UNIVERSITI TEKNIKAL MALAYSIA MELAKA

ALIGNING NEW PRODUCT DEVELOPMENT WITH REVERSE ENGINEERING METHODOLOGIES FOR HEAD LAMP

MUHAMMAD SHOFWAN AMRULLAH BIN A AZIZ
B092010237

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (PROCESS AND TECHNOLOGY) WITH HONOURS

2024

Faculty of Industrial and Manufacturing Technology and Engineering

ALIGNING NEW PRODUCT DEVELOPMENT WITH REVERSE ENGINEERING METHODOLOGIES FOR HEAD LAMP

Muhammad Shofwan Amrullah Bin A Aziz

Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours

2024

ALIGNING NEW PRODUCT DEVELOPMENT WITH REVERSE ENGINEERING METHODOLOGIES FOR HEAD LAMP

MUHAMMAD SHOFWAN AMRULLAH BIN A AZIZ

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

Faculty of Industrial and Manufacturing Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **ALIGNING NEW PRODUCT DEVELOPMENT WITH REVERSE ENGINEERING METHODOLOGIES FOR HEAD LAMP**

SESI PENGAJIAN: **2023-2024 Semester 1**

Saya **MUHAMMAD SHOFWAN AMRULLAH BIN A AZIZ**

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

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

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

Disahkan oleh:

Alamat Tetap:

LOT 4525, KAMPUNG PADANG LIMAU NIPIS,
BUKIT PAYONG, 21400 MARANG,
TERENGGANU.

Cop Rasmi:

DR NOOR IRINAH OMAR
PENSYARAH KANAN
FAKULTI TEKNOLOGI DAN KEJURUTERAAN DAN PEMBUATAN
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Tarikh: 28 / 1 / 2024

Tarikh: 28.1.2024

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

DECLARATION

I declare that this Choose an item. entitled “Aligning New Product Development With Reverse Engineering Methodologies for Head Lamp Jig” is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
Name	:	**Muhammad Shofwan Amrullah Bin A Aziz**
Date	:	10/1/2024

APPROVAL

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

Signature	:	
Supervisor Name	:	Dr Noor irinah Omar
Date	:	10.1.2024

DEDICATION

I would like to dedicate the success of this research to my parents, A Aziz bin Haron and Khatijah Binti Sidek. This report is dedicated to them because I want to express my gratitude for all their sacrifices for me throughout my time at this university. Second, this dedication is made to my siblings, who assisted me incompleting this report through counsel, financial assistance, and encouragement. Following that, I'd like to offer my heartfelt appreciation to my supervisor, Dr. Noor Irinah Binti Omar and my friends for their assistance in finishing this Final Year Project.

ABSTRACT

It goes into the crucial field of reverse engineering within the automobile industry, concentrating primarily on the remanufacturing of spare components, with a particular emphasis on the headlight jigs. The study, driven by New Product Development (NPD), aims to find the best composite material to replace standard hardened materials like mild steel and die steel. The impetus for material replacement stems from the negative consequences of temperature-induced expansion in steel constructions, which cause vibrations and structural deterioration, undermining the fundamental purpose of jigs in accurately guiding cutting tools. The study investigates existing jigs to discover their limits using cutting-edge reverse engineering approaches such as scanning technologies and computer-aided design (CAD). The project, supported by NPD initiatives, aims to identify a composite material capable of withstanding high temperatures, avoiding wear, and retaining structural integrity through material analysis. Thermal conductivity, mechanical strength, and general durability are important concerns, as are the environmental and economic ramifications. By addressing these issues through NPD, the thesis advances automotive manufacturing methodologies and provides practical solutions for improving the remanufacturing process of headlamp jigs, aligning with industry demands for adaptability and innovation in the face of technological and material constraints

ABSTRAK

Ia memasuki bidang penting kejuruteraan songsang dalam industri automobil, menumpukan terutamanya pada pembuatan semula komponen ganti, dengan penekanan khusus pada jig lampu. Kajian itu, didorong oleh Pembangunan Produk Baharu (NPD), bertujuan untuk mencari bahan komposit terbaik untuk menggantikan bahan standard yang dikeraskan seperti keluli lembut dan keluli mati. Dorongan untuk penggantian bahan berpunca daripada akibat negatif pengembangan akibat suhu dalam pembinaan keluli, yang menyebabkan getaran dan kemerosotan struktur, menjejaskan tujuan asas jig dalam memandu alat pemotong dengan tepat. Kajian itu menyiasat jig sedia ada untuk mengetahui hadnya menggunakan pendekatan kejuruteraan songsang yang canggih seperti teknologi imbasan dan reka bentuk bantuan komputer (CAD). Projek itu, disokong oleh inisiatif NPD, bertujuan untuk mengenal pasti bahan komposit yang mampu menahan suhu tinggi, mengelakkan haus, dan mengekalkan integriti struktur melalui analisis bahan. Kekonduksian terma, kekuatan mekanikal, dan ketahanan am adalah kebimbangan penting, begitu juga kesan alam sekitar dan ekonomi. Dengan menangani isu-isu ini melalui NPD, tesis ini memajukan metodologi pembuatan automotif dan menyediakan penyelesaian praktikal untuk menambah baik proses pembuatan semula jig lampu depan kereta, sejajar dengan permintaan industri untuk kebolehsuaian dan inovasi dalam menghadapi kekangan teknologi dan material..

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to express my heartfelt gratitude to Allah the Almighty for his assistance and guidance during my life and at the moment of fact. I successfully finished my final year project study at University Technology Malaysia's Faculty of Industrial and Manufacturing Technology and Engineering (UTeM). At this time, I would like to express my appreciation to all parties involved, especially Dr Noor Irinah Binti Omar, the supervisor of the final year project, for providing me with the opportunity to complete the final year report project.

There are many lessons I can learn when doing this final year study. Finally, I'd like to thank my parents for their encouragement and belief in my ability to complete my Final Year Project Thesis. I'd like to thank everybody once again. Both of their kindness and generosity to me will be honored till the end of time. Thank you so much.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

3D	-	Three-dimensional
CAD	-	Computer-aided design
CAE	-	Computer-aided engineering
CAM	-	Computer-aided manufacturing
CGI	-	Computer-generated imagery
CNC	-	Computer Numerical Control
CMM	-	Coordinate measuring machine
CT	-	Computer tomography scan
LED	-	Light-emitting diode
NC	-	Numerical control
NURBS	-	Non-Uniform Rational B-Splines
MRI	-	Magnetic Resonance Imaging
MRO	-	Maintenance, repair, operations
OPL	-	One point lesson
OEM	-	Original Equipment Manufacturer
PLM	-	Product lifecycle management
STL	-	Standard triangle language
FRP	-	Fiber-reinforced plastic
CFRP	-	Carbon fiber reinforced polymer
GFRP	-	Glass fiber reinforced polymer
RTM	-	Requirements Traceability Matrix
NPD	-	New Product Development
PDCA	-	Plan Do Check Act
TQM	-	Total Quality Management
NDT	-	Non Destructive Testing
NA		Not Applicable

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

In automobiles, the headlamp is very important since it provides the necessary lighting for sight and safety while driving at night. Cost, weight, design flexibility, durability, and performance requirements all need to be carefully taken into account when designing and producing headlights. Metal moulds have been used in headlamp manufacture traditionally, and while they provide precision and durability, they have drawbacks in terms of cost-effectiveness, weight reduction, and design freedom.

Reverse Engineering is a comprehensive and careful procedure for unraveling the complexities of current goods, whether they are individual parts or full components. This process entails a thorough examination of a product's physical dimensions, structural features, and attributes in order to recreate its design or develop a new concept. It is simply a benchmarking approach that may be used to regenerate parametric designs for better goods. The fabrication of components such as the complicated headlight jigs is one famous example of reverse engineering in the automobile industry.

The headlamp is known for its forward-looking and modern design, and its attractive headlamps serve greatly to its overall visual appeal. A rigorous process, including the application of a protective coating, is required to achieve the desired level for these headlights. After that, the coating is dried in a UV oven at temperatures ranging from 120 to 500 degrees Celsius. The essential nature of this operation highlights the importance of properly manufactured jigs that can tolerate high temperatures. As a result, reverse engineering becomes critical to improving the performance of these jigs and ensuring they fit smoothly with the headlamp complicated production needs.

When an organization agrees to invest in reverse engineering, it is making a strategic decision to produce a new product inspired by an existing one or to improve the capabilities of a product that is currently on the market. This choice is critical for businesses navigating the complex route of new product development (NPD). During the NPD process, reverse engineering may provide significant insights and knowledge, allowing for a smoother and faster development cycle and the successful launch of a new product.

An extensive knowledge of the technical viability, performance properties, and manufacturing requirements of composite materials is necessary to properly accomplish this material transition from metal molds to composites in the manufacture of headlamps. Furthermore, a comprehensive reverse engineering investigation of the current headlamp design is required to describe internal components, comprehend functioning and structural requirements, and spot areas for improvement.

This project intends to develop headlamp design, manufacturing methods, and materials by addressing these issues and investigating the possibilities of composite materials in headlamp production. By successfully integrating composite materials, the automobile industry will benefit from increased cost effectiveness, weight reduction, and design flexibility. This study's findings will offer insightful advice in this regard. Additionally, this research will open the door for more eco-friendly and effective production procedures for headlamps, supporting the industry's objectives of minimizing environmental impact and satisfying changing consumer needs.

1.2 Problem Statement

The headlight currently in use is made using conventional metal moulds, which has drawbacks in terms of cost, weight, and design flexibility. The various forms and geometries that may be achieved for the headlamp may be limited by the pricey, heavy, and unwieldy nature of metal moulds. Additionally, the conventional techniques of producing metal moulds could not offer the amount of design flexibility or adaptability necessary to satisfy shifting consumer expectations. The fabrication of headlamps using composite materials has the potential to be more affordable, lighter, and more flexible in terms of design. Composites are recognised for their strength-to-weight ratio, corrosion resistance, low weight, and ability to mould into intricate shapes. But comprehending the technological viability, performance characteristics, and production needs of composites for lighting. However, understanding the technical feasibility, performance characteristics, and manufacturing requirements of composites for headlamp applications is essential for successful implementation.

The necessity for high-temperature-resistant composite materials originates from the thermal expansion issues faced during the curing of the protective coating in the molding procedures for the headlight jig. This thermal expansion, caused by the heat generated during curing, has resulted in cracks in the jigs after going through the tunnel oven, jeopardizing the headlamp's proper drying. Addressing this issue involves a careful examination of materials capable of withstanding the extreme heat involved with manufacturing processes, emphasizing the crucial necessity of material science developments in the creation of long-lasting and high-performance components.

The complicated thermal problems in product development, particularly with the headlight jig, highlight the critical significance of the new product development (NPD) process. NPD acts as a technique to differentiate the organization from rivals in addition to satisfying the special demands of industrial clients. The reverse engineering process, which is essential to the creation of the headlamp jig, entails multiple sophisticated phases and significant time and resource commitments. Recognizing this, there is an urgent need to investigate and promote novel NPD models that expedite the reverse engineering process, reduce resource consumption, and improve the efficiency of manufacturing high-quality final goods. This holistic strategy not only assures the resolution of current production difficulties, but it also allows organizations to prosper in a dynamic market by producing results.

.

1.3 Research Objective

This main goal is to propose a new product development (NPD) model for headlamp jig. Specifically, the objectives are as follows:

a) To identify the mold used in headlamp jig.

b) To use reversed engineering process to fabricate composite mold.

c) To create a New Product Development (NPD) model by integrating the PDCA (Plan-Do-Check-Act) methodology

1.4 Scope of Research

The scope of this research are as follows:

- Design composite mold for the headlamp using reverse engineering to ensure proper part replication and minimize defects.
- ropose a new product development (NPD) chart for Headlamp jigs using the PDCA method.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Due to the outdated nature of the product technology, the reverse engineering (RE) process creates a digital clone of a product whose original drawings, blueprints, or other technical specifications are missing. The output of RE is used to reconstruct a computer-aided design (CAD) model and can be either point cloud data or two-dimensional cross-sectional pictures. On the other hand, additive manufacturing (AM) techniques are becoming more and more popular since they can create physical parts with intricate features by gradually adding material. The main prerequisite for AM is a CAD model, which is acquired through RE procedures and used to produce a product after carrying out the required operations in the AM interface. For product development, it's not required to create a CAD model each time. After data has been processed by algorithms, RE and AM may be merged by immediately making the data points compliant with the AM interface.(Kumar et al., 2023).

