# OPTIMIZATION OF INVESTMENT CASTING PARAMETERS FOR PROPELLER HUB TO IMPROVE MECHANICAL PROPERTIESLM25


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BACHELOR OF MANUFACTURINGENGINEERING TECHNOLOGY (PROCESS AND TECHNOLOGY) WITH HONOURS

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# Faculty of Industrial and Manufacturing Engineering Technology

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**ALIA NUR FATIHAH BINTI MAT YUSOP**

**A thesis submitted**
**in fulfillment of the requirements for the degree of**
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| Date | : | *10/01/2024* |

# DEDICATION

I dedicate my dissertation to my family and many others who have provided constant support and inspiration during my studies. I would like to express my sincere appreciation to my affectionate parent, Encik Mat Yusop Bin Awang and Puan Aisah Binti Tahir, whose words of encouragement and unwavering commitment have deeply influenced me. My brother Muhammad Abdillah and my sister Tahirah have consistently remained by my side and provide unwavering support, making them exceptionally significant to me.

Furthermore, I would like to express my gratitude to my respected supervisor, Ts. Zolkarnain bin Marjom, for consistenly offering me an exceptional source of inspiration and motivation during my attempt to complete this thesis and achieve excellence. Next, I would like to express my gratitude to Tc. Mohd Fauzi Bin Suleiman and Tc. Norhisham Bin Abdul Malik for their valuable support and expertise in handling the laboratory equipment.

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# ABSTRACT

The thesis report discusses the difficulties of manufacturing propeller hubs shell moulds focusing the difficulties caused by the complex geometric design. The complex shape of the propeller hub requires precision in the casting procedure to guarantee accurate measurement, excellent surface quality and also minimum defects. The investment casting method known for its versatility for different materials such as aluminium alloy, stainless steel and also nickel based alloys that is suited for the propeller applications. In this thesis report also discusses an experimental parameter that concerned with the optimization of investment casting parameter for propeller hub to improve the mechanical properties of LM25 aluminium alloy. The LM25 investment casting product were studied in this thesis report based on the parameter of investment casting within the parameter of types of mixture, number of layers and also preheat temperature. 9 experiments were conducted to asses the effect of this parameter.The optimization process for propeller hub ceramic shells will be determined by the analysis of mechanical properties which will be performed by using the tensile testing, hardness testing and also elongation in the tensile testing and analyze the data by using the Taguchi method. This experiment aims to optimize the the overall efficiency of investment casting for complex components by optimizing the investment casting parameters according to the propeller hub requirements.

# *ABSTRAK*

*Tesis ini membincangkan kesukaran pembuatan acuan hab kipas, memfokuskan kesukaran yang disebabkan oleh reka bentuk geometri yang kompleks. Bentuk kompleks hab kipas memerlukan ketepatan dalam prosedur tuangan untuk menjamin pengukuran yang tepat, kualiti permukaan yang sangat baik dan juga kecacatan minimum. Kaedah tuangan pelaburan yang terkenal dengan serba boleh untuk bahan yang berbeza seperti aloi aluminium, keluli tahan karat dan juga aloi berasaskan nikel yang sesuai untuk aplikasi kipas. Dalam laporan tesis ini juga membincangkan parameter eksperimen yang berkaitan dengan pengoptimuman parameter tuangan pelaburan untuk hab kipas untuk menambah baik sifat mekanikal aloi aluminium LM25. Produk tuangan pelaburan LM25 telah dikaji dalam laporan tesis ini berdasarkan parameter tuangan pelaburan dalam parameter jenis campuran, bilangan lapisan dan juga suhu prapanas. 9 eksperimen telah dijalankan untuk menilai kesan parameter ini. Proses pengoptimuman bagi cengkerangseramikhab propeller akan ditentukan melalui analisis sifat mekanikal yang akan dilakukan denganmenggunakan ujian tegangan, ujian kekerasan dan juga pemanjangan dalam ujian dan analisis tegangan. data dengan menggunakan kaedah Taguchi. Percubaan ini bertujuan untuk mengoptimumkan kecekapan keseluruhan tuangan pelaburan untuk komponen kompleks dengan mengoptimumkan parameter tuangan pelaburan mengikut keperluan hab kipas.*

