive manufacturing can produce complicated geometries with little postprocessing and nearly no material waste (Pérez et al., 2020).

ii) Main process categories

Figure 2.6 illustrates the classification of additive manufacturing into seven process categories according to the ISO/ASTM 52900 standard: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat polymerization (Pérez et al., 2020).

Among the frequently utilized technologies are fused deposition modeling (FDM), laminated object manufacturing (LOM), stereolithography (SLA), selective laser melting (SLM), and selective laser sintering (SLS) (Jin L, et al.,2018)

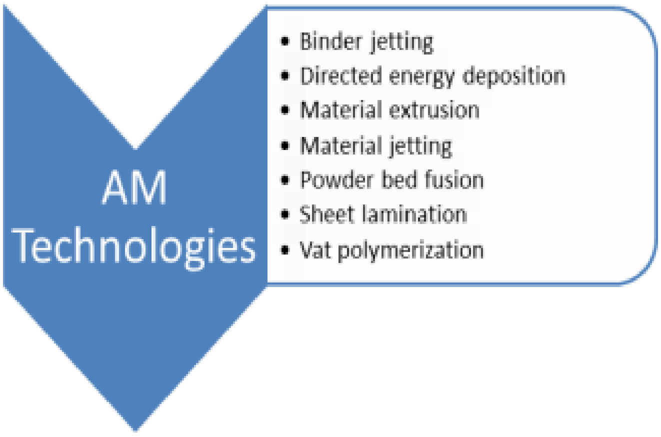

Figure 2.5: Additive manufacturing process categories based on ISO/ASTM 52900 standard(Pérez et al., 2020).

iii) Materials

The material used can have a direct impact on the shape, dimensions, durability, and cost of a printed object, limiting its potential applications. The number and types of materials that may be used in additive manufacturing are currently limited, but there are high hopes for the next generation of 3D printers, which must have enhanced processing methods to allow manufacture with a wider range of materials. In general, materials are classified into three types: liquids, solids, and powders. Ceramics, composites, metals, and polymers are among the materials included in each of these three groups (Pérez et al., 2020). Appropriate materials for the procedure should be chosen based on the additive manufacturing process that will be used (Chua CK et al., 2017).

iv) 3D scanner

A 3D scanner captures a real object's three-dimensional structure and converts the scan data into a digital format that may be used in design, development, analysis, and production processes. The final digital CAD file may be exported in a variety of formats, including Standard Triangulate Language (STL), which allows for the construction of prototypes via 3D printing. The combination of 3D scanning and 3D printing technology enables significant customisation, allowing people all over the world to scan objects and get personalised 3D printed duplicates. This convergence eliminates the need to use traditional plaster casting procedures to create item archetypes. Some applications go beyond basic object scanning and allow the reproduction of virtual industrial settings, such as plant scans for floor plan visualisation. The blue light 3D scanner, which is distinguished by exact measurements and high-speed detailed resolution, works as a non-contact technology, removing the need for programming abilities while scanning. This scanner uses blue light to illuminate the item, and a camera gathers the reflected surface data for scanning purposes (Javaid et al., 2021).

2.6 Composite

The term "composite material" refers to a material that is made by combining two or more different materials together to create a new and useful material. These materials cannot dissolve or mix with each other on a large scale. In a composite material, there are two main parts: the reinforcing phase and the matrix phase. The reinforcing phase can be in the form of particles, fibers, or flakes, and it is harder than the matrix phase. The matrix phase is usually flexible and continuous (Patel et al., 2020). In other research, Technological breakthroughs have increased the demand for specific materials with unique qualities not found in metal alloys, ceramics, or polymer blends. Composite materials were created to meet these demands. They are constructed from two or more separate and immiscible materials with distinct mechanical, physical, and/or chemical properties. Composites are heterogeneous and multiphase designed materials in which the matrix is responsible for binding the reinforcement together and transferring loads between the fibers, while the reinforcement contributes stiffness to the structure and prevents fracture propagation (David Müzel et al., 2020). Next research said Composite materials/structures are becoming more efficient, cost-effective, and have improved specified characteristics (strength and modulus). There is a growing need for their use in load-bearing constructions in aircraft, wind turbines, transportation, medical equipment, and other industries. Manufacturing composite materials is a complex operation requiring numerous procedures in which various types of errors may arise inside a composite product, raising substantial safety problems in service (Wang et al., 2020).

2.6.1 Classification of Composites

Composites can be categorized based on their matrix phase into:

- Metal matrix composites (MMCs),
- Ceramic matrix composites (CMCs),
- Polymer matrix composites (PMCs).

Classifications based on the type of reinforcement:

- Particulate Composites (composed of particles),
- Fibrous Composites (composed of fibers),
- Laminate Composites (composed of laminates) (Patel et al., 2020).

2.6.2 Why We Use Composite Materials in Place of Conventional Metals?

The composite materials provide several benefits over traditional materials. Notable among these advantages is its lightweight design, which improves fuel efficiency and overall performance. The composites have high specific stiffness and strength, which contribute to structural integrity while keeping a good weight-to-strength ratio. Because of their adaptability, they can be easily molded into complicated shapes and decorations. In addition, composites are easily bondable, making assembly procedures more efficient. These materials have good damping qualities, which reduce vibrations and improve overall performance. Composites provide thermal stability as well as electrical insulation due to their low electrical conductivity and expansion. Their excellent fatigue resistance assures long-term durability under repeated load. Furthermore, composites enable part consolidation, resulting in lower total system costs and more efficient production. (Patel et al., 2020).

2.6.3 Hand layup and spray techniques

Hand layup is a method of laying down single layers or manually laying 'plies' into a type of reinforcement known as 'prepreg'. Thousands of fibres are pre-impregnated with resin by pouring, brushing, spraying, and rolling with a paint roller before being bundled into tows with fibre arrangements that are either single unidirectional ply or weaved together. Hand manipulated ply into form. Then it must be tightly adhered to the mould surface or prior layer, with no air pockets between plies. Fibre that has been woven, knitted, stitched, or bonded and has been saturated with resin by hand. The roller was used to press the resin deep into the fibre, and the fibre was left to cure under ordinary atmospheric conditions. (Zulkepli et al., 2019). Figure 2.7 shows illustrations of hand layup processes.

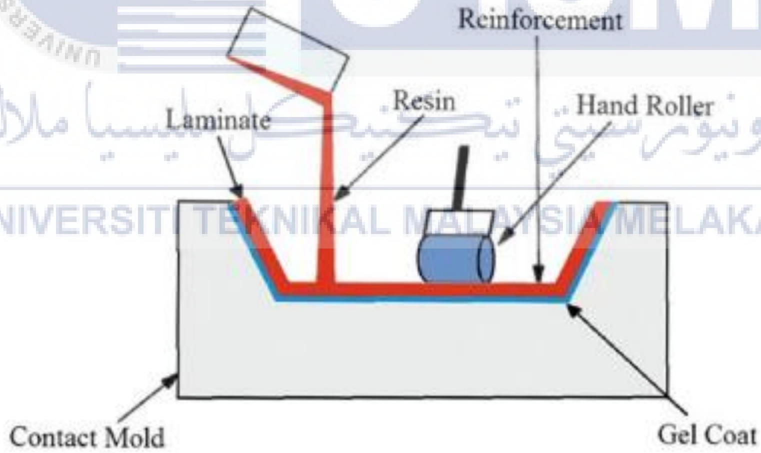

Figure 2.6: Hand Layup (Chawla, K. K., 2019).

A pneumatic gun sprays chopped fibre and resins into the mould simultaneously during the spray layup process. Bath tub construction using glass reinforced unsaturated polyster layer with separated resin (acrylic resin) by spray lay up process. The specimens must be moulded to obtain a flat surface before being laminated by spray layup to obtain multiple colours and thermal stability. This thermal stability temperature must be constant with the resin during the spray lay up procedure. (Zulkepli et al., 2019). Figure 2.8 show illustrations of spray techniques.