Reverse engineering, often known as back engineering, is the act of disassembling a variety of items, such as machinery, software, machineries, and architectural structures, in order to get design data. The practice of designing, fabricating, assembling, and maintaining systems and products is referred to as engineering. Forward engineering and reverse engineering are two different subtypes of engineering. The conventional strategy entails moving from logical and abstract designs to the actual physical implementation of a system. When a physical product or component is missing technical information, such as drawings, bills-of-materials, or engineering data, reverse engineering is used instead. Reverse engineering is the process of making an identical product, subassembly, or part from scratch without the use of the aforementioned standards, documentation, or computer models. The process of creating a geometric CAD model from 3-D points obtained by scanning or digitizing existing components or products is referred to as reverse engineering. Researchers frequently describe reverse engineering (RE), the technique of digitally recording the physical entities of a component, in relation to their particular work.

Several industries, including manufacturing, industrial design, and jeweler design and replication, have seen substantial growth in reverse engineering. For instance, when a brand-new automobile hits the market, rival manufacturers may buy one and deconstruct it to learn more about its design and operation. High-quality source code frequently originates from model code when it comes to software engineering. Additionally, designers can use materials like clay, plaster, wood, or foam rubber to initially give their ideas shape in situations like vehicle designs. For the part's actual fabrication, a CAD (Computer-Aided Design) model is necessary. CAD design presents difficulties when product designs become more organic and complicated in shape since there is no assurance that the CAD representation will accurately duplicate the sculpted item.

Reverse engineering serves as a valuable method to acquire essential knowledge, ideas, and design principles in situations where such information is inaccessible. It becomes particularly relevant when the information is either owned by someone who is unwilling to share it or when it has been lost or destroyed. In these cases, reverse engineering allows for the reconstruction of vital details, enabling further analysis, reproduction, or improvement of a product or system.

2.2 History of Reverse Engineering

Given that it requires the application of inverse techniques, discovery, and deduction, reverse engineering is widely acknowledged as one of the most crucial components of product design. Reverse engineering, which is based on mechanical engineering, has undergone a significant transformation from the manual redesign process's inception to a better-extravated method. (Fares et al., 2021). It frequently entails disassembling something and studying its internal workings and details in order to perform maintenance or to attempt to create a new tool or programme that does the same task without needing or merely replicating the original. The idea of reverse engineering a technical advancement enables the creation of an online version that implements data stored from an earlier issue. Research on creating personal computer established declaration of the dependable circuit has been done from areas like appearance, computer graphic sophisticated manufacturing, and even multimedia truth. To recreate the issue while varying in the indicated places by no more than a preset tolerance, an all-encompassing reconstruction of the item variety is unquestionably needed in engineering applications. There are currently a huge number of commercially successful reverse engineering innovation concepts based on a list of requirements, even rangers, and even though they are really divided into contact and non-contact.

2.2.1 Why Use Revese Engineering

- The product is needed even when the original maker is no longer in business, as is the case with aviation spares, which are frequently needed after a plane has been in operation for a while.

- A product's original producer no longer makes it, i.e., the original product has lost its usefulness.

- The initial product design documentation either didn't exist or has been lost.
- Generating CAD data to repair or produce a part for which there aren't any, or for which the data are outdated or missing.
- Comparing a manufactured part to its CAD description or to a standard item constitutes inspection and/or quality control.
- Some undesirable characteristics of a product must be eradicated, for example, excessive wear may point up areas for improvement.
- Enhancing a product's positive attributes through continued use.
- Examining the positive and negative aspects of rivals' products.
- Investigating fresh ways to enhance the functionality and features of products.
- Converting a model or sculpture into 3-D data for animation in video games and motion pictures.
- To make, scale, or replicate artwork, 3-D data from a person, model, or sculpture is created.
- Measurement and documentation for architecture and construction.
- Sizing shoes or apparel for people and calculating a population's anthropometry
- Creating data for tissue-engineered body parts, surgical planning, or dental or surgical prosthetics.

- Crime scene documentation and recreation.

There are many more justifications for employing reverse engineering than those listed above, thus the list provided is not all-inclusive.

2.2.2 Application of Reverse Engineering

Figure 2.1 below describes the process and end application of reverse engineering.

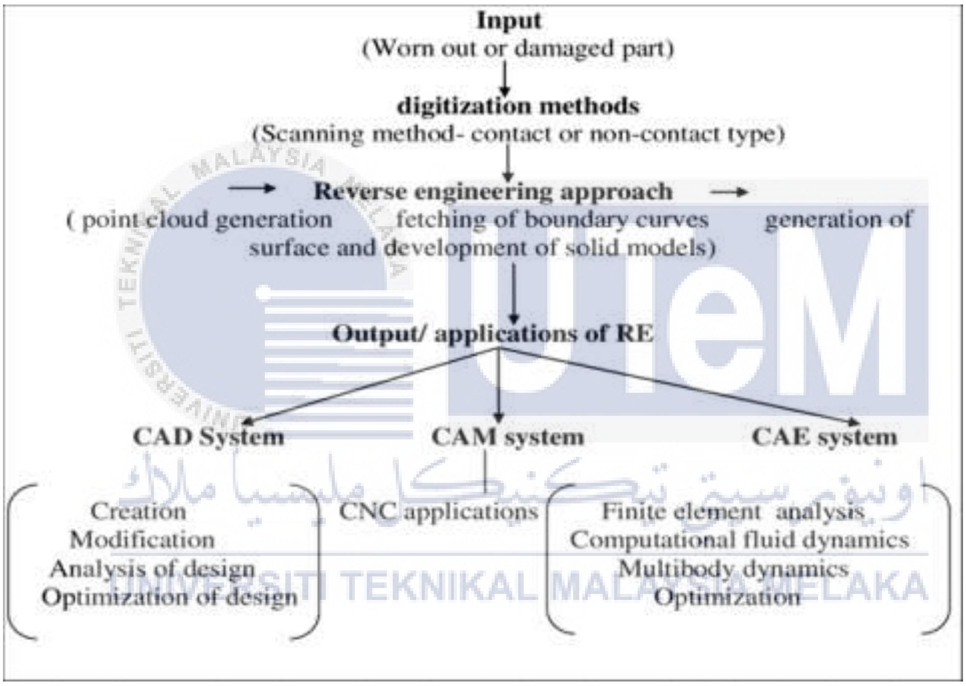

Figure 2.1 Application of Reverse Engineering(N. & P. K., 2014)

2.2.2.1 Application in Mechanical Industries

In mechanical industry one can use reverse engineering in order to fulfill following requirements:

1. For creating 3D model of a physical part with lost documentation.

2. For keeping a digital 3D record of own products.
3. For assessing competitor’s products.
4. To analyze the working of a product.
5. To inspect and compare actual geometry with CAD model.
6. To measure wear of tools

Reverse engineering (RE) is the act of figuring out a system's technological underpinnings by dissecting its operation, structure, and purpose. It frequently entails disassembling something and carefully dissecting its internal workings for maintenance purposes or to attempt to create a new gadget or programme that accomplishes the same objective without emulating the original in any way (Shabani et al., 2019). Reverse engineering has become a practical way to produce a 3D virtual model of an existing physical item for use in 3D CAD, CAM, CAE, and other tools as computer-aided design has grown in popularity. In the reverse engineering process, an object is measured and then rebuilt as a 3D model. (Ahmed, 2019).

Using two case studies, we will examine the features and advantages of product lifecycle and management (PLM) and how they apply to the working procedures of maintenance, repair, and overhaul in the aviation sector. They have also talked about how product data management systems have helped CAD, CAM, and CAE tools evolve. PLM emerged from two streams: supply chain management and enterprise management. In the first case study, it was determined that the inability of downstream repair companies to accurately perform repairs was caused by a lack of information sharing between OEMs and those companies, as evidenced by the fact that the jigs and fixtures created for repairs were based on a virtual model created using a damaged part rather than the actual design. In order to solve this issue PLM setup is utilised, allowing for secure information flow between the two without impairing the OEM's intellectual property rights.

Reverse engineering is used in the automotive sector on a variety of parts, including mechanical seals, sprinkler valves, high-temperature bolt/washer assemblies, valves, dryer housing assemblies, and more.

2.2.2.2 Application in Software Industries

Reverse engineering, in its widest sense, is the act of dissecting a programme from the outside in, often by someone who was not involved in its creation. Even in the absence of source code, persons who practise it may comprehend how a programme or system operates. Reverse engineering may be used for a variety of cyber security activities, such as identifying system flaws, learning about viruses and malware, and figuring out how difficult it will be to retrieve crucial software algorithms that can help stop fraud(Forbes, 2020). The software industry has used reverse engineering as well. Since the programme in question is simply being examined, no modifications have been made. There are a number of reasons why RE is utilised in the software industry, including:

1. The software's source code is accessible, but its more complex features are either no longer relevant or their documentation is incomplete.
2. If the source code itself is not available for the software.
3. Security auditing.
4. Removal of copy protection.
5. To detect and neutralize viruses and malware

2.2.2.3 Application in Medical Life Sciences

In the past, doctors used hand measurements or specialised equipment to diagnose patients, determine their treatment options, and assess their overall health. Currently, X-rays, computed tomography (CT) scanners, ultrasound, and magnetic resonance imaging (MRI) are often utilised to create 3D interior pictures of a patient's body. A new clinical application field is emerging thanks to the development of 3D scanners, which are safe and practical to use to measure a person's body form, size, texture, colour, and skin-surface area correctly. 3D scanning has a high capability of recording 3D measurement without physical contact(Haleem & Javaid, 2019). Reverse engineering is crucial in the medical and life sciences since it allows for time and cost savings as well as greater product accuracy. A better medical manufacturing system is made up of four basic components:Measurement system to measure and capture human anatomy.

1. CAD model creation software that uses digitised data.
2. Advanced fabrication system in order to manufacture the part.
3. In comparison to manual techniques, new materials were utilised for improved manufacturing..

RE is used in the medical industry for the following purposes:

1. Orthopaedic, dental, and reconstructive surgery applications.
2. Imaging modeling and replication of a patient’s bone structure.
3. Before surgery, models may be physically examined, which helps with the appraisal of the procedure and its execution in challenging instances.
4. By cutting down on theatre time, the cost was decreased because to the patient's lower risk.

2.2.3 Advantages of Reverse Engineering

Digitizing has become an essential tool in reverse engineering as it allows for the accurate capture of physical component geometry, which is often difficult with conventional measurement methods. With the use of this technology, contemporary production may transition from using poorly or never recorded tooling to completely customizable 3D CAD models. Reverse engineering makes effective changes, upgrades, and duplication possible by translating physical components into digital representations. It increases product quality, improves design flexibility, lowers mistakes, and makes it easier to make spare parts for machinery that is no longer in production. Manufacturing has been transformed by digitizing and reverse engineering, which made it possible to seamlessly combine physical and digital components for improved design and production processes. The advantage of RE is certainly shown.

a) Cost saving for developing new product.

b) Lesser maintenance costs.

c) Quality improvement.

d) Competitive advantages.

2.2.4 Classification of Different approach of Reverse Engineering

2.2.4.1 Contact Method

Reverse engineering that involves having contact with the system or item being researched. This often entails taking measurements, establishing direct personal touch with the thing, and deconstructing it to comprehend its interior workings. In-person contact with the item is necessary when utilising equipment like callipers, gauges, coordinate measuring machines (CMMs), or 3D scanners.

The most popular, accurate but time-consuming traditional approach calls for physical contact between a measuring device's surface and a contact probe or stylus..

1) Manual measurement

Expert product designers can determine crucial component dimensions that are utilised to create preliminary drawings. Callipers, height gauges, slip gauges, radius gauges, and other measuring devices are examples. A surface's identified key measurements may be easily imported into a CAD system. This approach is adaptable, little employed in RE, inconsistent in precision, constrained by the shape of surfaces or objects, and time-consuming.(Payal & Tomer, 2020)

2) Coordinate measuring machine (CMM)

The CMM has been the most widely used piece of RE gear since the early 1960s. Through the stylus that is attached to it, it translates the spatial points on the component surface into a 3D Cartesian coordinate system. When the stylus makes contact with a component's surface, a signal is formed that triggers the stylus and allows for the recording of a measurement. The three main criteria that impact CMM performance are:(Payal & Tomer, 2020)

1. types of configuration,
2. control types, and
3. fixture design

The performance of CMM is always being improved by researchers. Few scientists have suggested using CMM to scan free form surfaces and are working on CMM software calculations to prevent CMM probe collisions, however the majority of their analysis is based on CAD correlated techniques. In the field of free-form surface inspection, a pattern of CMM mechanisation assessment approach arranging without CAD has emerged.(Payal & Tomer, 2020)

3) **Numerical control (NC)- based machine**

Due of the high initial cost associated with CMM, researchers began looking for alternatives to scanning technology. Businesses have been using NC-based machines that are easy to install for automated manufacturing changed with modern state-of-the-art scanning techniques and cutting-edge route planning algorithms since the early 1940s. (software).(Payal & Tomer, 2020)

2.2.4.2 Non-Contact Method

Reverse engineering is the technique of obtaining data and information from an object or system without making contact with it. This approach is typically applied when the object is delicate, sensitive, or difficult to access physically. Non-contact approaches relying on 3D scanning, laser scanning, photogrammetry, or computer vision techniques are frequently used to collect the surface geometry, measurements, and other essential data of the item.