## ACKNOWLEDGEMENTS

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| | | |
|---|---|---|
| ˚C | - | Degree Celcius |
| % | - | Percentages |
| kg | - | Kilogram |
| N | - | Newtons |
| kgf | - | Kilogram-force |
| ‘’ | - | Inch symbol |
| sec | - | second |
| kN | - | Kilonewtons |
| N/A | - | Not Applicable |
| N.D | - | Not Defect |
| Cu | - | Copper |
| Mg | - | Magnesium |
| Si | - | Silicon |
| Fe | - | Iron |
| Mn | - | Manganese |
| Ni | - | Nickel |
| Zn | - | Zinc |
| SiO2 | - | Silicon Dioxide |
| Al | - | Aluminium |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

A basic propeller comprises two components which is the blades and also the hub (Coşkun and Doğru n.d.). The propeller hub is a crucial part and has a complex profile. The propeller hub is a crucial part and has a complex profile of a marine engine as it acts as one of the drive systems for any marine transportation. This propeller plays an essential function in the movement of marine vessels and is situated on the exterior of the boat, connected to the propeller blade. When selecting a propeller hub with a complex design, it is essential to consider its stability, lifespan and cost. Propeller hub are commonly constructed from materials such as steel, aluminium and cast iron. However, recent research has shifted towards the use of aluminium alloys and other similar alloys (Harsha Vardhan et al. 2019) The purpose of this paper is to provide the development of investment casting shell mold for complex shape propeller hub. The investment casting method is commonly employed for the production of small, complex castings with thin wall (W. Everhart and J. Chen n.d.). Investment casting also referred to as a "lost wax casting" has been a common practice for decades. It is widely recognised for its production with an excellent surface finish, precise dimensions and also complexshapes (Pattnaik, Karunakar, and Jha 2012). This technique of investment casting process is a particular technique that suitable for producing a propeller hub or other components with a complex shape. For this purpose, the shell mold or the ceramic shell is a disposable pattern that used to create the mold cavity for the propeller hub.

## 1.2 Problem Statement

The research has focused on the production of shell mould of the propeller hub encounters the difficulties in breaking the mould due to its complex shape and geometric design. The propeller hub design exhibits a complex shape with a complicated geometry and high level of dimensional precision. The casting process is a crucial for ensuring the accurate dimensions, high quality surface finishing and also minimal surface defects in the production of propellers. The investment casting process is used for the purpose of manufacturing the complex components with precise dimensions, thinner walls and also high-quality of surface finish. Investment casting is a versatile process that can accommodate a range of materials including the stainless steel, aluminium and nickel-based alloys, making it suitable for the propeller applications.

Therefore, the development of the ceramic shell mold for investment casting plays an important part in every aspect of the investment casting process (Jones and Yuan n.d.). Investment casting is a precise and labor-intensive process used to manufacture complex and valuable components for several specialized industries. Currently, the manufacturing process for the mould requires 72 hours due to the necessity of carefully removing moisture in a controlled manner during the water-based colloidal gelation process for each layer. If a sufficient amount of moisture stays arounds, the previous coating will lack the necessary mechanical strength to support the laying of another layer. Drying and strength development are the most important rate-limiting factors for the business when it comes to reducing the lead times (Jones and Yuan n.d.).So, to improve the investment casting process, the research and the development effort is a must to improve the issue.

## 1.3 Research Objective

The main aim of this research is to to finding the best result of good surface finish, high dimensional accuracy, optimization the cost and also high quality of propeller hubs that suitable for the demanding application.

a) To determine the optimal settings of investment casting parameters such as combination type of mixture , number of layers and also preheat temperature.

b) To measure the mechanical properties towards the tensile testing, hardness testing and elongation in tensile testing.

c) To propose optimize parameter for propeller hub ceramic shells.