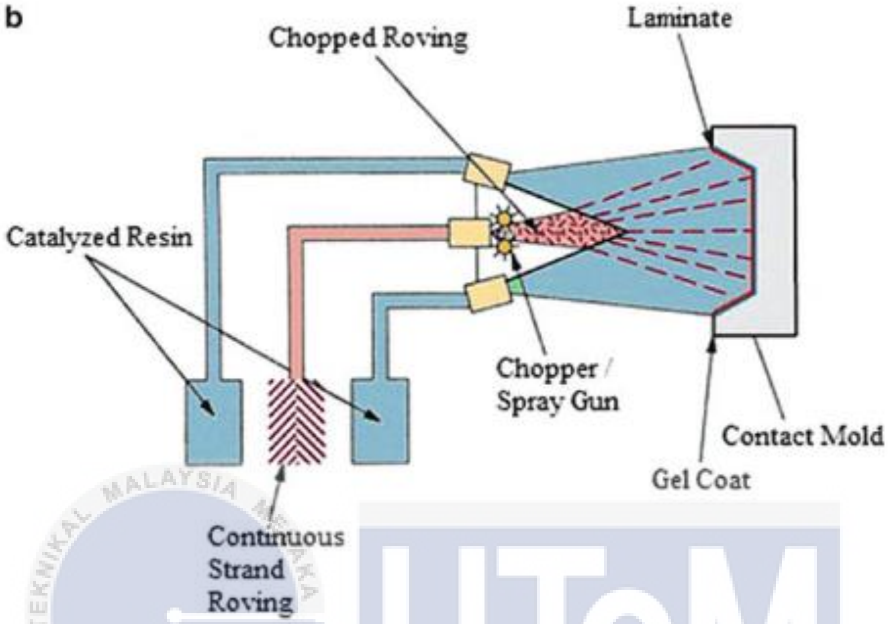

Figure 2.7: Spray technique (Chawla, K. K. 2019).

As shown in the figures 2.9, the method of adding pre-preg carbon fibre to a mould is divided into numerous stages. Initially, a particular number of layers are inserted at a zero angle, aligning the carbon fibre weave with the mould, and carbon fibre threads, visible as black dots, are interspersed between each layer. The mould is vacuum packed in the second stage, as indicated by the green line encircling the mould and carbon fibre layers in the second figure, to ensure that no air is evacuated between the layers by pressing them against the mould. Another set of layers is added in the third step, often at a 90-degree angle (sometimes a 45-degree angle), to improve structural integrity in all directions. The procedure then returns to stage 2, where the vacuum packing is repeated and, if necessary, more layers are added at a zero angle. After reaching the proper thickness, the mould is vacuum-bagged and placed in an oven to cure (Maksimainen, 2012).

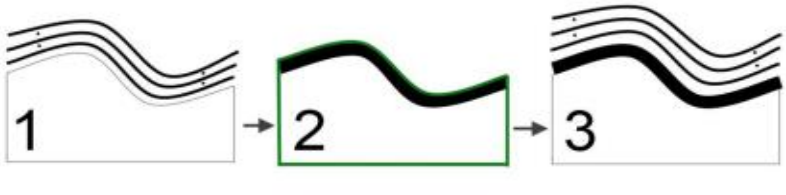

Figure 2.8 : The fabric layers are laid on the mould (Maksimainen, 2012).

2.6.4 Types of Reinforcing Materials

The reinforcing phase in composite materials can be composed of various materials, such as fibers (e.g., carbon fiber, glass fiber, aramid fiber), particles, or flakes. These reinforcing materials contribute to the strength, stiffness, and other desired properties of the composite.

- Carbon Fibers (CF)

Carbon fibers, often known as graphite fibers, can be made from three different materials: polyacrylonitrile (PAN), rayon, and petroleum pitch. Figure 2.10 show the Carbon fiber. The manufacturer's formulation determines the precise makeup of each precursor. PAN-based fibers have outstanding mechanical characteristics, making them ideal for structural applications. Pitch-based fibers, on the other hand, have greater modulus values and better thermal expansion characteristics. The main advantages of carbon fibers are their light weight, high strength-to-weight ratio, and stiffness. However, they are more expensive and brittle compared to other types of fibers (Patel et al., 2020).

Figure 2.9: Carbon Fiber (Kazmi et al., 2020)

- Glass Fibers (GF)

Alumina, lime, and borosilicate are the main ingredients in the composition used to create glass fiber. Figure 2.11 show the example of glass fiber. Glass fibers of many sorts, including E-glass, C-glass, R-glass, S-glass, and T-glass, are offered commercially. With a 90% market share, E-glass leads the pack of them. E-glass has strong mechanical qualities, a low susceptibility to moisture, and high electrical insulating capabilities. It is frequently combined with a polyester matrix. While S-glass fibers have stronger strength, heat resistance, and modulus, C-glass fibers exhibit superior resistance to chemical assault. Glass fiber reinforced polymers (GFRP) have good electrical and thermal insulation qualities as well as transparency. They do, however, weigh more than carbon fibers and call for careful design consideration when rigidity is a key element (Patel et al., 2020).

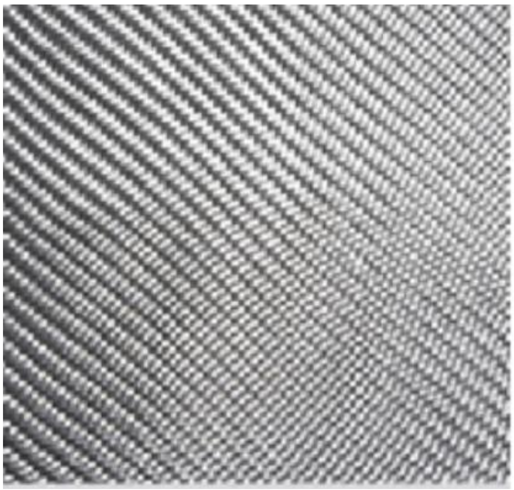

Figure 2.10: Glass Fiber (Kazmi et al., 2020)

2.6.5 Matrix materials

The matrix phase in composite materials acts as a binder and holds the reinforcing materials together. It can be a polymer (e.g., epoxy, polyester, vinyl ester), metal (e.g., aluminum, titanium), or ceramic (e.g., silicon carbide). The matrix material provides protection, transfer of loads, and compatibility with the reinforcing phase.

2.6.6 Epoxy resin and hardener

Resin is a synthetic organic polymer that can be solid or liquid and is used to make a variety of goods such as plastics, adhesives, and varnish. Hardener, on the other hand, is a curing component required for epoxy resin applications to achieve the appropriate characteristics. The use of a hardener is critical since it improves the mechanical and chemical characteristics of epoxy resins. Without the addition of a hardener, epoxy resins fall short of the outstanding properties required for their intended applications. (Murugu Nachippan et al., 2021).

2.6.7 Types of Molds

i) Male mold

Male molds or positive molds are terms for projecting molds. Seeing as how Figure 2.12's depiction of the composite's layering on the mold. The mold's surface roughness affects how smoothly the composite side that is in touch with the mold is finished. Although creating a male mold is simple, the composite portion expands unintentionally while curing. As a result, their coefficient of thermal expansion needs to be carefully considered to avoid the mold harming the composite component during the curing process. To let the item to develop into the correct proportions, the molds are therefore made somewhat smaller (Roy & Dickens, 2017).

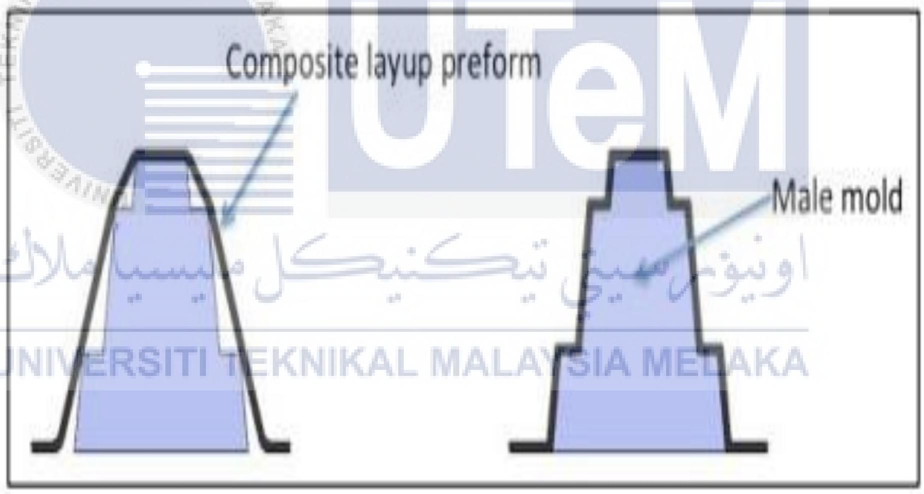

Figure 2.11: An example of a male mold(Roy & Dickens, 2017).

ii) Female Mold

As seen in Figure 2.13, a female mold or a negative mold has voids, making it difficult to lay down fiber layers in all of the edges and corners. Due to interaction with the mold, the completed composite part's outside surface will be smoother and more accurate. To avoid the mold separating from the component during curing owing to expansion, the CTE of the mold, if it is constructed of metal, must be considered. Female molds are more expensive to produce, but because the item produced in one has a smooth exterior, they need less post-processing time (Roy & Dickens, 2017).