1) **3D scanning**

A new method for capturing an actual object's three dimensions is 3D scanning. With this technique, a conventional camera captures a 3D image and produces a whole digital file of the real-world item. The resolution of 3D scanning systems, or the separation between the points captured at a specific scanning distance, varies. It means that details of the scanned object that are smaller than the resolution of the scanner are not captured(Chikkangoudar et al., 2021). Surface scanning for reverse engineering demands higher resolution; laser and structured 3D light scanners provide accurate results. The distance between portable 3D scanners and the calibre of the scanning reconstruction determine how accurate they can be. The best resolution and precision are often provided by structured light scanning, often surpassing laser scanning methods.(Fan et al., 2021). Portable 3D scanners may be physically moved and have less size restrictions. These scanners are able to take pictures of both small industrial products and objects as large as an entire room. The gap is filled by portable, high-end scanning devices that have an even wider range and can measure everything precisely. Portable 3D scanners are useful for ergonomic and medical applications for human measurements since they can rapidly record product data. Because 3D scanning can scan and evaluate structures in great detail, it is extremely desired to engage in architectural services.

2) **Magnetic resonance imaging(MRI)**

This imaging technology utilized for disease detection and treatment monitoring and works on the principle of nuclear magnetic resonance. Image quality is dependent on the strength of the magnetic field. Because of strong magnetic field, the metallic objects are prohibited for scanning in MRI.

3) **CAD**

Reverse engineering (RE), a significant area of mechanical design and manufacturing applications, is now widely acknowledged as a critical stage in the design process for new products. A typical automated manufacturing process starts with product design using computer-aided design (CAD) tools and ends with the creation of the machining instructions required to turn raw materials into finished items. In contrast to the standard manufacturing process, reverse engineering is a technique for developing new designs for items without an existing CAD model. Figure 2.2 show where a real model is scanned with a 3D scanner to create a digital version that may be used for surface fitting and point pre-processing. For the CAM/NC processing, a strong 3D structure is then completed.

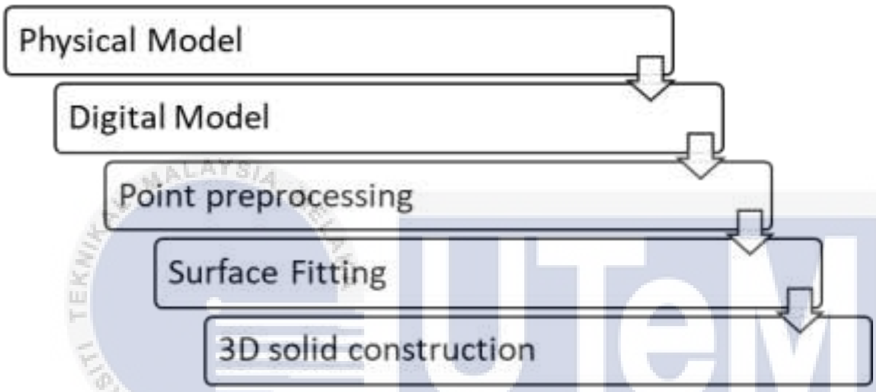

Figure 2.2 The process of reverse engineering

Digitization from the surfaces of an existing part is how RE often starts. These digital data points are then nicely fitted to produce the CAD model of this component.

The coordinate measuring machine (CMM), which employs extremely accurate linear transducers and a microcomputer-based controller to produce a precise, sensitive, and repeatable indication when the component surface is touched, is a typical example of a contact probing device. In general, contact probing devices are more precise yet take longer to collect data than non-contact types of sensors. Non-contact technologies, including a laser scanning machine, CT scanning, MRI, and CGI, have lately been developed with the considerable use of optics and electron components. Recent developments in non-contact technologies, such as a laser scanning device, CT scanning, MRI, and CGI, have made extensive use of optics and electron components.

2.3 Head Lamp

There are study working in the section that should be handle with this section. Literature review were required to collect the knowledge or data needed to validate this study of the Reverse Engineering for Head Lamp. Product businesses are continually looking for innovative solutions to reduce lead times for new product innovations that fulfil all client requirements in today's fiercely competitive global market. Reverse engineering, often known as back engineering, is the act of disassembling a variety of items, such as machinery, software, machineries, and architectural structures, in order to get design data.

2.3.1 Design

There are various types of headlamp designs used in automotive lighting. Each design offers a distinct appearance and can contribute to the overall aesthetic appeal of a vehicle. Below are some common types of headlamp designs:

1. **Projector Headlamps:** Projector headlamps feature a compact lens system that produces a sharp and focused beam of light. They typically have a distinctive circular or rectangular shape with a clear lens covering. Projector headlamps provide a precise and controlled lighting pattern, offering improved visibility and a more upscale appearance. Figure 2.3 below showed projector headlamp.

Figure 2.3 Projector Headlamp

2. **Reflector Headlamps:** Reflector headlamps utilize a curved mirror-like surface, called a reflector, to direct the light produced by the bulb. The reflector helps spread the light over a wider area, providing a broad and even illumination. Reflector headlamps often have a simple and traditional design and are commonly found in older vehicles or entry-level models. Figure 2.4 below showed reflector haedlamp.

Figure 2.4 Reflector headlamp

3. LED Matrix Headlamp: LED matrix headlamps incorporate an array of individual LED elements that can be individually controlled. This

allows for advanced functionalities, such as adaptive lighting and selective dimming of specific sections of the headlamp. LED matrix headlamps offer improved lighting performance, precision, and energy efficiency. Figure 2.5 below showed LED Matrix headlamp.

Figure 2.5 LED matrix headlamp

4. Halo Rings/ Angle Eyes: Halo rings, also known as angel eyes, are a popular design feature in modern headlamps. They consist of a circular or semi-circular ring of LEDs surrounding the main headlamp or integrated within the headlamp assembly. Halo rings provide a distinctive and stylish appearance, often giving the vehicle a premium or high-tech look. Figure 2.6 below showed Halo Rings/Angle eyes headlamp.

Figure 2.6 Halo Ring/Angle eye headlamp

2.3.2 Functionality

The numerous functions and characteristics of a car's lighting system are referred to as headlamp functionality. Headlamps' main purpose is to illuminate the road in front of a vehicle, providing driver vision and enhancing safety in low light. However, current headlamp systems frequently include extra features to improve functionality, convenience, and safety. Below are key aspect of headlamp functionality:

1. **Illumination:** Headlamps are primarily used to produce enough illumination so that drivers can see and be noticed on the road. To illuminate the road, signs, people, and other hazards, headlamps must have enough brightness, coverage, and cooler temperature.
2. **Beam Control:** Depending on the driving circumstances, headlamps may have different beam control techniques to optimize illumination. This features high beam and low beam

settings, enabling drivers to change between them based on traffic and surrounding lights. The beam pattern, direction, or intensity of some headlights can be automatically adjusted based on variables including vehicle speed, steering input, or ambient light conditions.

3. **Fog Light:** Low on the front bumper, the fog lights feature a wide, low beam pattern. They are particularly made to cut through fog, mist, or other bad weather, decreasing glare and improving vision.
4. **Aesthetic Design:** Since headlights are an integral part of the vehicle's entire external appearance, headlamp functioning also includes the aesthetic component. To improve the aesthetic and brand identification of the car, automakers frequently use distinctive lighting signatures or LED accent lighting.

2.4 Composite

A composite material is a mixture of two or more materials that exhibits superior qualities than those of the component parts utilised separately. Each substance maintains its own chemical, physical, and mechanical characteristics, unlike metallic alloys.A matrix and a reinforcement are the two components. When compared to bulk materials, the key benefits of composite materials are their high strength and stiffness paired with low density, allowing for a reduction in the end product's weight(Hussein, 2019). A composite is a substance made up of at least two distinct ingredients. This concept would include materials like fiber-reinforced polymers (FRP), bricks, concrete, wood, bone, and manmade composites(Mahmood et al., 2023). FRPs are used nowadays to create a variety of structures because of their high strength, high stiffness, and low weight. They typically consist of epoxy resin and synthetic fibers.(Khalid, Al Rashid, et al., 2021)(Khalid, Arif, et al., 2021). Figure 2.7 below illustrated how composite materials are divided into three primary categories: structural composites, fiber-reinforced composites, and particle-reinforced composites.

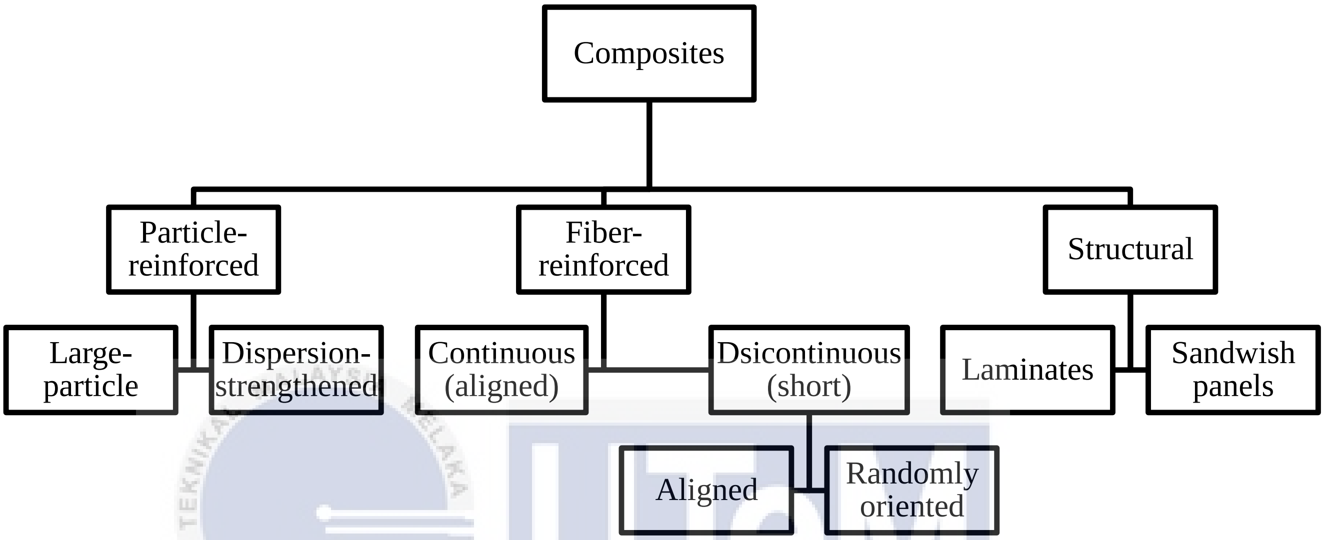

Figure 2.7 Classifications of composite(Mansur, 2023)

2.4.1 Composite Classifications

Two categories are used to classify composite materials:

1. **Composites made of natural**
2. **Synthetic fibres**

- **Natural fiber:** Animal and plant sources are used to create natural fibres. The six groups of natural fibres include: a) Sugarcane-derived fibres, including those from rice, maize, and wheat. b) Leaf fibres, such as sisal, acacia, and pineapple. Basic fibres include hemp, jute, and linen. Examples of bast fibres are ramie and kenaf. d) Seed fibre, such as coconut, cotton, and kapok. c) Basic fibre; Kenaf is an example. Other scripts include roots and vegetation.(Mishra et al., 2022). Table 2.1 below showed advantages and disadvantages for selection of natural fibres.

Table 2.1: Advantages and disadvantages for selection of natural fibers

	Advantages	Disadvantages
Physical–Mechanical	Less density, therefore less weight. Higher specific strength and hardness than glass. Good thermal and acoustic insulating properties.	Fibers absorb water which causes swelling. Lower strength properties than fiberglass composites, especially impact resistance. Because of degradation process odor generation takes place.
Processing	Stainless steel and more Machine parts. Non-invasive design, no tools to wear and no angry skin.	The maximum temperature setting is limited, especially regarding fiberglass. Some fiber must be pelleted to make it greater density.
Environmental	It's renewable so an inexhaustible supply. The production strength is only 1/3 of fiberglass. The amount of CO2 absorbed by plants during their growth is the same as that released during their decay.	The durability is low, because of fungi invasion, bad weather, etc. Price changes are relatively large because crop yield or agricultural policy. Attitudes are different, based on uncertainty effects such as weather.