## 1.4 Scope of Research

The scope of this research are as follows:

- Identify the ideal materials for the investment casting process for propeller hub ceramics shells.
- Determine the suitable mixture and ratio of ingredients in the investment casting mixture.



- Perform a tensile, hardness and elongation testing on representative samples according to the standards and procedures.
- Perform a statistical analysis on the data to evaluate the impact of process parameters and the selection of material on the mechanical properties.
- Optimize the investment casting parameters such as the type of mixture, the number of layers and the preheat temperature according to the requirements of the propeller hub.

## 1.5 Rational of Research

Accordingly, to the research, there are several rational of research that are importantly consider as follows:

a) The selected materials must be suitable for the investment casting process ensuring easy manufacture and minimizing difficulties during the production.
b) Optimizing the material selection that has an effect on the final characteristic and performance of the propeller hub ceramic shells.
c) Furthermore, Tensile, hardness and elongation tests provide exact information regarding material performance, helping in preparing for the actual behavior and potential points of failure.
d) Then, performing statistical analysis on the test data enables an understanding in determining of the relationships between process parameters, material selection and also mechanical properties. This knowledge enables the investigation of more options for optimising the casting process and selecting materials.



## 1.6 Thesis Arrangement

The purpose of this study is about the research and development of investment casting process for complex shapes propeller hub. This report chapter consists of introduction, literature review, methodology, result and discussion. In PSM 1 it will cover Chapter 1, Chapter 2 and Chapter 3 meanwhile for the PSM 2 it will cover Chapter 4 and Chapter 5. Chapter 1 is about the introduction of research outside of the background study, problem statement, objectives, scope of research and the rational of the research. Chapter 2 is about the literature review of previous research and contains the introduction of investment casting, the combination of percentage between refractory powder and colloidal silica. For chapter 3 is the overview methodology in detail regarding the preparation of material and also a preparation of process in making a shell complex for complex shape propeller hub. The preliminary result and data analysis will be discussed in chapter 4. All the data that collected are from the previous study that relate with this study.

## 1.7 Summary

As a conclusion, this chapter not only includes about the project information but also include the basic knowledge for the readers to understand the essence of what the usage of this project. This chapter provides the project objectives, the problem statement from the previous research, the scope of the project and the rational of the research. The problem statement is then used to improving the parameter percentage of the refractory powder and colloidal silica for get a better surface finish and also optimization the cost. Lastly, the project scope is quite unique and require the efficiency.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter will more focusing on the details of investment casting and also ceramic shell mould build up process for a complex shape propeller hub. A propeller hub is a complex shapes component for the casting process to make a shell mold of propeller hub, the suitable method to use in the casting process is the investment casting process. In investment casting process, it can create a complex casting shape with a high standard of dimensional precision and also a smooth surface polish and also design flexibility that can't be done by utilising other casting technique. The term of investment casting process derives from the use of mobile ceramic slurry characteristic or the 'investment' to form a mold with a very smooth surface (Jones and Yuan n.d.; Pattnaik et al. 2012). Investment casting process is a group of processes in which liquid refractory slurries are used to create the moulds and give a very slight surface roughness to the moulds which is then transferred to the castings. It is important to know the exact percentage will depends on the factorssuch as the material used, the design of the product and the desired surface finish. In casting foundries or any manufacturer in casting, they have their own optimized formula based on their experience and requirements.