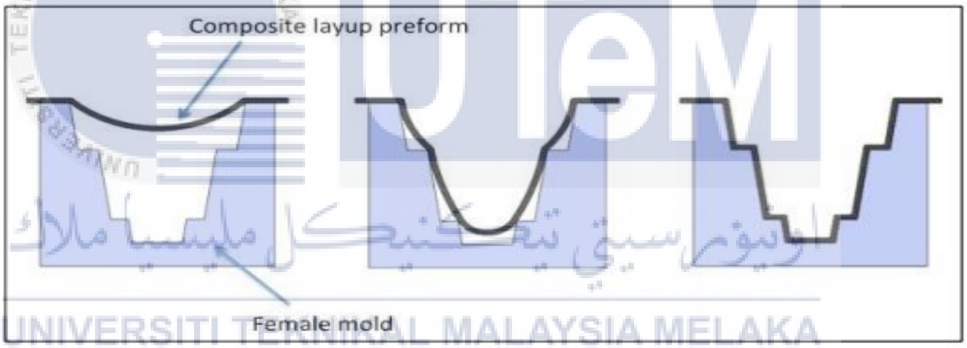

Figure 2.12: An example of a female mold(Roy & Dickens, 2017).

2.6.8 Headlamp

The headlamps are a signature feature of vehicles. They are thin and angular, with a sharp LED strip that runs across the top. The headlamps are also integrated with the grille, which gives the front end of the car a sleek and modern look. The headlamp is manufactured in a state-of-the-art facility that is equipped with the latest manufacturing technologies. The facility is staffed by highly skilled and experienced engineers and technicians. The headlamp is a critical safety feature of any vehicle. It is responsible for providing the driver with adequate visibility in all driving conditions. The headlamp is designed to meet or exceed all applicable safety standards.

Here are some of the benefits of the headlamp design:

- High-quality LED light source
- Precision-machined housing
- Complex lens system
- State-of-the-art control unit
- Rigorous testing process
- High standards of quality and performance
- Critical safety feature
- Meets or exceeds all applicable safety standards

2.7 New Product Development (NPD)

New product development is an important management technique that helps organizations succeed in the face of competitive market challenges. Clark and Fujimoto (1991) define product development as the translation of data and market possibilities into meaningful knowledge for the purpose of creating commercial goods. The product development process model can be general or personalized to the organization, allowing experts to approach product development from a consistent viewpoint. This encourages communication and integration among experts and related industries, emphasizing the need to use quality tools in the product creation process. (Francisco et al., 2023).

In other research, Product Development refers to a set of design methods that convert generally specified market demands or concepts into precise information for the construction of satisfying and manufacturable goods. This is accomplished by applying scientific, technological, and artistic concepts while taking into account the requirements of following life cycle operations. (Pant & Chavan, 2018).

2.8 Total Quality Management (TQM)

Total Quality Management (TQM) is a comprehensive management technique that aims to improve a company's overall effectiveness, efficiency, adaptability, and competitiveness. It is a governance system that promotes continual improvement, guaranteeing that the organization not only meets but exceeds consumer expectations, thereby contributing to its long-term success (Talha, 2004). In Other research, TQM is the general term for a variety of strategies used by an organization to provide benefits that support increased profitability and better resource quality. TQM is defined as a systematic approach that prioritizes customer satisfaction while addressing management changes. These improvements are made in several areas, including the organization's goods and services. Pursuing continuous improvement to consistently achieve high-performance outcomes is the main goal of Total Quality Management (Arifin et al., 2022).

To stimulate innovative thinking, problem-solving, and continuous improvement in performance and customer satisfaction, Total Quality Management (TQM) methods must be implemented. These tools include techniques and frameworks for helping people better express company issues and solutions. TQM tools worth mentioning include Quality Function Deployment (QFD), Six Sigma, the Plan-Do-Check-Act (PDCA) cycle, and the European Foundation for Quality Management Excellence Model (Alfalah, 2017).

Total Quality Management (TQM) benefits may be divided into two categories: improving the manufacturing process to reduce mistakes and strengthening the company's competitive position in the market. Organizations that are adept at adopting TQM stand to benefit in a variety of ways. These benefits include enhanced product quality, decreased manufacturing mistakes, and a persistent commitment to continuous improvement in management, eventually improving the company's overall quality (Arifin et al., 2022). Figure 2.15 show the Principles of TQM.

Figure 2.13: TQM principles (Othman et al., 2020).

2.9 PDCA

The PDCA (Plan, Do, Check and Act) cycle is a well-known strategy for quality improvement. The PDCA approach, which originated in the 1930s, grew in popularity during a time when items were viewed as freely accessible, commonplace, and experiencing growing market rivalry. This resulted in a movement towards the use of quality management principles. William Edward Deming, the methodology's originator, launched it in the 1950s, establishing it as one of the world's most known improvement approaches. PDCA was first used to regulate product quality, particularly in Japanese firms where it became known as the Deming Cycle, but it has now grown into a recognized tool for improving organizational processes. The cycle is marked by its emphasis on continual development, to raise the quality of both products and processes (Raodah et al., 2020).

The first stage of the Deming cycle, "Plan" (P) is related with recognizing the prospect of change, namely its improvement and scheduling. It establishes improvement targets and develops an action plan to achieve them. It is required to identify the problem, analyze the reasons of the problem, provide solutions, and create an implementation strategy. Every activity during this stage can be assisted by tools and methodologies such as the Ishikawa diagram, the Pareto-Lorenz diagram, process mapping, or brainstorming (Jagusiak-Kocik, 2017).

The next stage, "Do" (D) is the implementation of the prepared plan to make changes in the process in the company (to increase productivity or quality and remove the sources of issues). It occurs with the management's cooperation and understanding. Tools such as an action strategy, benchmarking, flow diagram, or check sheet might be employed during this phase (Jagusiak-Kocik, 2017).

The "Check" (C) stage is to determine if solutions offered to a corporation produced appropriate outcomes. The measurements are obtained and compared to the values integrated into the design. Control sheets, control charts, and process capacity indices can all be of assistance. If the solution implementation is proven to be suitable, it is followed by four PDCA cycle steps - "Act" (A), if not, one must return to step one - "Plan" (P) (this is a vital region in the process of improvement) (Jagusiak-Kocik, 2017).

The last stage of the PDCA cycle, marked as "Act" (A), is executing the tested and confirmed successful solutions. Once certified, these solutions become the accepted standard, opening the path for standardization and continued monitoring of operations. This stage is especially important when using tools like process mapping, action plans, or benchmarking (Jagusiak-Kocik, 2017).

The PDCA cycle is represented as a circle because it generates an infinite loop. Improvement is considered as a continual process with no clear finish, and contentment with the existing state is not the ultimate aim (Jagusiak-Kocik, 2017). Figure 2.16 show the PDCA cycle.

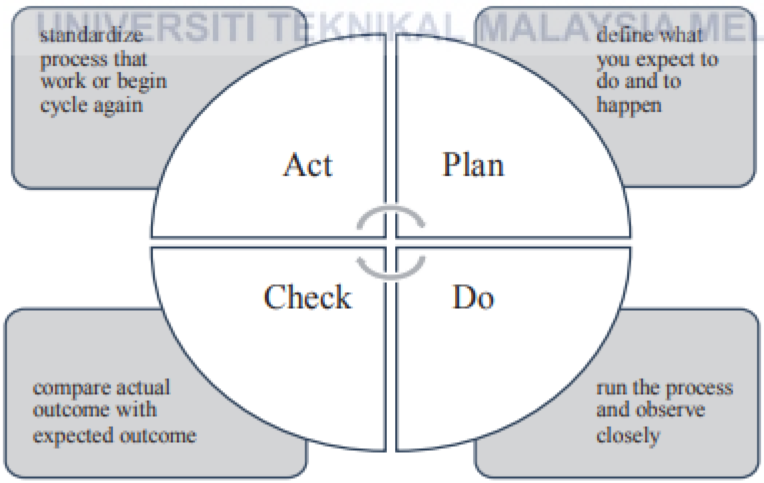

Figure 2.14: The Plan-Do-Check-Act (PDCA) cycle (Chojnacka-Komorowska & Kochaniec, 2019).

CHAPTER 3

METODOLOGY

3.1 Introduction

The process of designing new goods requires a methodical strategy that assures precision, efficiency, and the achievement of predefined goals. This chapter explores into the critical planning and processes required for the smooth execution of the project centered on the reverse engineering of headlamp jigs. The primary purpose is to ensure the effective completion of all project objectives.

This methodology chapter serves as a detailed reference, outlining the complexities of the New Product Development (NPD) process, which is especially adapted for the reverse engineering of headlight jigs. The PDCA approach was chosen as the foundation for this project. An established management method, PDCA, provides a structured approach to continuous improvement, ensuring that each phase of the project matches with the overall goals.