- **Synthetic (man-made) fibres:** Artificial materials like carbon fibre, glass fibre reinforced plastic (GFRP), and quickly expanding reinforced polymers (CFRP) are used in nearly every industry, from aviation to automobiles. Motors, paper springs, panels, airframes, rockets, weapons and aeroplane doors are a few examples of common usage. There are many different industrial uses for GFRP, including building wooden furniture, light ships, wind turbine frames, and vehicle bodywork..

2.4.2 Composites-classification based on their constituents (matrix, reinforcement and ply)

2.4.2.1 Metal matrix composites

The majority of current global research and development activities are focused on matrix metal complexes. The materials are produced using fluid filtration techniques such high pressure infiltration mounds, compression molding, infiltration vacuum mounds, combination casting, and pressure-less metal intrusion. In addition to boosting strength, stiffness, and resistance to wear and tear, MMCs can provide improved oxidation resistance to operating restrictions at high temperatures with density.

Hand lay-up is a manual technique used in composite manufacturing to create composite parts. It involves the careful layering of reinforcement materials, such as fiberglass or carbon fiber, and the application of resin to create a laminate structure as shown in figure 2.8 below.

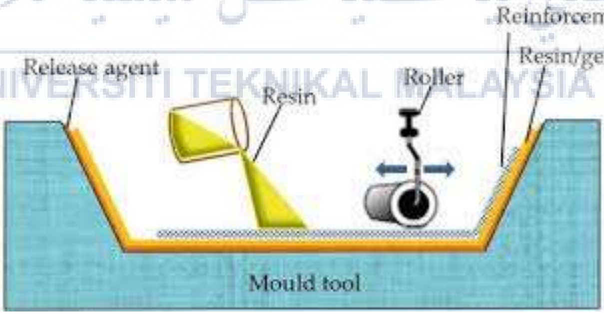

Figure 2.8 Hand lay-up process(Sumithra et al., 2023)

Spray lay-up, also known as spray-up, is a composite manufacturing technique that involves applying reinforcement materials and resin simultaneously using a spray gun. It is a relatively quick and efficient method for producing composite parts. Figure 2.9 below showed spray lay-up process.

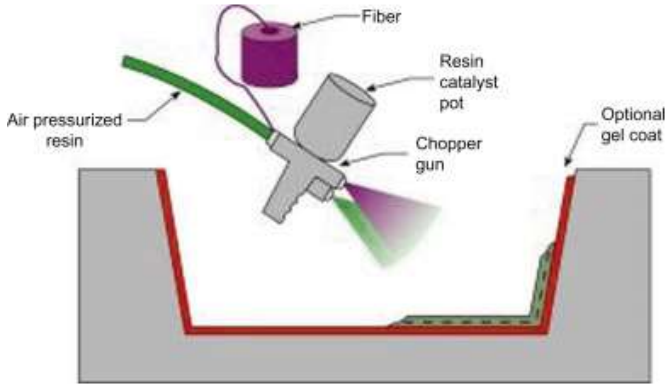

Figure 2.9 Spray lay-up process(Sumithra et al., 2023)

2.4.2.2 Polymer matrix composites

A layer of evenly dispersed fiber reinforcing fibers is layered on top of a polymer (resin) matrix to create materials known as polymer matrix composites (PMC). The majority of industries currently use these polymer matrix materials. Mechanical qualities in general are inadequate for many industrial applications due to their poor strength, fatigue, hardness, and toughness. These defects are corrected for glassware, ceramics, and other materials utilizing a range of enhancements blended appropriately and uniformly with epoxy resin. PMCs do not require high temperatures or pressures. Basic tools are also required for PMC production. Polymer matrix composites are quite popular due to their low weight and good stiffness and strength.(Sumithra et al., 2023). Compression molding uses the criteria Traceability Matrix (RTM) as a tool to make sure that the criteria for the molding process are recognized, followed, and satisfied. It makes it easier to connect the dots between the defined criteria and the various molding process components, including mold design, material choice, operating conditions, and quality control systems.. Figure 2.10 below describes the schematic of the RTM process.

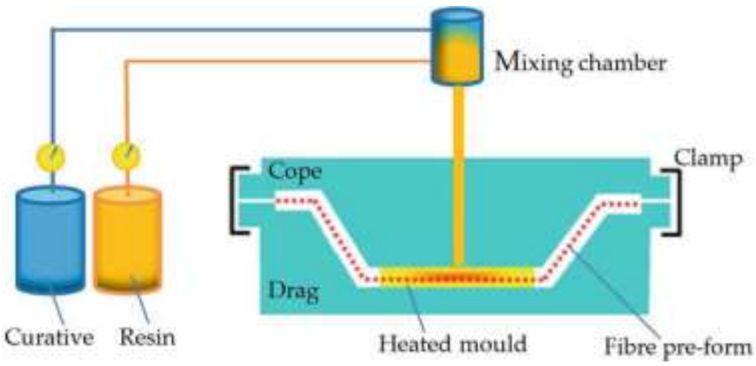

Figure 2.10 RTM process

Compression molding is a manufacturing method where material, like plastic or composite, is heated and pressed into a mold to create a solid product. The material is placed in the mold, heated until it melts, and then compressed under pressure. After cooling, the mold is opened, and the finished product is taken out. Compression molding is used to make a variety of items, such as automotive parts and electrical components. Below are showed the figure 2.11 process of compression molding.

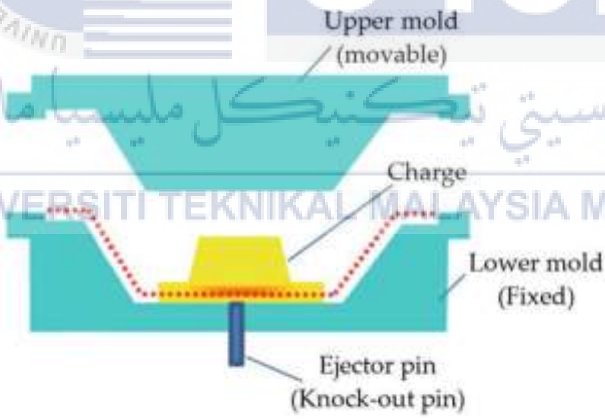

Figure 2.11 Compression molding process

The thermosets or thermoplastics categories encompass the polymer matrix and all of its component elements. There are thermoplastic matrices including polypropylene, polyurethane, nylon, and others; the most popular thermosetting matrices are polyester and epoxy. Epoxy resin is the most often used matrix in polymer composites because of its promising properties, which include little shrinkage, low toxicity, excellent adhesive capabilities, and a range of industrial uses.

2.4.2.3 Ceramic matrix composites

Ceramics are hard materials that typically exhibit incredibly potent ionic connections and, in certain cases, covalent interactions. High melting point, powerful corrosion resistance, and indoor stability. High temperatures and compressive strengths are used to create ceramic-based matrix materials. The material of choice when structural elements need to endure temperatures of more than 1500 C. They are made of a textile that has ceramic fibers woven into the fabric to act as reinforcement and form a ceramic matrix. The high melting point, excellent toughness, enhanced corrosion resistance, and stability at high temperatures of CMCs are further benefits. Clay, silicon carbide, alumina, and ceramics are a few examples.

2.5 Headlamp Jigs

A key component in the expert production of the car's headlight assembly are the headlamp jigs. The purpose of these specialist tools is to ensure consistency and precision throughout the production process. Headlamp jigs are essential for precisely aligning and keeping the housing, lens, and bulbs, among other parts of the headlamp, in place. Company can provide a consistent headlamp unit assembly process and an excellent, dependable lighting system for the by using these jigs. The performance and safety on the road are eventually improved by the jigs, which also assist to simplify production and fulfill strict quality requirements. These factors add to the manufacturing process' overall efficiency.

Jigs play a vital role in the manufacturing sector by holding work pieces in place while they are being assembled or machined. Jigs facilitate accurate component placement by offering a steady and regulated environment, which guarantees precision and reproducibility in manufacturing. Since they provide the functions of placing, supporting, and fastening the components that need to be combined, jigs and fixtures are essential production tools in the manufacturing industry (Fiedler et al., 2024). A tool used in manufacturing to regulate the position and/or motion of components or other tools, enabling compatibility, precision, and reproducibility in the production of goods. The final product's overall quality is greatly enhanced by this painstaking control over the workmanship.

The implementation of jigs not only improves component assembly precision but also optimizes production processes, resulting in higher productivity and efficiency. In addition, the capacity to duplicate precise placement with the use of jigs is essential for attaining standardized and consistent component production a need for satisfying demanding quality requirements across a range of sectors. In the end, jigs must be used in manufacturing processes in order to get the best possible outcomes in terms of accuracy, dependability, and overall product quality.

One of the most important steps in the production of headlights is curing, which calls for the use of specialist jigging equipment in tunnel ovens. In order to ensure lifespan and durability, heat is applied at this critical step to solidify and reinforce the materials used in the headlights. During the curing process, the use of specialized jigs is necessary because they support the complex headlamp components and ensure that they are precisely aligned within the tunnel ovens. In addition to holding the fragile components in place, the specialist jigging equipment allows for uniform curing, which adds to the headlights' consistently high quality.

2.6 New Product Development (NPD)

The careful method of successfully bringing a new product onto the market is called the New Product Development (NPD) process. Idea generation, idea screening, concept development and testing, business analysis, marketing strategy development, product development, test marketing, and commercialization are some of the steps that are usually included. Idea screening is the process of assessing and sorting these concepts according to a variety of criteria. Idea creation is the process of generating new product ideas. Companies use new product development (NPD) as a comprehensive and strategic method to effectively launch innovative goods and services. The procedure is dynamic, consisting of a number of linked phases that call for strategic decision-making, innovation, and market knowledge. Customers and technologies with innovative methods who demand quick response and lower costs simultaneously have increased rapidly in the world (Nandakumar et al., 2020). NPD is essentially a planning process that requires an in-depth understanding of consumer behavior and market dynamics in addition to encouraging innovation.

A dedication to flexibility, a willingness to receiving criticism, and a proactive strategy for satisfying changing customer demands are necessary for successful NPD. A company's ongoing growth and competitiveness are targeted at by creating goods that resonate with customers through a continual cycle of innovation, analysis, and improvement. However, there are many obstacles in the way of successful New Product Development (NPD) initiatives, which might result in failure either in the latter phases of development or during commercialization. These breakdowns often stem from the critical early phases of NPD, also referred to as the front end (Falahat et al., 2024).

2.7 Total Quality Management (TQM)

The complete management idea known as Total Quality Management (TQM) places a strong emphasis on an organization's internal processes, goods, and services being continuously improved. TQM, which is based on the idea that everyone has a duty to uphold quality, aims to include every employee in a company in the quest for excellence. It incorporates a number of ideas, including as fact-based decision-making, staff participation, continuous improvement, and customer focus. Using a comprehensive approach to quality and incorporating it into all facets of an organization's operations is encouraged by TQM. By solving waste, cutting defects, and creating a creative environment, this entails not only meeting but surpassing consumer expectations. By empowering staff to see issues and find solutions, Total Quality Management (TQM) seeks to instill a dedication to quality at all organizational levels. Businesses that use Total Quality Management (TQM) aim to improve customer happiness, lower expenses, and boost overall productivity, all of which contribute to long-term success in a fierce market. The goal of TQM is to match customer expectations for quality production. Customer satisfaction determines the quality level in TQM (Othman et al., 2020).

Organizations that follow to the concepts of Total Quality Management (TQM) may gain several benefits. Focusing on ongoing improvement, Total Quality Management (TQM) raises the standard of goods and services, which in turn increases client happiness and loyalty. Prioritizing process efficiency and optimization boosts output and makes better use of available resources, which lowers operating expenses. TQM may also have a favorable effect on customer service, productivity, reaction time, and product quality (Othman et al., 2020). The capacity of TQM to be flexible and adaptive allows firms to react quickly to changes in the market, and creating a culture of innovation and ongoing learning makes them more competitive overall. An organization's position in the market is strengthened and risks are minimized when it follows to TQM principles over the long run. In summary, TQM is a comprehensive approach to management that aims to improve quality and customer satisfaction through the involvement of all members of an organization and the use of various tools and principles.

2.8 Plan Do Check Act (PDCA)

In Plan-Do-Check-Act, or PDCA, is a methodical structure for ongoing process, product, or improvement in services. Organizations define goals, define area for development, and create a thorough action plan during the planning stage. The proposed adjustments are put into action during the next "Do" phase, during which time data is frequently gathered to track and comprehend the consequences of these modifications. Organizations may determine if adjustments have resulted in the expected improvements by comparing the results to the planned objectives through the "Check" process. Ultimately, the cycle restarts in the "Act" phase once any necessary corrections or modifications are made in light of the evaluation. The PDCA process is iterative and focuses on improving methods, learning from each cycle, and gradually increasing the efficacy and efficiency of operations. It is a fundamental tool for quality management that gives firms the flexibility to innovate, adapt, and continuously enhance their processes.