## 2.2 Investment Casting

Investment casting is the most common method used in the precision casting industry for producing components with complex geometries, tight accuracy and also an excellent of surface finishes (Bansode, Phalle, and Mantha 2019; Özer et al. 2020). Investment casting is also a term for a group of methods in which liquid refractory slurries are used to make casts. Investment casting is also can be called as a “lox wax casting” (Dave and Kaila n.d.; Prasad 2012). The investment casting process is commonly used when working with both ferrous and non-ferrous materials to produce complex shapes. The investment casting process involves the use of either the solid shell mould method, the ceramic shell method or a combination of both to create a shell mould (Dave and Kaila n.d.). Figure 1 show the primary steps involved in creating a ceramic shell mould for use in investment casting. Dimensional precision, surface polish and design flexibility are all enhanced by the investment casting. Investment casting normally has a very good surface finish (2 μm to 4 μm) and close dimensional tolerance limits (± 0.08 mm in a 25 mm overall size). During the process, a wax or plastic design is covered or “invested” with a refractory material that acts as a mold into which metal can be cast.



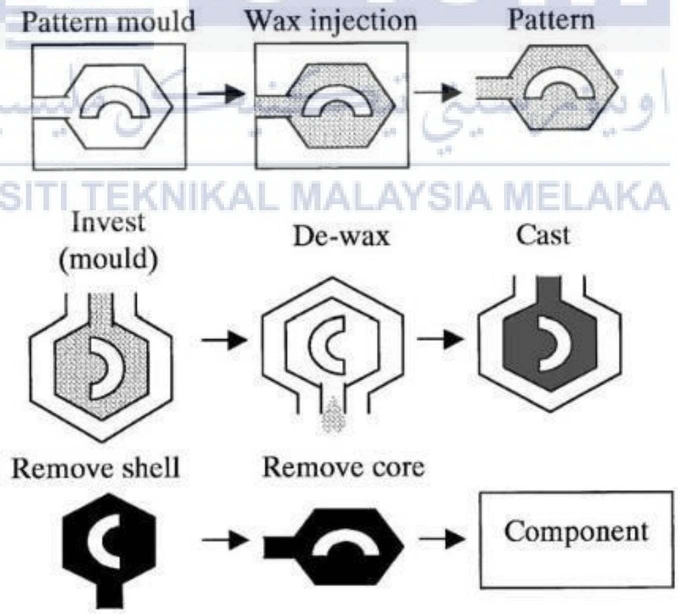
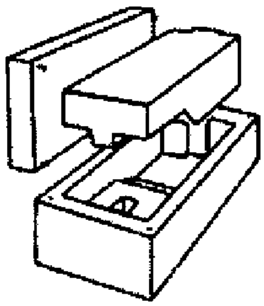


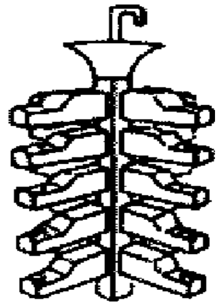
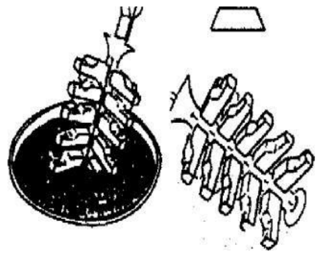
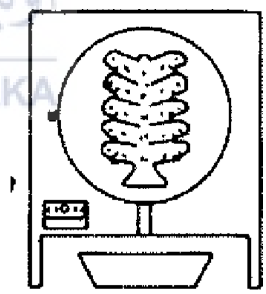
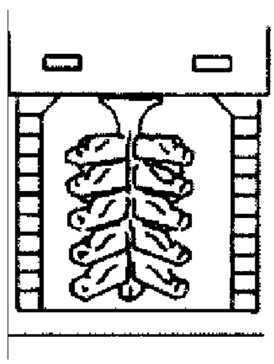

Figure 1.0: Basic Steps of the investment casting (Jones and Yuan n.d.).