In this chapter, we will look at the PDCA method's methodical planning, execution, assessment, and refining procedures. This technique is intended to not only analyze the delicate aspects of reverse engineering but also to create a road map for attaining excellence in product development while adhering to the highest standards and objectives established for the headlamp jig project.

The first step, "Plan," entails recognizing difficulties or opportunities, establishing defined objectives, and developing a thorough plan that takes risk into account. The next "Do" phase is the execution stage, during which the intended activities are carried out and data is gathered. The "Check" step next involves analyzing and comparing actual outcomes to the specified goals, detecting any mistakes, and rating the efficacy of the activities done. Finally, in the "Act" step, informed decisions are made based on the evaluation. If the objectives are satisfied, the process is standardized; if improvements are required, tweaks and changes are made to improve the entire process.

3.2 Proposed Methodology

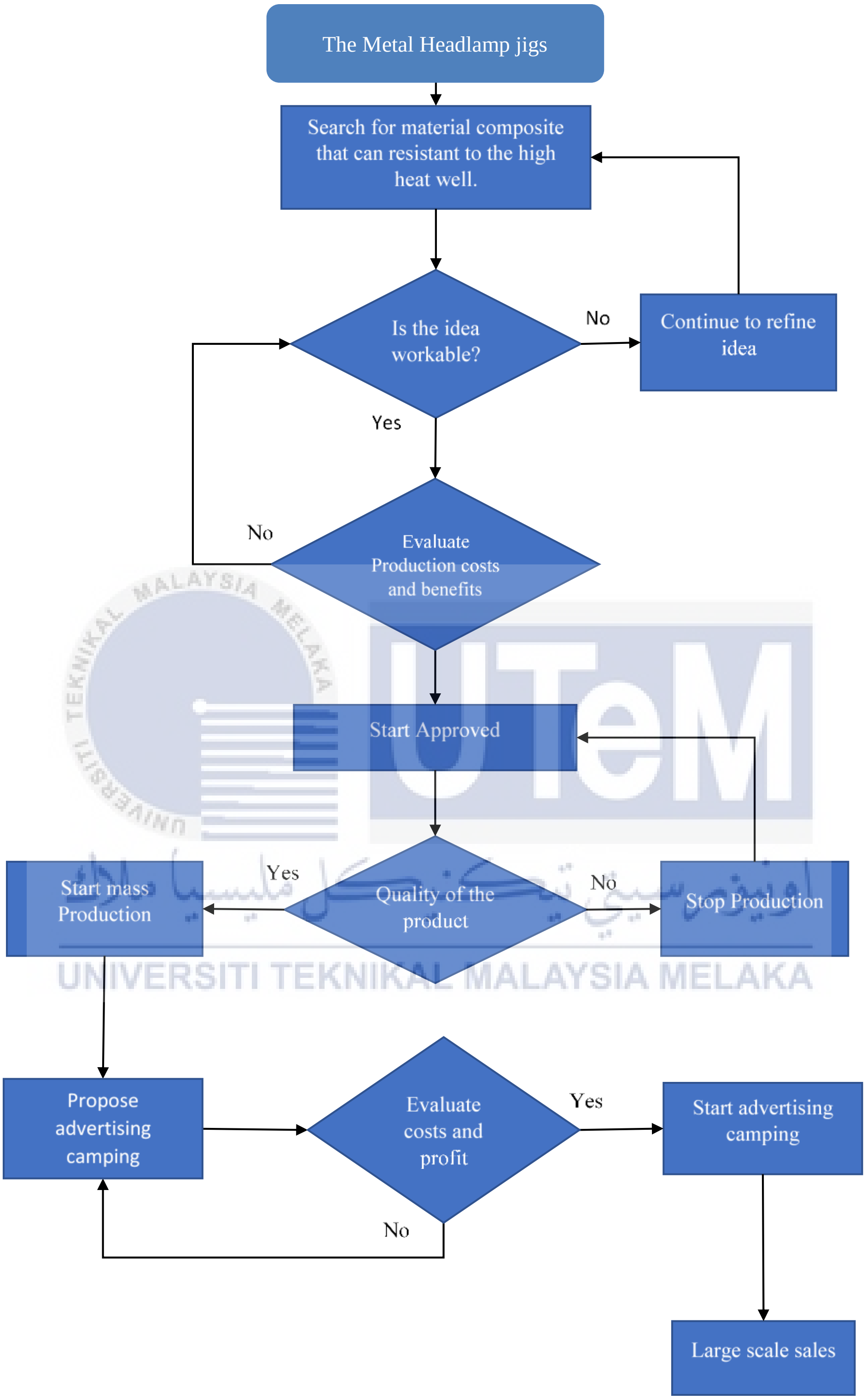

Figure 3.1: NPD Flowchart

3.3 Headlamp

Figure 3.2 and 3.3 show the top and sid view of the headlamp.

Figure 3.2: Top view

Figure 3.3: Side view

3.4 PLAN Stage

The focus of the Plan phase of the PDCA cycle is on overcoming the problem of bubbles in headlamp jigs caused by repeated exposure to the curing oven. The issue occurs from thermal cycling of the metal jig at temperatures ranging from 120°C to 500°C, followed by quick cooling to room temperature, providing an issue of decrease in mechanical properties. This is because the presence of bubbles can cause a failure of the bond between layers of composite material and will make easy to peeled off. This will make it affect the headlight curing process.

The Plan phase involves strong evaluations of the replacement process, potential problems, and the formulation of clear targets to drive the succeeding Do, Check, and Act stages in the continuous improvement cycle.

3.5 DO Stage

Figure 3.4 show the Process manufacturing for the headlamp jig.

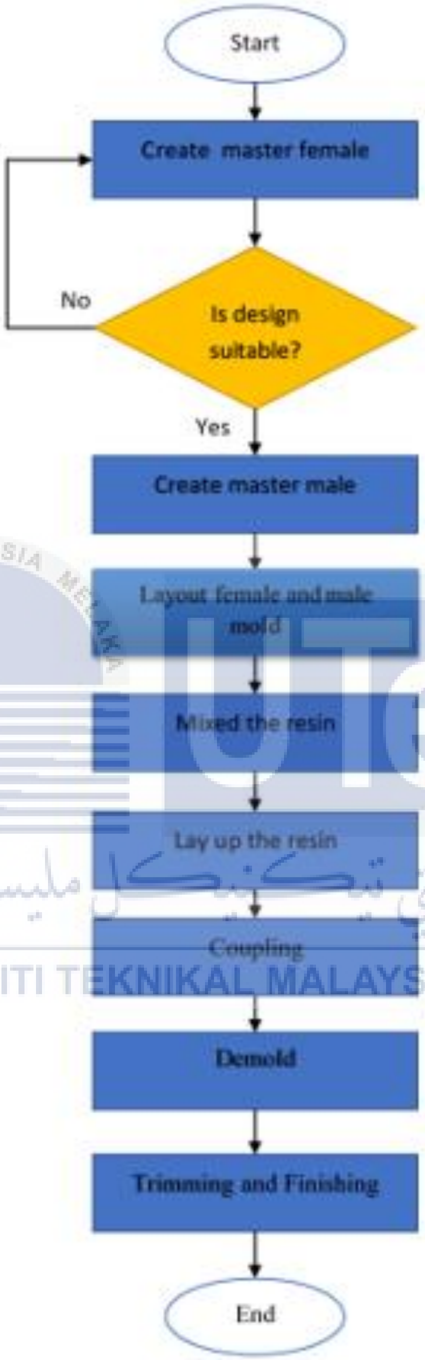

Figure 3.4: Headlamp jig manufacturing process.

3.5.1 Creating Master Female

The production of the master female component was a crucial phase in the headlamp lens mold-making process. This involves creating an inside platform on the lens's surface using materials such as foam, cardboard, or plywood. Figure 3.5 show the Master Female Platform for base. The next stage is to establish an outside platform on the surface of the inner lens. In this stage, the jig position on the headlamp is determined. Afterward, the platform is filled with a filler patty to achieve the desired shape, and it is left to dry for an extended period, ensuring the completion of the shaping process. When the surface is dry, it is gently polished to create a flawless finish. This master female component serves as the foundation for producing molds, and it is critical in the production process for replicating uniform, high-quality headlight lenses. Figure 3.6 show the example of Master female for another model.