A crucial instrument for addressing issues and attaining ongoing process and product improvement is the PDCA cycle. Originally created in the manufacturing industry, it is frequently used to manage a number of processes for ongoing improvement. The cycle is especially useful for closely monitoring everyday work at the operational level, and it may be repeated at several intervals, including weekly, monthly, or even daily (Song & Fischer, 2020).

2.8.1 Stage of PDCA cycle

Plan:

The PDCA cycle is built on the planning phase. Companies start by doing a comprehensive analysis of their processes, goods, or services as they are right now. They clearly outline the issue or area in need of change and provide goals. This stage entails obtaining pertinent information, comprehending limitations, and weighing several possible options. The final plan describes the precise steps to be followed, the materials needed, and the anticipated results. Thorough planning guarantees that the company has a clear approach for bringing about improvements.

Do:

The real changes are carried out in accordance with the plan during the implementation phase, often known as the "Do" phase. To test the suggested changes on a smaller scale, it can entail a pilot project or a phased approach. Team members must coordinate and work together throughout this practical phase. Gathering data at this point is essential for tracking the impact of the modifications, spotting unforeseen problems, and learning more about the usefulness of the suggested enhancements.

Check:

In the "Check" step, the outcomes from the implementation phase are assessed. In the planning stage, organizations set goals and expectations, and then compare the actual results with those. Determining the efficacy of the modifications entails a comprehensive examination of the gathered information. Should the outcomes match the goals, the company can go on to the following phase. Should disparities exist, nonetheless, this stage offers a chance to find the reasons behind them, comprehend variances, and highlight areas that require development.

Act:

Based on the information acquired during the "Check" phase, the "Act" phase entails remedial action or additional changes. Should the modifications prove effective, establishments strive to incorporate them into routine procedures. On the other hand, the organization goes back to the planning stage if problems or chances for improvement are found. This cyclical procedure promotes resilience and flexibility by establishing a culture of ongoing learning. It guarantees that businesses can adapt to shifting conditions and continuously pursue excellence.

The PDCA cycle, which emphasizes careful planning, active execution, thorough assessment, and proactive modifications, is essentially a dynamic and iterative method to improvement. Continuous improvement cycles support organizational learning and the long-term, steady development of procedures, goods, or service.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The goal of this thesis is to look into how Reverse Engineering and New Product Development (NPD) techniques may be combined to change the mold material for the headlight from metal to composite. The process starts with a thorough analysis of the literature, exploring topics such as composite materials and reverse engineering methods applied to the manufacture of automobile headlights. In addition to pointing out areas of incomplete information, this preliminary study creates a thorough framework for next phases. After that, the research carefully examines the existing headlamp design, analyzing its advantages, disadvantages, and future difficulties. This critical analysis directs the material selection and design optimization process by bridging theoretical underpinnings with real-world concerns.

This study's implementation of Total Quality Management (TQM) concepts is made possible by the methodical use of the Plan-Do-Check-Act (PDCA) framework. The project evaluates the present headlamp design and conducts a thorough literature analysis in order to set clear goals and scope during the first "Plan" phase. As the research moves to the "Do" phase, digital modeling through reverse engineering is utilized to implement the anticipated activities. The "Check" step that follows is a data-driven assessment that entails a thorough assessment of composite materials based on specified criteria. This is in line with the PDCA principles, which guarantee a careful analysis of the results and the pinpointing of areas in need of development. After that, the "Act" phase concentrates on creating a composite mold while conducting thorough testing and evaluation of the headlamp prototype. This iterative cycle, which uses the PDCA framework as a planned method for advancement and improvement, highlights the project's dedication to ongoing innovation and development.

By implementing the PDCA framework to the New Product Development (NPD) process, it seeks to demonstrate the viability of using composite molds in the manufacturing of automobile headlights and to provide insightful information to the larger automotive industry. The integration of composite materials, reverse engineering, and the PDCA methodology exemplifies a holistic approach to innovation, stressing excellence in the advancement of automotive technology. The research's advancement shows a dedication to methodical development and paves the way for later innovations in the use of cutting-edge materials and technology in the creation of vehicles.

3.2 Proposed Methodology

The many stages of a process are shown in chronological order on a flowchart. It is a versatile tool that may be used to describe a range of procedures, including project planning, office work, customer support, and manufacturing. A sequence of events, materials or services entering or leaving the process (inputs and outputs), choices that must be taken, participants, the amount of time needed at each stage, and/or process metrics are examples of things that may be included in a flowchart.

The use of flowcharts to illustrate the steps necessary to complete a task is crucial. It represents a process using symbols. Each process step is denoted by a separate symbol and is accompanied by a succinct description. Figure 3.1 below showed flowchart of NPD.

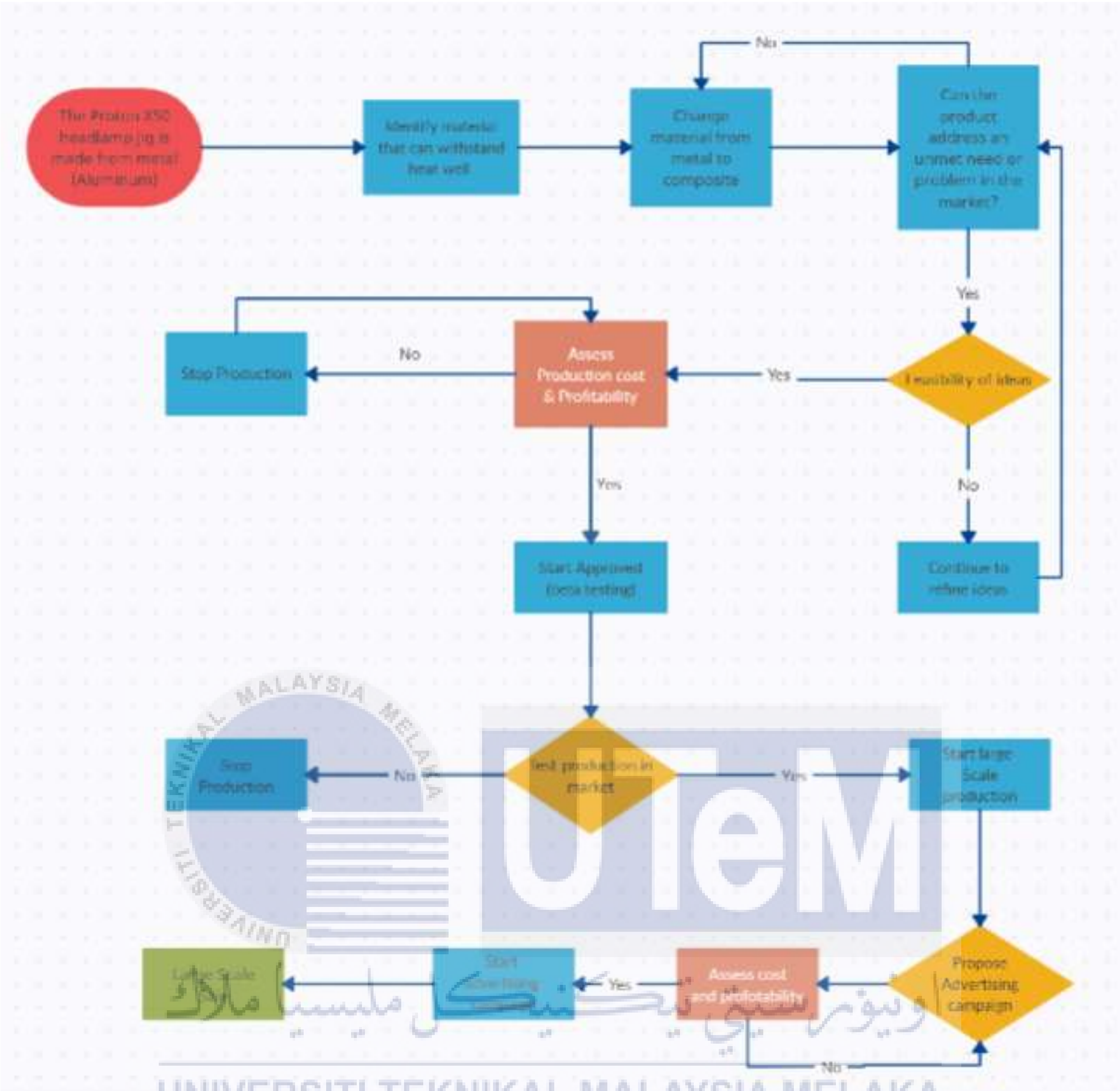

Figure 3.1 Flowchart of New Product Development (NPD)

3.3 Integration of PDCA with Reverse Engineering

3.3.1 Plan

Concerns about this method surfaced when it was discovered that the headlamp jigs were cracking as a result of frequent contact to the curing oven. Frequent heat cycling of the aluminum jig, which ranged from 120°C to 500°C, presented difficulties for the complex headlight curing procedure. The quick cooling to ambient temperature that followed presented a thermal shock danger, which might lead to fractures and reduce the overall curing process efficacy.

This problem was attempted to be solved by placing two metal bar forms on top of the jig in an effort to lessen heat stress. Unfortunately, this strategy failed due to insufficient heat transmission. The main problem was that the metal bars couldn't distribute the heat produced during thermal cycling, which made things worse.

To address these difficulties, a conscious choice was taken to look into other possibilities, which resulted in the usual metal jig being replaced with a composite material. The decision was made with the intention of finding a more dependable and effective way to deal with the recurring problem of cracking. In order to improve thermal endurance and resistance to thermal stresses brought on by the curing process, a composite material was used, which eventually led to the creation of more dependable and efficient headlights. This search for a different approach shows a dedication to ongoing development and an active approach to handling problems in the manufacturing process.

3.3.2 Do

Below showed Figure 3.2 of the reversed engineering stage.

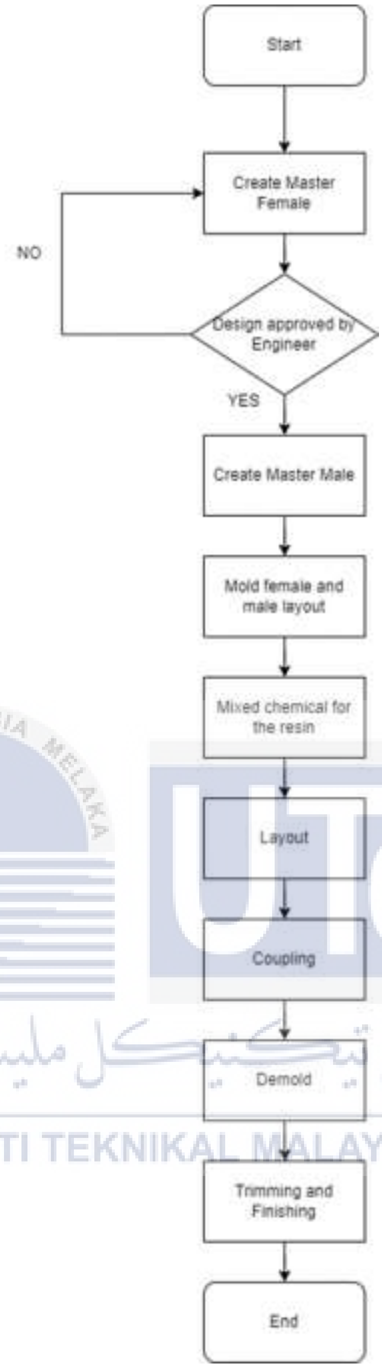

Figure 3.2 Reversed Engineering Stage (Beta Testing Flowchart)

3.3.2.1 Creating Master Female and Master Female

The molding process is a multi-step, laborious process that begins with the development of a master female. This crucial part is carefully produced by creating an inner platform on the headlamps glass' surface. The building method is flexible because to the availability of materials like foam, cardboard, and plywood that are very adaptable. The next step is to carefully build an outer platform on the surface of the lens once the inner lens has been fashioned. This platform is skillfully loaded with a filler the mixture to create the correct shape. It is then allowed to dry for a certain period of time before performing a thorough finishing procedure to provide a flawless surface.

The following step involves creating a master male when the master female is finished and the engineer has given the design permission to proceed. For the laminating procedure, 100 grams of resin and 30 grams of hardener are combined first. The master female is then covered with this resin-hardener combination. Eight layers of fiber carbon and fiber glass are then alternately applied, and the mold is allowed to dry overnight. A further laminating method is carried out following the curing phase. When the resin is completely cured, the mold is demolded, trimmed, and completed. Below are the figures of the master female and master male.