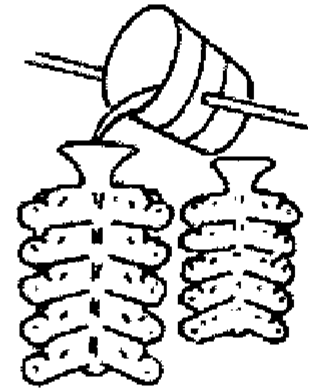
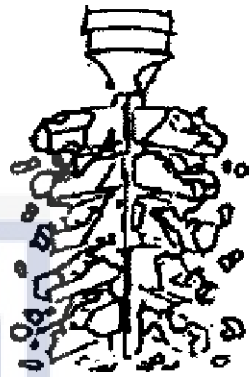
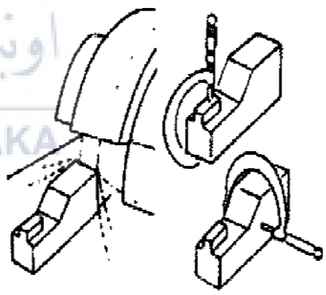
### 2.2.1 How the Investment Casting Process Works

The investment castingtechnique sometimes known as the “lost wax” method, allows for the creation of castings with complex geometries and a wide range of achievable wall thickness (Angrecki et al. 2019) , (Kumar et al. 2019) , (J. Kolczyk-Tylka 2023) , (Ao and International Association of Engineers. 2011) . Making the ceramic shell mould is an essential step in investment casting process (Yuan and Jones n.d.). Investment casting has a distinctive characteristic which it is ability to reproduce a CAD design using wax to create the pattern for the manufactured item also a technique that can be used to create complex elements and components.There are several distinct stages involved in designing and fabricating the applicable workpiece. This is because the parts are poured and fastened into a mould that once include a shelled casting which is subsequntly removed. In order to make a pottery shell mould using the investment casting method, there are eight steps which is making a pattern, putting together on an assemblt tree, making a shell mould, taking off the shell, finishing the mould and checking it. It is crucial to tick this off the lost to ensure a high - quality final casting. In Table 1.0 there a provided brief summary of the investment casting procedure.

Table 1.0: Investment Casting Process (Prasad 2012).

| Process | Description | Illustrations |
|---|---|---|
| Pattern Making | The pattern is carved out of the wax using various tools. It is possible to use injection moulding to fashion it into a mould to carve it by hand out of a block of wax or to print it using a 3D printer and the appropriate wax material. |  |

| | | |
|---|---|---|
| Pattern Assembly | Construct a several pattern and link each one of them to a “gate”. For the purpose fabricating the required workpieces here is where the metal and any other materials will be placed. |  |
| Investment and Stuccoing | After the tree has been placed, the shells should cast all around it. First, the object was submerged in a ceramic slurry. After that, it was coated with a plaster made of fine sand. Before the moulding can be used, it needs to be allowed to completely fry out. Repeat these two steps as many times as necessary until the mould is robust enough to withstand the stresses of casting. |  |
| Dewaxing | Before selecting a material to use for the new shell, the wax pattern must be eliminated first. This method involves heating the wax with steam or by cooking it in an oven beforehand. The oven is used to heat the wax. The mould is flipped on its side so that the liquid wax may flow out and the resulting design can be utilized to build another was pattern. The wax can also be removed from the shelled casting by heating it until it “burns off” and completely removed from the surface of the casting. |   |

| | | |
|---|---|---|
| Firing and Casting | When the wax has been removed, the formal wax pattern will be able to be seen inside the shelled casts where they were cast. The molten metal or another liquid is poured into the casting once it has been prepared. The material is left in the mould until it has completely cooled and solidified into this final form. |  |
| Knockout Process | Hammers and other implements are utilized in order to chip away at the solid casting until nothing but the natural tree is left. The wax patterns will be removed and the last three components will have their final attachments made. After casting has been removed, the workpiece is cut carefully form the tree. |  |
| Finishing and Inspection Operations | Each individual workpiece is examined to see whether or not it has any defects or irregularities. In any found, there will be thrown away and maybe recycled as well. Sanding, coating, smoothing by hand or using a machine are all viable options for the finishing procedure. |  |