Figure 3.5: Master Female Platform for base

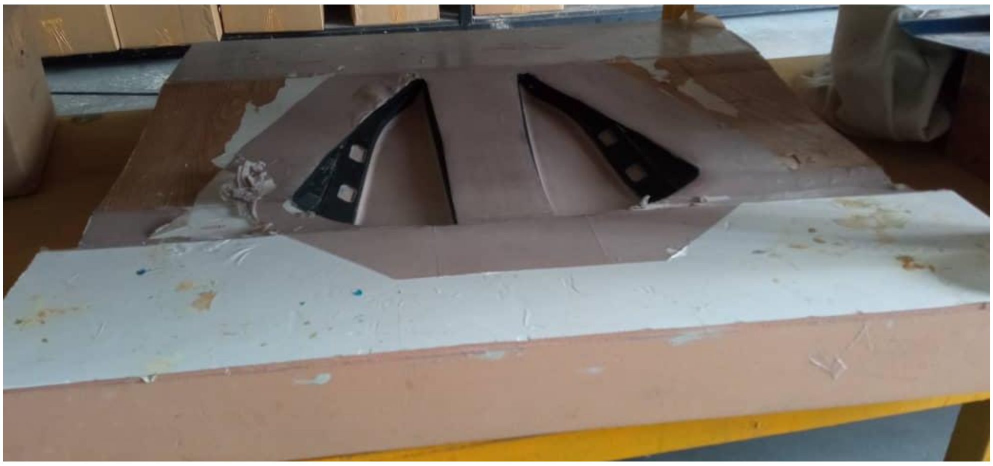

Figure 3.6: Master Female

3.5.2 Creating Master Male

When a female master is completed and the engineer has approved the design, a male master will be built. The first stage in the laminating process is to combine 100 grams of resin with 30 grams of hardener. The female parent is then covered with mixed resin and hardener. The mold will then harden overnight after 8 layers of fiberglass and carbon fiber are applied alternately. Once the mold has hardened, the secondary laminating process will begin. After the resin hardens, the mold will be demolished and cut to completion. Figure 3.7 show the Master male for headlamp model.

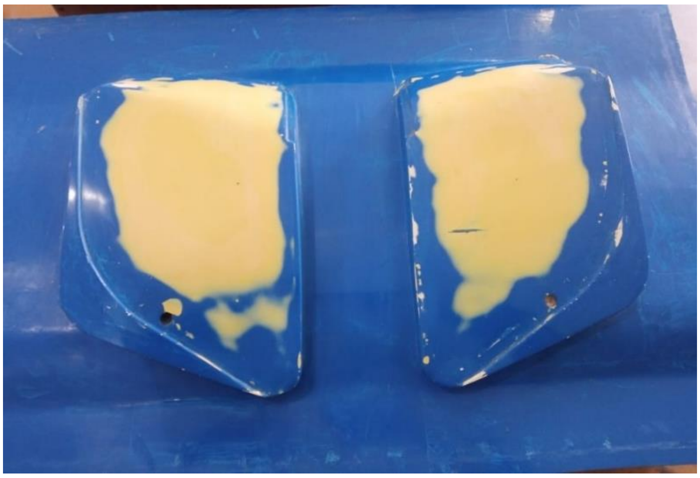

Figure 3.7: Master Male

3.5.3 Layout Female and male mold

Figure 3.8 show the female mold of the model. The female mold are created from the master male. Before layup the mix resin, the wax must be applied to the master male surface. The wax will help to avoid the mold from sticking to the master female and smooth demolding process. Then, 100 grams of resin with 30 grams of hardener are mixed for laminating process. At the start, applied 3 layers of wax on the master male surface and 8 layers of fiber glass and fiber carbon are placed alternately. After the mold is cured, the mold will be demolded, and finishing will be done. Same process will be done for the mold male using mold of master male.

Figure 3.8: Female mold

3.5.4 Mixed the resin

For the chemical mixture, 100 grams of epoxies 2051 are used with 20 grams of hardener. The color of the resin is dark blue, and the hardener has a light amber color. The density of the resin is 1.25-1.35 at temperature 25 degree Celsius, while for the hardener is 1.05-1.09 at temperature 25 degrees Celsius. Figure 3.9 and figure 3.10 show thw hardener and resin. To make the mixture thicker for stronger bond is by mixing the resin, hardener and fumed silica. Fume silica is a powder material that helps to thicken the mixture. Figure 3.11 show the mixing of the hardner, resin and fume silica. When the mixture concentrates high, it can make the composite materials more pliable and easier to handle during the layup process. This can simplify the molding and shaping of the composite structure, allowing for more intricate designs.

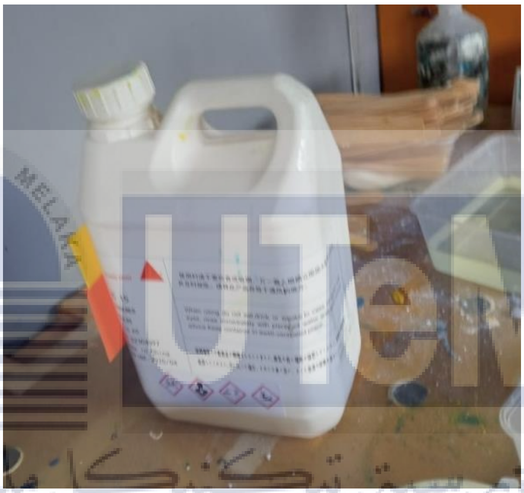

Figure 3.9: Hardener

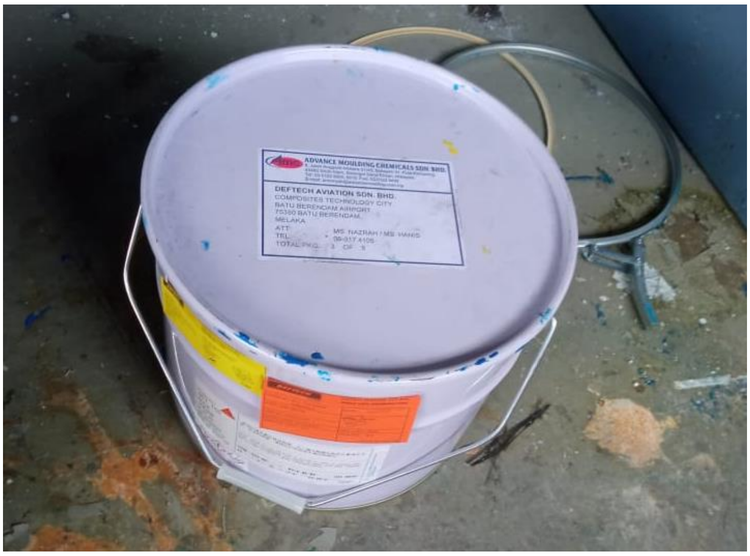

Figure 3.10: Resin

Figure 3.11: Mixing hardener, resin, fume silica and paint

3.5.5 Layup

In the layup process, the male and female mold will be applied 3 layers wax to make sure the jigs can be demolded smoothly. Then, fiber glass and fiber carbon will be cut with suitable size based on the size product. Make sure the size of fiber glass and fiber carbon are have excess or bigger than product. Figure 3.12 show the first layer with different colour to differentiate left and right. After that, the chemical that have been mixed are place on top of the wax surface, then, two layers of fiber carbon are placed on top of both male and female mold. The fiber carbon on the female mold needs to fit nicely, do not have many extra surfaces to make sure the mold doesn’t break. After that, 2 layers of fiber glass were placed on top of the fiber carbon and lastly two more fiber carbon are placed on top of the fiber glass. The layup must be smothered with the resin mixture and all layers need to apply the resin mixture to make sure the fiber carbon and fiber glass stick together. Before continuing with coupling process, the final layers need to be layered with thick resin that has been mixed with fumed silica.

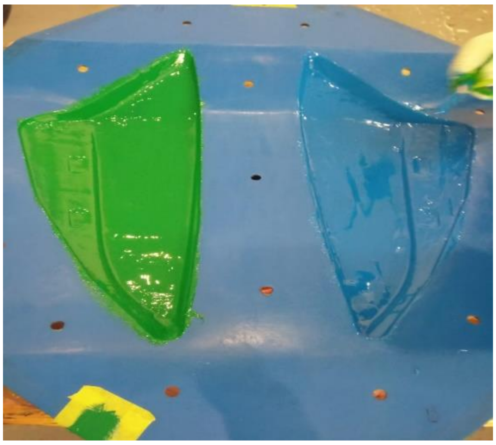

Figure 3.12: First layer lay up process

3.5.6 Coupling

Coupling process is a process where the female and male mold are stick together using screw and nut method. This process needs to be done as soon as the final layers are placed to avoid the resin from drying. After the mold is close tightly, the curing process will be overnight. Figure 3.13 show how coupling process are occured.