Figure 3.3 Master Male

Figure 3.4 Master Female

3.3.2.2 Mold Male and Female Layout

Epoxies are the recommended bonding solution, and whether polyester or resin are used in the layout process. Wax is used to prepare the master female for the mold, acting as a releasing agent to keep it from adhering and to facilitate a seamless demolding procedure. Next, 100 grams of resin and 30 grams of hardener are combined to form a slurry for laminating. After applying this glue mixture to the wax surface, eight layers of carbon fiber and fiberglass are carefully arranged in alternate patterns. The mold is demolded when it has cured, and finishing touches are meticulously applied to get the desired result.

By using the master male mold, the mold man is also crafted with the same care and attention to detail. Throughout this process, the material data sheet (MDS), which includes crucial details regarding the fiber material, resin, and vacuum process conditions, is consulted to establish the thickness of the jigs. The quality and integrity of the finished product are guaranteed by this meticulous attention in the production procedures for both mold male and mold female. Below are figures of male and female layout.

Figure 3.5 Male Mold

Figure 3.6 Female Mold

3.3.2.3 Chemical Mixture

There are 20 grams of hardener and 100 grams of epoxy 2051 in the chemical combination. The hardener is a pale amber tint, but the resin is a dark blue color. The density ranges for the resin and hardener at 25 degrees Celsius are 1.25 to 1.35 and 1.05 to 1.09, respectively. Fumed silica is added to the resin and hardener mixture to increase the mixture's thickness and create a stronger bond. The mixture is meant to be thickened with powdered fumed silica. Figures below show the hardener GC 15, GC1 150 Resin, and Fumed silica.

Figure 3.7 Hardener

Figure 3.8 Resin

Figure 3.9 Fumed Silica

3.3.2.4 Layup

To ensure smooth demolding of the jigs, a critical waxing step is applied to the completed male and female molds during the layup process. The wax use as a mould release agent. The name of the wax is Miracle Gloss. Below show the figure of the wax that have been used.

Figure 3.10 Mould Release Wax

Fiberglass and carbon fiber are then carefully cut using a template supplied by the engineer after this preparation. Two layers of fiber carbon are carefully positioned on both the male and female molds after the previously combined chemical has been applied to the waxed surface. In order to minimize any superfluous surfaces that would potentially cause mold breaking, extra care is taken to guarantee that the fiber carbon fits precisely on the female mold. The fiber carbon is next covered with two layers of fiberglass, and then two more layers of fiber carbon are layered on top of the fiberglass. The whole layup is liberally covered with the resin mixture to achieve a strong adhesion and a stable connection between the fiberglass and fiber carbon layers. For further stability, the last layers are coated with thick resin that has been combined with fumed silica before going on to the coupling procedure. Figure below show of the process of layout process. Below show figure of fiberglass and fiber carbon are layered.

Figure 3.11 Fiberglass and fiber carbon are layered

In keeping with the layup process, this carefully method guarantees that every layer is done properly, resulting in a solid and well-coordinated framework. In order to strengthen the layup's overall integrity, the resin mixture is essential in tying the fiberglass and carbon fiber layers together. Prior to proceeding with the coupling process, a thick resin impregnated with fumed silica is applied to the final layers as a preventive step, so providing an additional layer of reinforcement. Setting the basis for later production stages, this thorough approach to the layup process enhances the end product's longevity and accuracy.

3.3.2.5 Coupling

The coupling process, which involves screwing the male and female molds together firmly, is an essential stage in the production process. This crucial step must be completed as soon as possible, once the last layers have been positioned. The goal of this step is to keep the resin from curing too quickly so that the molds can be bound together smoothly and effectively. The next stage is to start the curing process so that the composite materials can set and harden once the molds are firmly secured. Usually lasting an entire night, this curing phase gives the resin enough time to go through the required chemical reactions and acquire the material qualities and structural integrity that are needed in the finished product. The composite mold's overall quality and endurance are greatly enhanced by the careful planning and execution of the coupling and curing steps. Below show the figures of the process of put the male into female, correction marking and mold have been closed with bolt nut.

Figure 3.12 Mold male to female

Figure 3.13 Marking check

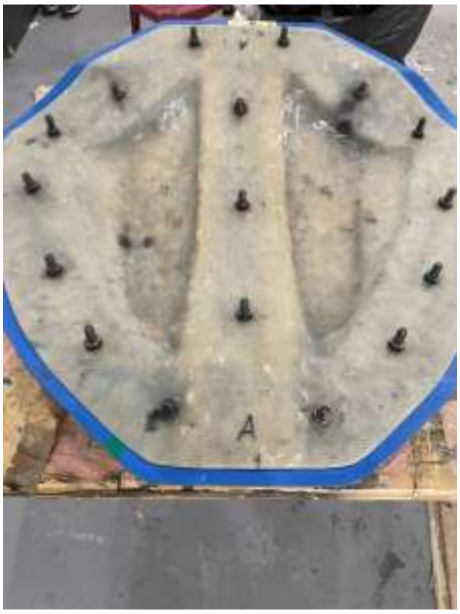

Figure 3.14 : Mold closed with bolt nuts

3.3.2.6 Demold, Trimming and Finishing

The cured composite jigs are released during the demolding step with careful care and accuracy. Using a spatula, this precise process entails slowly unscrewing the mold and carefully removing it from the carefully constructed jigs. At this point, maintaining structural integrity is crucial, and the careful process is crucial in defining the overall caliber of the finished product.

It then turns to the use of diamond-edge cutting tools during the trimming stage. By reducing the possibility of burr faults, this calculated decision seeks to maintain the flawless quality of the composite jigs. The end product's overall visual appeal is enhanced by the cutting accuracy, which also precisely defines the edges. The finishing stage of the production process involves careful sanding and drilling procedures that provide consistently smooth surfaces on all composite jigs. These finely crafted finishing touches improve the jigs' touch quality in addition to their visual appeal. Furthermore, careful application of edge seals strengthens structural integrity and solves safety issues; these seals not only prevent fiber extrusion from the edges but also improve the overall safety and durability of the composite jigs. The combination of these steps demonstrates a dedication to creating composite jigs that are of the best quality and without defects. Figures below show process of demold and process trimming before and after.

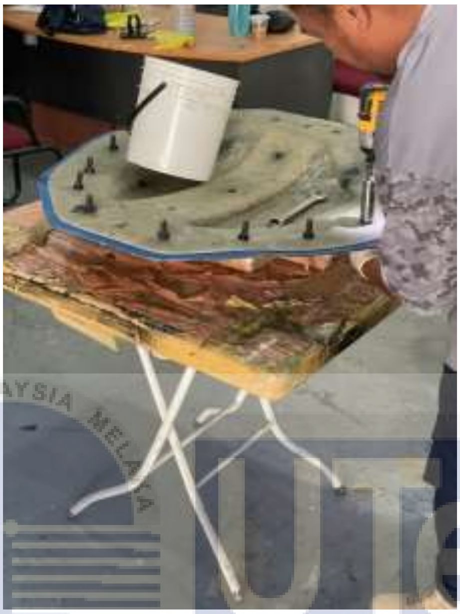

Figure 3.15 Demold male and female

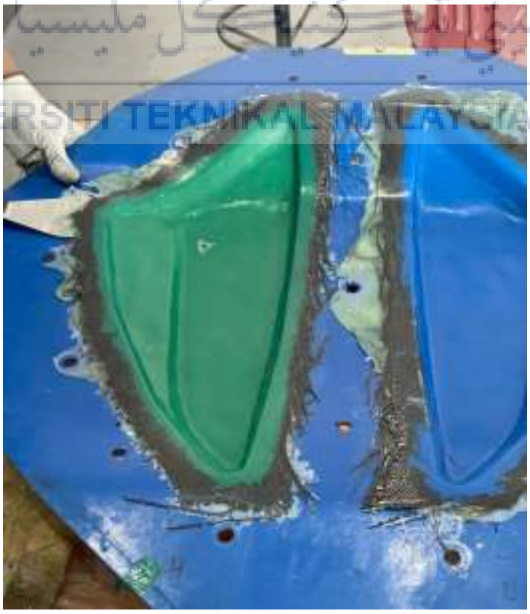

Figure 3.16 Demold composite jig from mold

Figure 3.17 Before trimming

Figure 3.18 After trimming

3.3.3 Check

For this stage, there are two method which is interview and ndt testing. Tap testing, a type of non-destructive testing (NDT), is used in regard to composite materials to find flaws. Using a specialized tool, the composite structure is tapped or struck, and the sound or vibrations that arise are then analyzed. The acoustic responses of composite materials are frequently distinct according to their structural integrity and composition. Variations in the sound generated or the vibrations experienced during the tap test might point to possible flaws in the composite material, such as voids, delaminations, or other anomalies. Expert find and uncover flaws without endangering the structure by leveraging their understanding of material properties and the unique acoustic signatures of composites.

In addition to the Tap Test and related non-destructive testing techniques, another valuable method for assessing composite materials is through semi-structured or in-depth interviews with key stakeholders such as production managers, engineers, and operators. Engaging in direct conversations with these individuals allows for a more holistic understanding of the practical aspects, challenges, and potential issues associated with the use of composite materials in specific industries.

Semi-structured interviews offer a chance to obtain qualitative insights that conventional testing techniques might not be able to reveal on their own. The research can learn about practical experiences and observations on the performance of composite materials in a range of applications by speaking with production managers, engineers, and operators. These interviews can include topics including material handling, production procedures, and operating circumstances. They can add important context to the results obtained from the Tap Test and other non-destructive testing methods.

Furthermore, feedback from interested parties may help improve testing procedures and provide more focused strategies for locating any weaknesses or trouble spots in composite constructions. The total efficacy of the assessment process is improved by combining technical testing techniques with industry specialists' perspectives, resulting in a more thorough understanding of the behavior and performance of composite materials.

3.3.4 Action

The action can be taken is using a tap test or comparable technique to look for abnormalities, such voids and delaminations. Following identification, targeted actions are implemented to address these problems and guarantee that the composite materials satisfy the necessary requirements. This might entail filling in gaps, fixing delaminations, or fixing other issues found during the testing stage.

Next, attention turns to putting corrective actions into action with the goal of improving the overall integrity and quality of the composite materials. This entails a thorough analysis and possible modifications to crucial production process elements like the resin mixture, layup procedure, or other pertinent characteristics. In addition to taking care of urgent problems, the goal is to systematically enhance the production process in order to raise its overall quality.

Most importantly, the results of the anomaly detection and remedial actions are included into the overall quality management system. This connection guarantees that the tap test findings are not isolated instances, but rather contribute to a continual improvement attitude. Manufacturers may support continued improvements by methodically implementing these insights into the manufacturing process, resulting in a sustained elevation of the quality and efficiency of composite materials production. This comprehensive strategy stresses not only the settlement of present challenges, but also the proactive pursuit of excellence in composite material manufacture.

3.4 Summary

This chapter presents the proposed methodology in order to develop new product with reverse engineering for the headlamp. In addressing the challenge of frequent headlamp jig deformations during the curing process, the PDCA methodology is employed with meticulous attention to detail at each phase. The Define phase brings clarity to the issue, articulating the problem and gathering information about the repeated curing process. It becomes apparent that prior attempts at improvement were hampered by insufficient heat transfer, prompting consideration of composite materials as a potential solution.

The PDCA cycle is more than simply a quality control tool. A key idea in continuous-improvement procedures that are ingrained in an organization's culture is the PDCA cycle. Many employees in the organization should utilize it because it is easy to grasp. The most crucial part of PDCA is the "act" stage, which occurs after a project is finished and the cycle is restarted for even more improvement. These results offer a place to start when implementing lean and/or quality improvement techniques, which is helpful information for practitioners looking to enhance organizational performance.

Moreover, the procedures that were found to be useless or poorly executed point to areas that academic programs or staff training could concentrate on to promote the application of these tactics. This work also offers recommendations for tools that might be useful to others working in similar environments by breaking down survey results by type of operation. However, more research is required to gain a better understanding of how additional techniques can be applied to different types of operations in an efficient manner. Lastly, the recurring patterns that arose from the analysis of the difficulties and causes of failure related to continuous improvement approaches offer confirmation.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter is directly based on the material supplied by the firm that is the topic of this investigation. In this chapter, the outcomes and discoveries of the headlamp jig, which intends to replace the standard mold material with a more efficient and dependable composite material. The document's results and discussion section will give a thorough analysis of the findings and their implications in the context of the research. It will go into the process used, including the use of Reverse Engineering and New Product Development (NPD) methodologies to shift the mold material for headlights from metal to composite. The discussion will center on the study findings' consequences, the efficacy of the Plan-Do-Check-Act (PDCA) framework in tackling production issues, and the possibility of employing composite molds in the manufacture of vehicle headlights. It will also look at the lessons learned from implementing Total Quality Management (TQM) ideas and their potential influence on the automobile sector.