## 2.3 Shell moulding in investment casting process

Shell moulding was created for the first time in the 1940s and has since expanded significantly (Kumar et al. 2019) , (Soroczynski, Haratym, and Biernacki 2019). By using a shell moulding process, it can make a variety of castings with low cost, good surface finish and rigid dimensional accuracy. Shell moulding is used for the manufacture of high precision moulding cores, cylinder heads, connecting rods and gear housings among other applications. Both solid mould and ceramic shell techniques are available. For many engineering projects, the ceramic shell mould technology has replaced the traditional investment casting process. (Dave and Kaila n.d.). Ceramic cores are utilized in a variety of investment casting processes due to the advantages which is the strength, the refractory qualities and also the stability in the harsh enviromental conditions.

### 2.3.1 Ceramic shell mould

Dr. Johannes Croning, a German scientist created the shell method during the World War II (P.R.Carey n.d.) . The shell process is characterised by the repetitive sequence of invest, drain, cure and strip which occurs throughout the production cycle. Ceramic shell mould is a form of investment casting that utilises the same sort of wax or plastic design, which is first submerged into ethyl silicate gel before being placed into a fluidized layer of fine-grained fused silica or zircon flour (Anon n.d.-b). Ceramic shell mould is a method of investment casting that has been around for a long time. It is quite similar to the process of making plaster moulds with the difference being that it uses refractory materials that are appropriate for use in high-temperature applications. Impellers are example of the common components that may be produced using this method. The slurry in ceramic shell mould is made up of fine-grained zircon, aluminium oxide and fused silica. These three components, together with bonding agent are mixed together and then poured over the design. A fluidized layer of very fine fused silica or zirconium flour is is utilised in the ceramics shell mould process which begins with the ceramics shell mould being submerged in ethly silicate gel. This create the desired microstructure for the finished product. The design is next dipped into a silica with coarser grain in order to build up additional coats and the appropriate thickness before the pattern is put through the heat shock of the pouring process. The remaining steps of the shell moulding process are very much like the investment casting process.

### 2.3.2 Ceramic shell mould built-up process.

Investment casting is a manufacturing method based on lost-wax casting. The mold for casting is consists of ceramic layers. During the investment casting process, the layers of ceramic shell mould have a considerable influence on the end product's quality (Soroczynski et al. 2019).In the process of investment casting, a ceramic mould known as the "investment" is produced by repeatedly carrying out a series of phases that include coating, sprinkling, and hardening. These procedures are repeated until the investment achieves the desired thickness, which is typically between 5 and 15 millimetres (0.2 and 0.6 in) in most cases. The investment moulds are then allowed to dry entirely, which can take anywhere from 16 to 48 hours. Common types of refractory materials that are utilised to manufacture these moulds include silica, zircon, and different aluminium silicates (Lee et al. 2020). In the ceramic shell moulding process, the main or the primary face coat of the ceramic shells is in charge of the surface finish of the casting and it is a key part of the process of building the shell.

The primary face coat has more refractory solids that the outer coatings, so the viscosity of the primary slurries is greater. The subsequent coatings, also known as the secondary coating, are applied to the ceramic shells and are made of a refractory liquid with a reduced viscosity. This slurry improves when its viscosity is decreased, and it penetrates into the porous primary layer, filling the crevices within the refractory stucco particles The ceramic shell's outermost coats, known as tertiary coatings, are comprised of a coarse refractory particle and provide the ceramic shell's basic structure with strength and stability. It is possible to apply five to ten layers of refractory coating, waiting for each one to cure between use, depending on the size, temperature and composition of the metal being cast (O'Sullivan, Mooney, and Tanner 2021). The next step is to shape a ceramic shell according to a pattern. A slurry of colloidal silica or ethyl silicate, combined with a refractory powder such as quartz, for example, fused silica, zircon, alumina or aluminosilicate, can be used to coat the design for this purpose. Then, the dried refractory grains were sieved onto the newly dipped pattern (Batllo 2009).