Figure 3.13: Coupling Process

3.5.7 Demold, Trimming and Finishing

In the demolding process, the cured composite jigs are demolded after left overnight. The spanner and drill are used to unscrewing the mold and carefully detaching the mold from the jigs. Figure 3.14 show the process of the demold .This process can be done by using a scraper. Diamond edge cutting tools are used in the trimming process to avoid any burr defects. To make sure all the jigs have smooth surfaces, the sanding process will be done at the finishing stage. Then, to ensure that the fiber does not come out of the edge, edge seals will be placed for safety purposes. The cleaning process for the surface female and male mold from excess resin to make sure the mold are ready for the next product. Figure 3.15 and 3.16 show the example headlamp jig before and after trimming process.

Figure 3.14: Demold Process

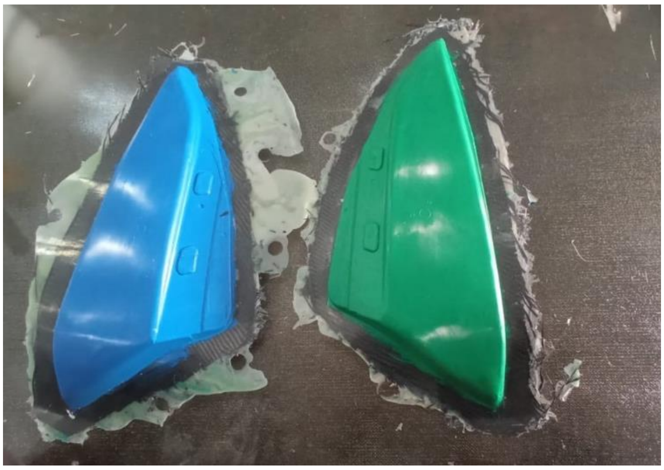

Figure 3.15: Headlamp jig before Trimming process

Figure 3.16: Headlamp jig after Trimming process

3.6 CHECK Stage

In the "Check" phase of the PDCA cycle, we use a simple and effective method known as "Go/No-Go." Consider it a decision-making light for the success of our plan. When we examine the results of our actions, we look for two indicators. The "Go" signal implies that everything is in line with our initial aims and expectations - it's a green light to go. In this situation, we go to the "Act" step, where we make our effective practices permanent and incorporate lessons learnt. If, on the other hand, we run into problems or deviate from our plan (the "No-Go" signal), it's the equivalent of a red light.

The "Go/No-Go" technique helps us navigate the complicated aspects of our processes by providing a clear decision point. It is a dynamic tool that encourages us to either celebrate our triumphs and continue doing what works, or to readjust our plans for continual improvement. This ease of use guarantees that our organization takes a systematic and progressive approach to quality improvement.

3.7 ACT Stage

The "Act" phase of the PDCA cycle in the context of resolving defects in composite materials entails focused and confined modifications inside the production process. we can efficiently control and minimize defects by concentrating on particular variables like as resin-fiber mixing, curing temperatures, or layup techniques, leading to the overall enhancement of composite material quality.

Simultaneously, the deployment of a new flowchart for improvement ideas becomes a tangible representation of the refined manufacturing process. This flowchart serves as a visual reference, explaining optimized methods and quality checkpoints for methodically recognizing and fixing faults. Through standardized and improved manufacturing methods, the combination of controlled improvement activities and the implementation of a new flowchart guarantees that defect-related difficulties are not only handled but also prevented. In this regard, the "Act" phase emphasizes the commitment to ongoing development in the creation of defect-free composite materials.

3.8 Summary

This methodology follows the Plan-Do-Check-Act (PDCA) cycle and includes many important steps. During the Plan phase, the emphasis is on fixing the issue of bubbles in headlamp jigs caused by exposing the metal jig to temperature fluctuations during curing. Creating master female and male components, setting out female and male molds, mixing the resin, layup, coupling, demolding, trimming, and finishing are all part of the Do phase. The Check phase involves evaluating the outcomes using the "Go/No-Go" technique, while the Act phase focuses on implementing targeted changes to manage and minimize defects in composite materials. The system emphasizes continuous improvement and fault avoidance throughout the manufacturing process, offering a comprehensive solution to the deformation problem.

CHAPTER 4

RESULT & DISCUSSION

4.1 Introduction

This chapter describes how to analysis the data collected of the composite jig for headlamp to achieve each of the objectives in order to solve issues the defect. This is accomplished by first identifying the issues that headlamp jig facing, which then helps identify the defect. Employee observation, employee interviews, and related information about the product were used to collect data. After that, a number of data collection steps are needed to determine the defect. After the data are gathered and verified to meet expectations, it will be analyzed to propose the improvements.

4.2 Detail of Headlamp Jig

Figure 4.1 show the dimension of the headlamp jig drawing. Figure 4.2 and Figure 4.3 show the front and bottom view of headlamp jig.

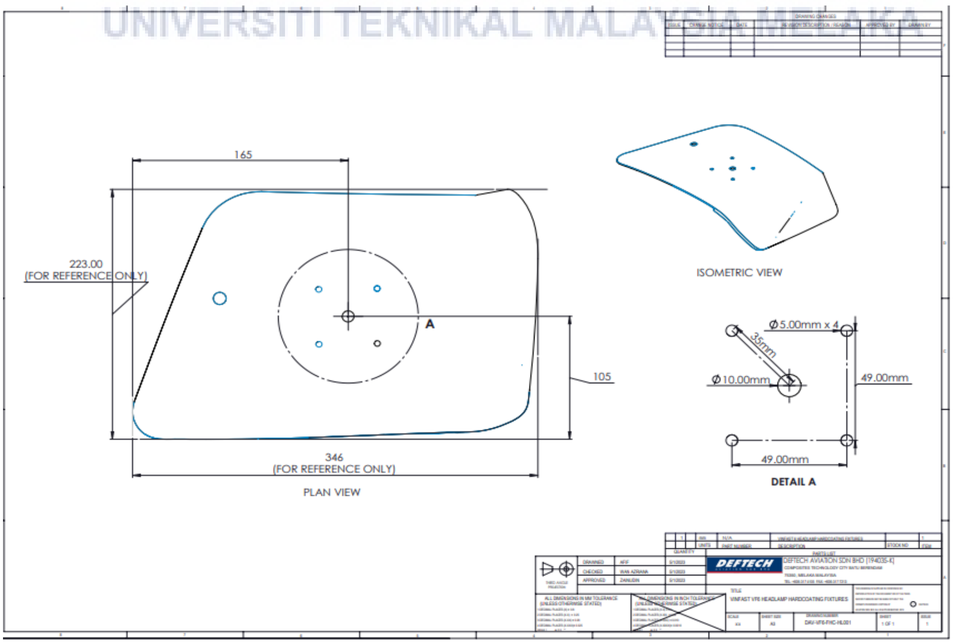

Figure 4.1: Dimension of the headlamp jig drawing


Figure 4.2: Front view of headlamp jig


Figure 4.3: Bottom view of headlamp jig

4.3 Application of “Check” In PDCA

4.3.1 Data Table

Table 4.1: Data defect collection of composite headlamp jig.

Sample	Visual Inspection	Position defect	Picture	Result
1	No defect	-	NA	Go
2	Bubble defect	Top surface of bottom view		No Go
3	No defect	-	NA	Go
4	No defect	-	NA	Go
5	No defect	-	NA	Go
6	No defect	-	NA	Go

7	No defect	-	NA	Go
8	Bubble defect	Edge of jig		No Go
9	No defect	-	NA	Go
10	Bubble defect	Edge part		No Go

4.3.2 Data analysis

During the worker interviews, information on 40 headlamp jig products was collected. The workers identified an important issue in production as "bubbles" in the composite material. These bubbles in the headlamp jig provide considerable issues because they damage the structural integrity and performance of the finished product. Out of 40 headlamp jigs, 15 of the headlamp jigs have a bubble defect. Based on the Table 4.1, from 10 sample jig that undergo inspection there are 3 defect of bubble that detect from visual inspection.

The observed consequence of the defect is an increased susceptibility of the composite jig to easy peeling off and breaking into two pieces. The observed result of the defect is the composite jig's increased sensitivity to simple peeling off and splitting into two parts. This indicates the existence of bubbles reduces the adhesiveness and overall strength of the composite material, making it more at risk for failure. The workers' perspectives on the defect's influence give useful information regarding the practical consequences of bubble-related difficulties in headlight jig manufacture.

Addressing and reducing bubble formation throughout the production process is critical not only for the overall quality of the headlight jigs but also for their operational stability. Further analysis and corrective actions should be undertaken to optimize the composite production process and remove or reduce the incidence of bubbles, hence assuring the end product's integrity and durability.