4.2 Headlamp detail Jig

Below are figure of the detail headlamp jig.

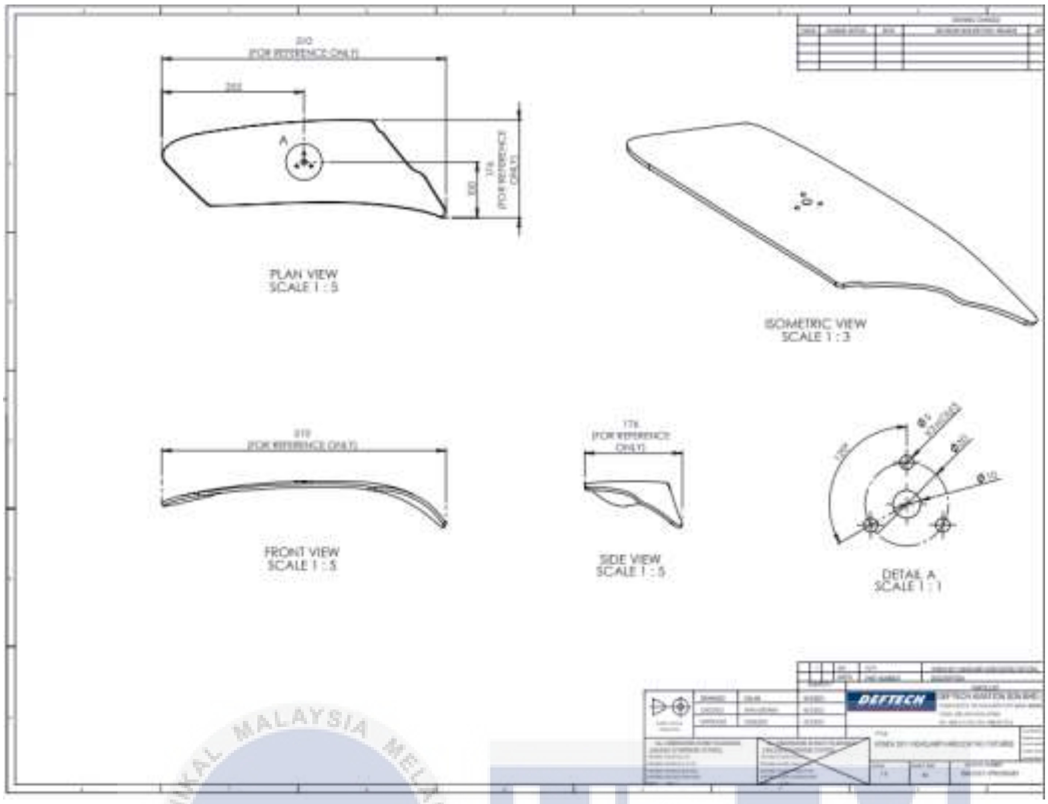

Figure 4.1 Detail of the headlamp Jig

4.3 Data Collection

This gathering data is an important phase in the research process in order to address the issue statement and achieve the stated aim. To answer the company's problems, data must be obtained for the purposes of factor identification, computation, and analysis in the factory's performance. As a result, data from the company is required to achieve this goal.

Table 4.1 Initial Sample Report

Description	Left Headlamp (LH)	Result	Right Headlamp (RH)	Result
Design and Fitting Condition a) Verified design and concept of fixture b) Check placement lens into the fixture [No scratches and part fall down]	Part crack [7/15 NG] Not applied pigment /raisin at edge [15/15 NG]	NG	No Part crack – OK Not applied pigment /raisin at edge [2/15 NG]	Need to Improve
Camera Recognition Check and verify reflection of camera sensor with/without part	With part : 5000 to 9000 pixel Without part : 0 pixel	Ok	With part : 5000 to 9000 pixel Without part : 0 pixel	Ok
Lacquering process a) Check fixture orientation [to avoid lacquer flow] b) Check fixture reliability after go through lacquer process [abnormality]	Set fixture orientation OK [No lacquer flow] No deformation No excess lacquer	TBC	Set fixture orientation OK [No lacquer flow] No deformation No excess lacquer Crack - Need more cycle to validation [TBC]	TBC

c) Check fixture condition [no access lacquer / lacquer contaminate to fixture]	Crack - Need more cycle to validation [TBC]			
Appearance check on hard coating Follow PIS Standard / Quality book]	Appearance check Excess Lacquer No fisheye,	OK	Appearance check Excess Lacquer No fisheye,	OK
Durability and Reliability of fixture Check deformation, crack and after washing with 200bar [pressure]	36 hours – OK 100 hours / > 150 cycle - In progress	TBC	36 hours – OK 100 hours / > 150 cycle - In progress	TBC

Right Headlamp:

Table 4.2 Composite Quality Control Log (Right Headlamp)

Sample No.	Types of Defect	Location of Defect	Description	Action Taken	Status
1.	No crack Pigment fully applied	NA	Pigment or resin have been applied at the edge	NA	Ok
2.	Pigment fully applied. No Crack	NA	Pigment or resin have been applied at the edge	NA	Ok
3.	Pigment fully applied. No crack	NA	Pigment or resin have been applied at the edge	NA	Ok

4.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
5.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
6.	Pigment fully applied. No Crack	NA	Pigment or resin have been applied at the edge	NA	Ok
7.	Pigment fully applied. No Crack	NA	Pigment or resin have been applied at the edge	NA	Ok
8.	Pigment fully applied.	NA	Pigment or resin have been	NA	Ok

	No Crack		applied at the edge		
9.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Patching with additional resin	Improvement needed
10.	Pigment fully applied. No Crack	NA	Pigment or resin have been applied at the edge	NA	Ok
11.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
12.	Pigment fully applied. No Crack	NA	Pigment or resin have been applied at the edge	NA	Ok

13.	Not applied pigment /raisin at edge.	Near edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
14.	Pigment fully applied. No Crack	NA	Pigment or resin have been applied at the edge	NA	Ok
15.	Pigment fully applied. No Crack	NA	Pigment or resin have been applied at the edge	NA	Ok

Left Headlamp:

Table 4.3 Composite Quality Control Log (Left Headlamp)

Sample No.	Types of Defect	Location of Defect	Description	Action Taken	Status
1.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
2.	Not applied pigment /raisin at edge. Crack	Edge surface Edge	Small crack found near the edge of the composite	Patching with additional resin	Improvement needed
3.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed

4.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
5.	Not applied pigment /raisin at edge. Crack	Near edge	Pigment or resin not applied at the edge	Repaired with composite patch	Improvement needed
6.	Not applied pigment /raisin at edge. Crack	Near edge	Pigment or resin not applied at the edge	Patching with additional resin	Improvement needed
7.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
8.	Not applied pigment /raisin at edge.	Edge	Small crack found near the edge of	Repaired with composite patch	Improvement needed

	Crack		the composite		
9.	Not applied pigment /raisin at edge. Crack	Near edge	Small crack found near the edge of the composite	Patching with additional resin	Improvement needed
10.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
11.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
12.	Not applied pigment /raisin at edge. Crack	Edge	Small crack found near the edge of the composite	Patching with additional resin	Improvement needed

13.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
14.	Not applied pigment /raisin at edge.	Edge	Pigment or resin not applied at the edge	Applied pigment and resin	Improvement needed
15.	Not applied pigment /raisin at edge. Crack	Edge	Pigment or resin not applied at the edge	Repaired with composite patch	Improvement needed

4.4 Proposed Improvement

After though PDCA study, the cause of the defect have been identified. Following the identification of the problem, a few initiative have been put out to address and overcome the company problems. These carefully considered suggestions are based on well-known engineering tools, PDCA, with the goal of achieving long-term gains. The action plan not only solves existing difficulties but also creates a framework for continual improvement, ensuring that the manufacturing process stays adaptable and solid to new challenges. Below are figure of the NPD flowchart that have been improve.

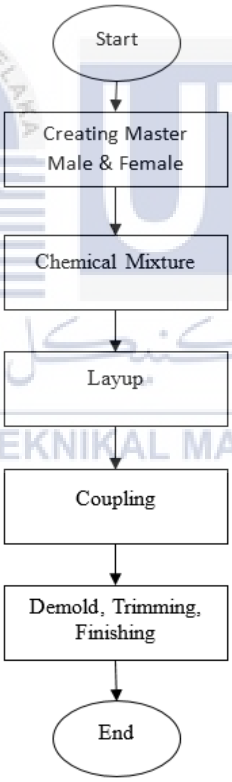

Figure 4.2 Improvement New Product Development Flowchart

The decision to combine the steps "Creating Master Female and Master Female" and "Layout Mold Male and Female" into a single step is based on the assumption that both of these steps involve creating molds. If they serve a similar purpose in the mold creation process, combining them can simplify and streamline the overall process. By merging the fabrication of the master female and master male molds into a single stage, you minimize redundancy in the process, making it more efficient and easy. This presupposes that the difference between master female and master male molds has no substantial influence on the succeeding phases and that the layup process incorporates the arrangement of the mold layers intrinsically. If there are unique reasons for keeping these processes distinct, they can be kept depending on the manufacturing process's specific requirements.

4.4.1 Optimization of Resin Mixtures

The analysis of the resin blend in the composite material is part of the resin mixture optimization process. It is critical to work with material scientists and suppliers to develop alternative resin compositions with enhanced thermal characteristics and durability. After that, a controlled trial phase is carried out to evaluate the performance of the changed resin mixture under simulated curing circumstances, assisting in understanding the influence on the material's qualities and leading additional modifications for improved efficacy.

4.4.2 Improvement of Layup Procedure

Layup technique improvement is a detailed evaluation of the current layup process to identify probable flaws that contribute to fault fractures. The layup technique is then modified, which may involve modifying layer orientation, thickness, or sequencing to improve the overall structural integrity of the finished product. Close engagement with production teams is required to smoothly incorporate the new layup techniques into the manufacturing workflow, ensuring that the upgrades are executed efficiently and contribute to the manufacture of higher quality and more robust products.

4.4.3 Process Component Changing

To enhance a process's overall quality and eliminate defects, it's necessary to identify the critical parts within the process that have a substantial effect on defect incidence. This entails carefully analyzing each phase to identify any flaws or difficulties. The next stage is to perform experiments after these important factors have been determined. These experiments are intended to investigate and discover the best combinations of variables such as temperature, pressure, and other important variables.

4.4.4 Training

Regular training sessions for production worker are required to ensure they are up to speed on processes. These training sessions are designed to acquaint personnel with any adjustments or modifications to operational procedures, assisting them in adapting to new ways and staying up to date with the most recent protocols. Furthermore, it is critical to implement continuing education initiatives to keep the personnel up to date on industry innovations.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The document explores the integration of Reverse Engineering and New Product Development (NPD) techniques to change the mold material for headlights from metal to composite. It begins with a comprehensive literature analysis and critical examination of the existing headlamp design, identifying its advantages, disadvantages, and future challenges. The study implements Total Quality Management (TQM) concepts through the systematic use of the Plan-Do-Check-Act (PDCA) framework, ensuring a methodical approach to addressing production challenges and achieving specific goals in automobile manufacturing organizations..

The proposed methodology includes a detailed flowchart of the NPD process, outlining the chronological stages of the project. It involves the use of reverse engineering for digital modelling, thorough assessment of composite materials, and the application of non-destructive testing techniques to ensure the quality and integrity of the final product. The meticulous process of creating composite molds is highlighted, emphasizing the dedication to creating high-quality composite jigs through precise manufacturing processes and non-destructive testing techniques.

The study also emphasizes the integration of composite materials, reverse engineering, and the PDCA methodology as a holistic approach to innovation in the automotive industry. It sets the stage for advancements in using cutting-edge materials and technology in vehicle production, paving the way for future innovations in the automotive sector.

In summary, the document provides a detailed overview of the methodology used to integrate reverse engineering and NPD techniques for changing the mold material of headlights. It outlines a systematic approach to addressing production challenges, ensuring the quality and integrity of the final product, and paving the way for advancements in automotive technology.

5.2 Recommendations

For future improvements, using Reverse Engineering and New Product Development (NPD) techniques to change the mold material for headlights from metal to composite is a strategic move to address the enduring deformation issue and improve thermal durability and resistance to thermal stresses during the curing process. The usage of composite materials is meant to provide more reliable and effective headlights. As a result, it is advised to maintain the focused pursuit of continuous improvement and active problem-solving throughout the manufacturing process.

Additionally, the study emphasizes the importance of non-destructive testing (NDT) techniques, such as the tap test, radiography, thermography, ultrasonic inspection, and laser shearography, to ensure the integrity and reliability of the composite components. It is recommended to continue utilizing these NDT techniques to improve safety and dependability in crucial industries. Furthermore, the careful planning and execution of the coupling and curing steps in the composite mold creation process should be continued to enhance the overall quality and endurance of the molds. This dedication to precision and quality will contribute to the development of high-quality composite molds for the headlights.