### 2.3.3 Requirements of preparation of ceramic shell mold.

For the investment casting process, there are few basic steps for the modern techniques for the production of molds. The process begins with making a heat-disposable design. Wax or plastic is injected into a metal die to make the pattern. The pattern is then assembled into an assembly by connecting every pattern gates to a heat- disposable runner.This step completes the process. This process is done more than once. Then, the back of the cluster is covered with several layers of a coarser ceramic material like mullite, alumina or fused silica until ½ to 5/8-inch-thick shell is formed as a self- supporting shell (Smith and Llewellyn n.d.). Therefore, the structure of an investment cast mould consists of layers that alternate of fine and coarser refractory elements that are bound together with a glue that has solidified into a gel-like consistency (Jones and Yuan n.d.). Then, when the shells are heated, molten metal is poured into them and the metal forms inside the shell. After casting, the parts are taken out of the clay shell using either mechanical or chemical method to obtain the parts (Jones and Yuan n.d.).

Ceramic slurry is refractory powder and water slurry which frequently includes colloidal silica as a fluid binder (Pattnaik et al. 2012). Silica sand, alumino-silicates, alumina, and zirconium silicate or zircon are all components of ceramic flour. Availability, pricing, and foundry efficiency all play a role in the decision. Alumino-silicates are derived from calcined, crushed, or powdered clays. Zircon, or zirconiumsilicate, is a popular main coating filler since it is both heat-resistant and non-toxic. Zircon may be mined from the ground and utilized as an excellent first layer stucco.

### 2.3.4 Materials for making shell mould

Shell moulding is widely recognized in the field of art for its exceptional suitability in manufacturing castings that require dynamic balance and complex process and finely-detailed characteristic of the surface (Anon n.d.-c) The quality of the shell mould is dependent upon the composition of the slurry, stucco and also the method that is employed in constructing the shell. Zircon is commonly utilised in the primary slurry or as a stucco in the majority of the investment casting foundries (Bundy and Viswanathan 2008) . Ceramic powder like silica sand, alumino-silicates, alumina, fused silica, zircon, molochite powder, alumino silicate are used in a variety of ways. With the right choice of ceramic materials, metal casts have a smooth surface finish, high accuracy and good properties (Liu Ming-Chuan Leu et al. 2004). Meanwhile, for binder it is another important part of slurry. To make a slurry, it mixed with the ceramic material. There are a few binder materials that can be chosen such as water glass, colloidal silica, silica gel, ethyl silicate, corundum and sodium silicate. For the stucco, the uses of zircon sand and zircon flour are commonly used but there are also mulite, corundum powder and molochite.

The study utilised a mixture of colloidal silica and zircon flour to construct the mould enclosing the wax pattern (Pussepitiya, Adikary, and Gunawardena n.d.). Typically, ceramic slurry is prepared by mixing environmentally acceptable water-based binders that contain silica sol, along with a small quantity of antifoam and wetting additives with refractory powders.

### 2.4 Shell mould properties.

The key requirement and ceramic shell mould properties for investment casting are as follows (Jones and Yuan n.d.):

i. Sufficient green (unfired) strength to withstand wax removal without failure.

ii. Sufficient fired strenght to withstand the weight of cast metal.

iii. Sufficiently weak to prevent hot-tearing in susceptible alloys.

iv. High thermal shock resistance to prevent cracking during metal pouring.

v. High chemical stability.



vi. Low reactivity with the cast metal to improve the surface finish.

vii. Sufficient mould permeability and thermal conductivity to maintain an adequate thermal transfer through the mould wall and ultimately the casting.

viii. Low thermal expansion to limit dimensional changes within the mould wall and ultimately the casting.