4.4 Factor Defect

The development of bubbles in composite materials can be related to a variety of factors observed throughout the production process. The resin used in the composite material is important since some resins have greater viscosities and are exposed to trapping air during mixing. Inadequate resin and hardener mixing, as well as poor additive dispersion, can cause air bubbles to become trapped in the mixture.

Vacuum bagging, a popular method for removing air and compacting layers, can be hampered by poor sealing or leaks, causing air to become trapped in the composite. The curing phase is important in composite production, and factors such as temperature variations, uneven curing, and gas outgassing can all contribute to bubble formation. Temperature variations, whether fast or unequal, play an important part in this process. Such variations can result in uneven curing, with some parts of the composite curing at different rates. The variation in curing might cause air to become trapped, resulting in the production of bubbles. Another effect is the release of gases during the curing reaction. Certain composite materials produce gases during the curing process. If these gases are not allowed to escape, they may become trapped within the material, resulting in bubble formation.

4.5 Propose Improvement (Application of "Act" in PDCA)

4.5.1 Composite materials

To avoid bubble problems, the quality of composite materials is important. It is critical to store, handle, and mix resin and reinforcement according to manufacturer specifications. During the curing process, any pollutants or impurities in the materials might lead to bubble formation. Consequently, the preparation of neat and accurate materials is important.

4.5.2 Mixing and degassing techniques

It is vital to use proper mixing and degassing techniques. A uniform mix is ensured by following the prescribed processes for mixing resin and hardener. Vacuum degassing is an important process in removing air bubbles from the mixed resin before application. This procedure aids in the removal of possible sources of trapped air, which might result in bubble formation during curing.

4.5.3 Rolling or Tapping

The rolling or tapping stage in composite production is an important process that focuses on removing air bubbles from resin-saturated reinforcing components, guaranteeing excellent consolidation and adhesion inside the composite structure. Air bubbles may become entrapped inside the composite matrix after the resin has been applied to the layers of fibers or textiles during the layup process. If not handled, these bubbles could damage the structural integrity and mechanical qualities of the final product.

The rolling technique involves the application of pressure across the composite surface using a roller. This process promotes consistent resin dispersion and assists in air pocket elimination, resulting in a more robust and defect-free finished product. Taping, on the other hand, is gently tapping the composite surface with a tool, usually a mallet or a specifically designed device. This tapping movement helps to eliminate any leftover air bubbles and increases layer adherence.

4.5.4 Bagging Process

Vacuum bagging is an advanced method used in composite production to improve curing and avoid the creation of bubbles, cavities, or faults inside the composite structure. After the composite materials have been put up and saturated with resin, the procedure begins. When sealed over the composite layup or mold, the airtight bag provides a controlled atmosphere suitable for multiple important functions.

First, the vacuum effectively removes extra resin, leaving behind a carefully regulated resin content. This prevents the development of excess resin, which would otherwise result in the production of unwanted bubbles. Second, vacuum bagging provides proper layer consolidation by applying consistent pressure to the whole composite surface. This pressure reduces the possibility of cavities or gaps between layers, resulting in a more structurally sound and consistent composite construction. Furthermore, the vacuum helps in the evacuation of trapped air inside the resin matrix, which is critical for preventing void formation and ensuring that the composite material is strong and defect-free. The result is a well-pressed and consolidated composite component with consistent pressure application, lowering the possibility of voids significantly.

4.5.5 Controlling the curing conditions

Controlling the curing conditions plays an important role in composite fabrication. Maintaining proper temperature and humidity levels during the curing process is important in preventing the rapid release of gases, which might otherwise lead to bubble formation. It is recommended to use a gradual curing method, which allows trapped air to escape gradually without causing bubbles. This controlled curing procedure provides greatly to the overall integrity and quality of the composite material.

4.5.6 Use resin gel coat

When dealing with minor defects or bubbles on the outside surface of a composite, using a resin gel coat is an efficient option. Gel coatings are particularly prepared to improve surface quality and are often placed before the primary resin layer. The gel coat acts as a protective layer, filling in tiny flaws and defects to provide a smooth and defect-free surface. This early application ensures that the finished composite retains a polished appearance while adding a layer that improves both aesthetics and overall durability. The gel coat is an important part of the finishing process, helping to create high-quality composites with a visually pleasing and structurally durable beyond the surface.

4.6 Propose New Manufacturing Process Flowchart

Figure 4.4 show the new flowchart for manufacturing after make the improvement.

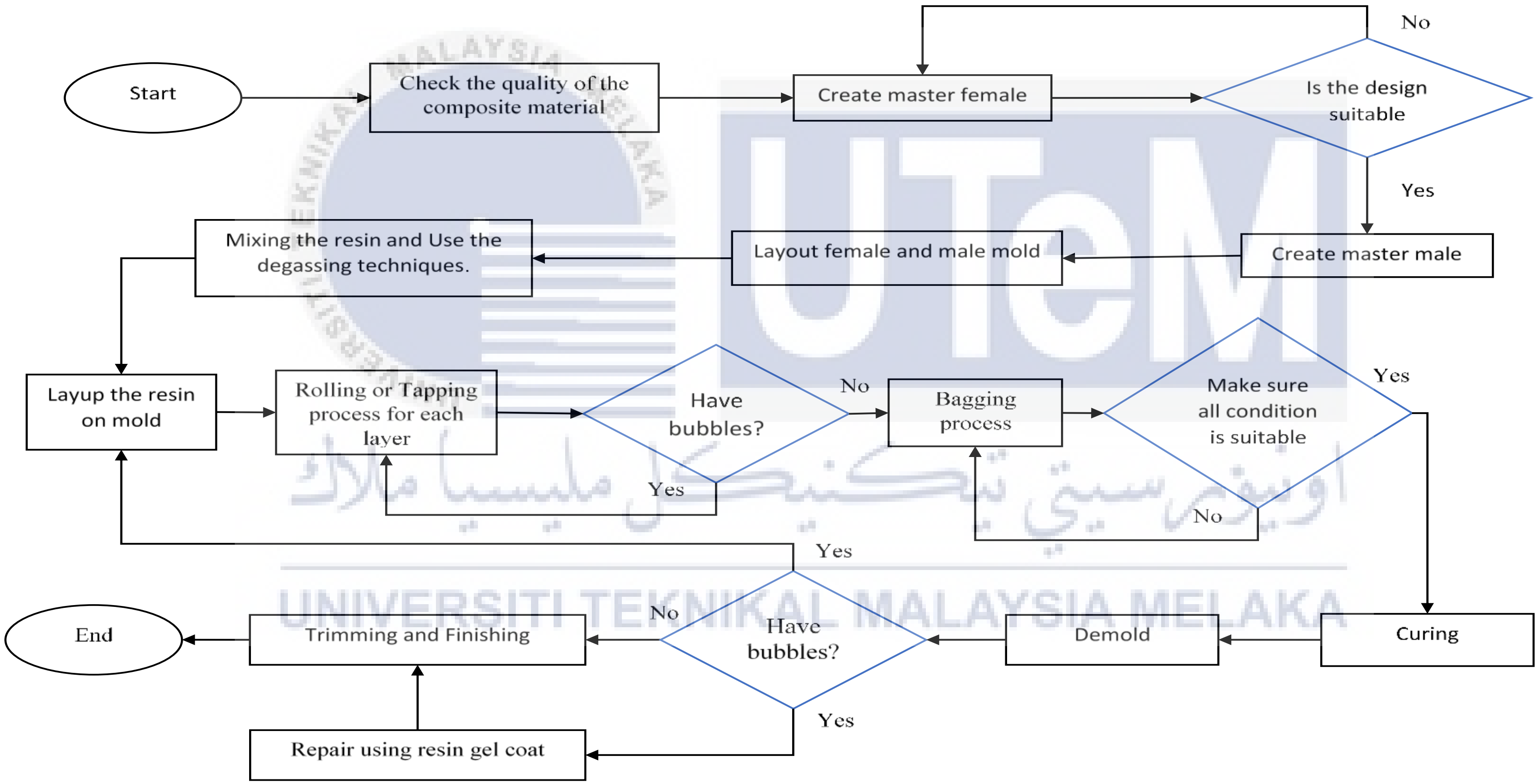

Figure 4.4: New Flowchart for Manufacturing Process

4.7 Summary

During the Check phase of the PDCA cycle for headlamp jig manufacturing, an assessment based on worker interviews and defect data collection discovered a serious problem with 15 out of 40 headlight jigs having bubbles. These bubbles not only damage structural integrity, but they also make the composite jig more prone to peeling off and fracturing into two parts. The observed outcomes highlight the importance of addressing and decreasing bubble formation during the manufacturing process to maintain overall product quality and operational stability. This phase is an important point for identifying inequality between intended targets and actual outcomes, offering significant insights for future improvements.