5.3 Improvement for Future Research

The Future research should broaden the scope beyond equipment efficacy and use the PDCA cycle concepts to meet the present difficulties mentioned in this study. It is suggested that the PDCA approach be used in future research to observe variances in results across various procedures. By identifying particular aspects that contribute to unsatisfactory results, comparable attention may be focused on other areas, such as overall performance improvement. The PDCA approach's adaptability extends beyond particular equipment, providing a complete foundation for continuous improvement in a variety of sectors. As a result, it is recommended to use the PDCA cycle as a strategic strategy for assuring long-term, optimal performance and driving continuous development across many processes and systems. This strategy corresponds to the dynamic character of industries, allowing for adaptation and continuous improvement for long-term success.

REFERENCES

Ahmed, N. (2019). Direct metal fabrication in rapid prototyping: A review. *Journal of Manufacturing Processes*, *42*, 167–191. https://doi.org/https://doi.org/10.1016/j.jmapro.2019.05.001

Chikkangoudar, R. N., Sachidananda, T. G., & Pattar, N. (2021). Influence of 3D printing parameters on the dimensional stability of polypropylene/clay printed parts using laser scanning technique. *Materials Today: Proceedings*, *44*, 4118–4123. https://doi.org/https://doi.org/10.1016/j.matpr.2020.10.456

Falahat, M., Chuan, S., & Liew, C. (2024). Navigating new product development : Uncovering factors and overcoming challenges for success. *Heliyon*, *10*(1), e23763. https://doi.org/10.1016/j.heliyon.2023.e23763

Fan, H., Yu, S., Wang, M., Li, M., Chu, J., Yan, Y., Zhang, S., Chen, D., & Harris-Adamson, C. (2021). Analysis of the external acoustic meatus for ergonomic design: part I – measurement of the external acoustic meatus using casting, scanning and rapid estimation approaches. *Ergonomics*, *64*(5), 640–656. https://doi.org/10.1080/00140139.2020.1858188

Fares, M. B., Jagannath, S., & Lashuel, H. A. (2021). Reverse engineering Lewy bodies: how far have we come and how far can we go? *Nature Reviews. Neuroscience*, *22*(2), 111–131. https://doi.org/10.1038/s41583-020-00416-6

Fiedler, F., Ehrenstein, J., Höltgen, C., Blondrath, A., Schäper, L., Göppert, A., & Schmitt, R. (2024). Jigs and fixtures in production: A systematic literature review. *Journal of Manufacturing Systems*, *72*(July 2023), 373–405. https://doi.org/10.1016/j.jmsy.2023.10.006

Forbes, D. A. (2020). Reverse engineering the Milky Way. *Monthly Notices of the Royal Astronomical Society*, *493*(1), 847–854. https://doi.org/10.1093/mnras/staa245

Haleem, A., & Javaid, M. (2019). 3D scanning applications in medical field: A literature-based review. *Clinical Epidemiology and Global Health*, *7*(2), 199–210. https://doi.org/10.1016/j.cegh.2018.05.006

Hussein, S. (2019). *composite materials*.

Khalid, M. Y., Al Rashid, A., Arif, Z. U., Ahmed, W., Arshad, H., & Zaidi, A. A. (2021). Natural fiber reinforced composites: Sustainable materials for emerging applications. *Results in Engineering*, *11*, 100263.

https://doi.org/https://doi.org/10.1016/j.rineng.2021.100263

Khalid, M. Y., Arif, Z. U., Al Rashid, A., Shahid, M. I., Ahmed, W., Tariq, A. F., & Abbas, Z. (2021). Interlaminar shear strength (ILSS) characterization of fiber metal laminates (FMLs) manufactured through VARTM process. *Forces in Mechanics*, *4*, 100038. https://doi.org/https://doi.org/10.1016/j.finmec.2021.100038

Kumar, A., Kumar, P., Singh, H., Haleem, A., & Mittal, R. K. (2023). Chapter 4 - Integration of reverse engineering with additive manufacturing. In A. Kumar, R. K. Mittal, & A. Haleem (Eds.), *Advances in Additive Manufacturing* (pp. 43–65). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-323-91834-3.00028-4

Mahmood, M. A., Alabtah, F. G., Al-Hamidi, Y., & Khraisheh, M. (2023). On the laser additive manufacturing of high-entropy alloys: A critical assessment of in-situ monitoring techniques and their suitability. *Materials & Design*, *226*, 111658. https://doi.org/https://doi.org/10.1016/j.matdes.2023.111658

Mishra, T., Mandal, P., Rout, A. K., & Sahoo, D. (2022). A state-of-the-art review on potential applications of natural fiber-reinforced polymer composite filled with inorganic nanoparticle. *Composites Part C: Open Access*, *9*, 100298. https://doi.org/https://doi.org/10.1016/j.jcomc.2022.100298

N., R., & P. K., J. (2014). *Reverse Engineering Applications in Manufacturing Industries: an Overview*. 567–576. https://doi.org/10.2507/daaam.scibook.2014.45

Nandakumar, N., Saleeshya, P. G., & Harikumar, P. (2020). Bottleneck Identification and Process Improvement by Lean Six Sigma DMAIC Methodology. *Materials Today: Proceedings*, *24*, 1217–1224. https://doi.org/10.1016/j.matpr.2020.04.436

Othman, I., Norfarahhanim Mohd Ghani, S., & Woon Choon, S. (2020). The Total Quality Management (TQM) journey of Malaysian building contractors. *Ain Shams Engineering Journal*, *11*(3), 697–704. https://doi.org/10.1016/j.asej.2019.11.002

Payal, H., & Tomer, R. (2020). Review on reverse engineering. *Journal of Critical Reviews*, *7*(7), 1408–1412. https://doi.org/10.31838/jcr.07.07.255

Shabani, B., Vrtanoski, G., & Dukovski, V. (2019). *INTEGRATED REVERSE ENGINEERING AND ADDITIVE TECHNOLOGY SYSTEMS*. *Vol. 36*, 47-54 (2018).

Song, M. H., & Fischer, M. (2020). Daily plan-do-check-act (PDCA) cycles with level of development (LOD) 400 objects for foremen. *Advanced Engineering Informatics*, *44*(February), 101091. https://doi.org/10.1016/j.aei.2020.101091

Sumithra, G., Reddy, R. N., Dheeraj Kumar, G., Ojha, S., Jayachandra, G., & Raghavendra, G. (2023). Review on composite classification, manufacturing, and applications. *Materials Today: Proceedings*. https://doi.org/https://doi.org/10.1016/j.matpr.2023.04.637

Ahmed, N. (2019). Direct metal fabrication in rapid prototyping: A review. *Journal of Manufacturing Processes*, *42*, 167–191. https://doi.org/https://doi.org/10.1016/j.jmapro.2019.05.001

Chikkangoudar, R. N., Sachidananda, T. G., & Pattar, N. (2021). Influence of 3D printing parameters on the dimensional stability of polypropylene/clay printed parts using laser scanning technique. *Materials Today: Proceedings*, *44*, 4118–4123. https://doi.org/https://doi.org/10.1016/j.matpr.2020.10.456

Falahat, M., Chuan, S., & Liew, C. (2024). Navigating new product development : Uncovering factors and overcoming challenges for success. *Heliyon*, *10*(1), e23763. https://doi.org/10.1016/j.heliyon.2023.e23763

Fan, H., Yu, S., Wang, M., Li, M., Chu, J., Yan, Y., Zhang, S., Chen, D., & Harris-Adamson, C. (2021). Analysis of the external acoustic meatus for ergonomic design: part I – measurement of the external acoustic meatus using casting, scanning and rapid estimation approaches. *Ergonomics*, *64*(5), 640–656. https://doi.org/10.1080/00140139.2020.1858188

Fares, M. B., Jagannath, S., & Lashuel, H. A. (2021). Reverse engineering Lewy bodies: how far have we come and how far can we go? *Nature Reviews. Neuroscience*, *22*(2), 111–131. https://doi.org/10.1038/s41583-020-00416-6

Fiedler, F., Ehrenstein, J., Höltgen, C., Blondrath, A., Schäper, L., Göppert, A., & Schmitt, R. (2024). Jigs and fixtures in production: A systematic literature review. *Journal of Manufacturing Systems*, *72*(July 2023), 373–405. https://doi.org/10.1016/j.jmsy.2023.10.006

Forbes, D. A. (2020). Reverse engineering the Milky Way. *Monthly Notices of the Royal Astronomical Society*, *493*(1), 847–854. https://doi.org/10.1093/mnras/staa245

Haleem, A., & Javaid, M. (2019). 3D scanning applications in medical field: A literature-based review. *Clinical Epidemiology and Global Health*, *7*(2), 199–210. https://doi.org/10.1016/j.cegh.2018.05.006

Hussein, S. (2019). *composite materials*.

Khalid, M. Y., Al Rashid, A., Arif, Z. U., Ahmed, W., Arshad, H., & Zaidi, A. A. (2021). Natural fiber reinforced composites: Sustainable materials for emerging applications. *Results in Engineering*, *11*, 100263.

https://doi.org/https://doi.org/10.1016/j.rineng.2021.100263

Khalid, M. Y., Arif, Z. U., Al Rashid, A., Shahid, M. I., Ahmed, W., Tariq, A. F., & Abbas, Z. (2021). Interlaminar shear strength (ILSS) characterization of fiber metal laminates (FMLs) manufactured through VARTM process. *Forces in Mechanics*, *4*, 100038. https://doi.org/https://doi.org/10.1016/j.finmec.2021.100038

Kumar, A., Kumar, P., Singh, H., Haleem, A., & Mittal, R. K. (2023). Chapter 4 - Integration of reverse engineering with additive manufacturing. In A. Kumar, R. K. Mittal, & A. Haleem (Eds.), *Advances in Additive Manufacturing* (pp. 43–65). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-323-91834-3.00028-4

Mahmood, M. A., Alabtah, F. G., Al-Hamidi, Y., & Khraisheh, M. (2023). On the laser additive manufacturing of high-entropy alloys: A critical assessment of in-situ monitoring techniques and their suitability. *Materials & Design*, *226*, 111658. https://doi.org/https://doi.org/10.1016/j.matdes.2023.111658

Mishra, T., Mandal, P., Rout, A. K., & Sahoo, D. (2022). A state-of-the-art review on potential applications of natural fiber-reinforced polymer composite filled with inorganic nanoparticle. *Composites Part C: Open Access*, *9*, 100298. https://doi.org/https://doi.org/10.1016/j.jcomc.2022.100298

N., R., & P. K., J. (2014). *Reverse Engineering Applications in Manufacturing Industries: an Overview*. 567–576. https://doi.org/10.2507/daaam.scibook.2014.45

Nandakumar, N., Saleeshya, P. G., & Harikumar, P. (2020). Bottleneck Identification and Process Improvement by Lean Six Sigma DMAIC Methodology. *Materials Today: Proceedings*, *24*, 1217–1224. https://doi.org/10.1016/j.matpr.2020.04.436

Othman, I., Norfarahhanim Mohd Ghani, S., & Woon Choon, S. (2020). The Total Quality Management (TQM) journey of Malaysian building contractors. *Ain Shams Engineering Journal*, *11*(3), 697–704. https://doi.org/10.1016/j.asej.2019.11.002

Payal, H., & Tomer, R. (2020). Review on reverse engineering. *Journal of Critical Reviews*, *7*(7), 1408–1412. https://doi.org/10.31838/jcr.07.07.255

Shabani, B., Vrtanoski, G., & Dukovski, V. (2019). *INTEGRATED REVERSE ENGINEERING AND ADDITIVE TECHNOLOGY SYSTEMS*. *Vol. 36*, 47-54 (2018).

Song, M. H., & Fischer, M. (2020). Daily plan-do-check-act (PDCA) cycles with level of development (LOD) 400 objects for foremen. *Advanced Engineering Informatics*, *44*(February), 101091. https://doi.org/10.1016/j.aei.2020.101091

Sumithra, G., Reddy, R. N., Dheeraj Kumar, G., Ojha, S., Jayachandra, G., & Raghavendra, G. (2023). Review on composite classification, manufacturing, and applications. *Materials Today: Proceedings*. https://doi.org/https://doi.org/10.1016/j.matpr.2023.04.637

APPENDICES

Appendix A Gantt Chart 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						MID-TERM BREAK									
		Actual															
2	Chapter 2: Literature Review	Plan															
		Actual															
3	PSM: Workshop	Plan															
		Actual															
4	Chapter 1: Introduction	Plan															
		Actual															
5	Chapter 3: Methodology	Plan															
		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															

Appendix B Gantt Chart 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	