In response to the observed problems, the Act phase of the PDCA cycle suggests a series of solutions to optimize headlamp jig manufacturing. The recommendations involve ensuring the quality of composite materials, using suitable mixing and degassing procedures, adopting effective rolling or tapping operations, optimizing vacuum bagging, managing curing conditions, and adding resin gel coatings. These recommended activities attempt to address particular aspects that contribute to bubble formation, improve the production process, and reduce faults. The Act phase is a proactive method to iteratively refining manufacturing operations, encouraging continuous improvement and aligning the process with the necessary quality requirements for headlight jigs.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In conclusion, this study aimed to find out what the mold jig for the headlamp model looks like and to create a headlamp composite jig using a reverse engineering process. By achieving these goals, the research helps us better understand how the mold jig works in making headlamps and introduces a new way of using reverse engineering to make a composite jig. This could lead to better ways of making headlamps, making the process more efficient and improving the quality of the final product. The Plan-Do-Check-Act (PDCA) cycle has proven to be an effective technique for addressing and minimizing the issues connected with the headlamp jig production process. The Plan phase focused on replacing the metal jig with a composite material to solve heat cycling-induced deformation. The Do phase consisted of several stages, such as generating master components, creating molds, resin mixing, layup, coupling, demolding, trimming, and finishing. The Check step involves analyzing outcomes using the "Go/No-Go" approach, which revealed a severe problem with bubbles in 15 out of 40 headlight jigs. The Act phase responded proactively, recommending specific adjustments to improve the production process and reduce errors in composite materials.

The PDCA cycle served as a systematic approach to continuous improvement, providing complete answers to the deformation problem while emphasizing fault avoidance throughout the manufacturing process. The goals of changing the mold material to composite were realized effectively. The composite headlamp jig was fabricated utilizing reverse engineering procedures, and a new product development (NPD) model was created using the PDCA approach. The new method not only improved the overall quality, functionality, and cost-efficiency of the headlamp manufacturing process, but it also demonstrated the usefulness of the PDCA cycle in providing successful outcomes and fulfilling research objectives.

5.2 Contribution

The PDCA (Plan-Do-Check-Act) cycle is important in the composite manufacturing sector since it helps in problem solving and promotes continuous development. During the planning stage, companies may discover and brainstorm solutions to problems such as avoiding bubbles in composite materials during curing. The execution phase (Do) entails carrying out these plans, whilst the Check phase evaluates results and finds flaws. The true power is in the Act phase, which enables businesses to implement proactive adjustments based on what they've learned. The benefits to the sector are clear. PDCA emphasizes a proactive approach to problem-solving, resulting in higher product quality. It creates a culture of continuous improvement, allowing businesses to perfect their processes over time. PDCA allows firms to optimize multiple production steps, making operations more efficient and cost-effective.

5.3 Improvement for Future Research

Future research in composite manufacturing should focus on better materials with improved characteristics and sustainable alternatives. Manufacturing processes may be optimized using automation and smart technology to increase efficiency and minimize production time. Developing improved inspection and testing procedures, such as non-destructive testing, can help improve product reliability. Furthermore, knowing the long-term behavior of composite materials under various situations is critical for predicting lifetime and maintenance needs.

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APPENDICES

APPENDIX 1: Gantt Chat for PSM 1

NO	Project Activities	Plan vs Actual	March		April				May					June			
		Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	PSM BRIEFING	Plan															
		Actual															
2	Chapter 2: Literature Review	Plan															
		Actual															
3	PSM: Workshop	Plan															
		Actual															
4	Chapter 1: Introduction	Plan															
		Actual															
5	Chapter 3: Methodology	Plan						MID-TERM BREAK									
		Actual															
6	Checking and make corection	Plan															
		Actual															
7	Slide Presentation	Plan															
		Actual															
8	Final Improvement	Plan															
		Actual															
9	Report Submission	Plan															
		Actual															
10	Final Presentation	Plan															
		Actual															

Plan	
Actual	

APPENDIX 2: Gantt Chat for PSM 2

NO	Project Activities	Plan vs Actual	October					November				December					January			
		Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	PSM 2 BRIEFING	Plan								MID-TERM BREAK								STUDY WEEK	FINAL EXAM	
		Actual																		
2	Chapter 4 Results & Discussion	Plan																		
		Actual																		
3	Chapter 5 Conclusion	Plan																		
		Actual																		
4	Check and make Improvement	Plan																		
		Actual																		
6	Final Improvement	Plan																		
		Actual																		
7	Report Submission	Plan																		
		Actual																		
8	Final Presentation	Plan																		
		Actual																		

Plan	
Actual	

APPENDIX 3: Question for Company interview for improvement of manufacturing composite .

HOD Engineer

1. How are decisions made regarding the implementation of changes in the manufacturing process for the composition of Headlamp Jig products?

   Answer:

   i) Customer request for changes

   ii) Conduct brainstorming meeting to generate an idea, and screen the ideas.

   iii) Develop the concept and produce sample for First Article Inspection.

   iv) Production test, feedback from customer & approval

2. What specific changes have been introduced in your manufacturing system to improve productivity in composite of Headlamp Jig manufacturing?

   Answer:

   i) Materials – At the early stage, we used polyester resin to produce the sample FAI unit. However, the jig deformed after the production test. We decided to use epoxy resin instead of polyester to withstand temperatures up to 120 deg C during lacquering process.

   ii) Design – Initially, we copied the design based on sample fixture made of metal, consigned by customer. However, this concept not suitable for composite materials where deformation occurred after several series of production run. We change the design by adding a stiffener at the edge of the jig to support its strength.

HR

3. How do you ensure everyone on the team gets the right training and support for these new processes in composite manufacturing of Headlamp Jig?

   Answer:

   Conduct Training Need Analysis for all staff, perform assessment & issue proficiency card.

Engineer

4. How do you manage production continuity while implementing these manufacturing changes for Headlamp Jig?

   Answer:

   We will inform any current status/situation through Engineering Notice Form to Production line. It might need to be hold, proceed with requirement quantities or stop the production line.

5. How does the company currently assess the performance and quality of headlamp jigs, and what metrics are used to evaluate the effectiveness of the manufacturing process for Headlamp Jig?

   - Each model requires its specific design, concept and requirements. For jig, its require to have a deep fitting and thin at tip's fixtures. While for other model its require to have close fit to the lens without any gap occur during assembly and its require to have stiffener to prevent deformation occur. All these specific design, concept and requirements are to be validate by our customer by performing run-processing test on their production line. If there any problem occurs to their product quality, our jig requires to change as per required by customer. Once the designs are all fit, DAV will proceed to the manufacturing process and DAV need to maintain its design as per accepted by customer. We will inspect the bubble occur after lay-up and delamination (standard composite inspection), thickness control, trimming line and fitting test.

6. How does the company select materials for manufacturing Headlamp Jig, and what factors are considered in this selection process?
   - The materials for all models will be selected according to requirements need by customer such as temperature resistance, the complexity of fixture design, and its durability. The temperature resistance needs to be known by understanding the customer's production line process where they have curing process that is 120°C. The design complexity of the fixtures requires to have flexible carbon fabric thus require to have low gsm (gram per meter square) and its durability need to use high durable resin that is epoxy type.
7. What level of detail is considered appropriate in production specifications to ensure consistent manufacturing processes for composite of Headlamp Jig products?
   - The trimming line need to have high details due to have exactly end-point as per sample design accepted by customers.
8. How does the company address the challenges associated with manual manufacturing processes in composite of Headlamp Jig manufacturing?
   - We require to have high monitoring activities to each process and manage the skillful workers to fabricate the fixtures.
9. What are the key factors considered when evaluating the scope and cost of proposed changes in the manufacturing system for the composition of Headlamp Jig products?
   - All models undergo same key factors to evaluate the scope and cost of proposed changes. We will look to our capability by looking at our staff's skills, tools and facilities to perform any changes.

10. Can you identify any bottlenecks or areas of inefficiency in the current composite production workflow?
    - Mostly inefficient on the chemicals used like resin or gel coat.
11. Are there any emerging technologies or techniques in composite manufacturing that you think we should explore?
    - Yes, you may explore in advance composite technology such as Infusion system, prepreg and autoclave process.
12. How, in your opinion, can we maximize the utilization of raw materials to cut down on waste throughout the headlight jig production process?
    - To fully utilized raw materials, we need to calculate the exact size of cutting fabric and control its using accurate cutting. Besides, the resin application used need to determine the requires time to perform mixing and lay-up before the resin become gels. Once its become gel, the resin cannot be used.