## 2.5 Propeller hub

The main parts of a marine propeller assembly consist of the blade, hub , cap attached to the hub and propeller shaft. The propeller hub is an essential component of the ship. The selection of a propeller is influenced significantly by factors like stability, lifespan and also costs. Conventionally, propellers have been manufactured using materials such as steel, aluminium and cast iron. However, in recent years, there has been a movement towards using an alloy for propeller production. Some commonly used alloys for propellers include aluminium alloys and copper alloys. Among these alloys, NAB and MAB are widely utilised (Harsha Vardhan et al. 2019).

## 2.6 Material Selection of Molten Metal

A variety of metals, both ferrous and non-ferrous, can be utilised in investment casting. Any metal can use as long as it melts in a regular inductive furnace or vacuumfurnace. Investment casting is particularly well-suited to hard-to-machine materials. (Vidyarthee and Gupta 2017). Very few alloys are unable to be investment casting but in order to ensure an optimal and cost-effective design, it is important to adhere to specific principles regarding alloy selection. The metal or alloy that is used must have the necessary properties and characteristic in order to perform the required component function (R F Smart n.d.). It is not always that the material that is selected should also be able to be cast soundly and reproducibly in the desired configuration.

Hence, foundry properties also known as “castability” constitute a crucial component in the selection process. Castability involves in a variety of features such as the capacity of liquid metal to run into and fill the mould, the capacity of metal the metal to resist breaking during the solidification process and the inclination to porosity resulting from shrinkage contraction throughout the solidification and cooling processes. The thinner the casting and the more complex the casting configuration, the greater the importance of castability. Figure 1.1 show the typical alloy groups in investment casting process and the specification. Aluminium alloy has excellent mechanical properties and possesses a low weight accompanied by a high strength to weight ratio. Aluminium alloy also has additional properties such as recyclability, resistance to corrosion, durability, formability and conductivity (Author 2012). The structural, aerospace, marine and also the automotive industries all are uses the aluminium alloys extensively.

**Carbon and Low Alloy Steel**
Based on BS3146 : Part I : 1974

**Corrosion & Heat Resisting Steel**
Based on BS3146 : Part II : 1975

**Nickel & Cobalt Superalloys**
Some of the nickel alloys are included in BS3146 : Part II. Most of nickel and cobalt superalloys are known by trade designations.

**Aluminium Alloys**
Many based on BS1490, LM series or aerospace series (BSL99, DTD716 etc)

**Copper Alloys**
Mainly based on BS1400

**Magnesium Alloys**
Alloys based on BS2970

**Titanium Alloys**
Based on range of commercial $\alpha$ or $\alpha$ $\beta$ titanium base alloys.



Figure 1.1: Investment casting Alloys and UK specification(R F Smart n.d.)

### 2.6.1 Appropriate molten metal material for investment casting

Based on table 2.0, the most suitable material that can be used for manufactured shell mold in investment casting is aluminium alloys. The process of adding extra elements to a parent metal in order to improve its strength, workability, corrosion resistance and electrical conductivity is known as alloying. Melted aluminium is mixed with additional elements such as iron, copper, magnesium, silicon and zinc before cooling to form a homogenous solution.

Table 2.0. Appropriate material for investment casting (Vidyarthee and Gupta 2017).

| Material | Fluidity | Shrinkage | Resistance to hot tearing | Castabiliy rating |
|---|---|---|---|---|
| Carbon steels | | | | |
| 1040 (G10400) | B | B | B | B+ |
| 1050 (G10500) | B | B | B | B+ |
| Alloy Steels | | | | |
| 2345 (G23450) | B | B | B | A- |
| 4130 (G41300) | B | B | B | A- |
| Nickel Alloys | | | | |
| Monel (QQ-N-288-A) (N04020) | A | B | B | B+ |
| Inconel 600 (AMS 5665) (N06600) | A | B | B | B+ |
| Cobalt Alloys | | | | |
| Cobalt 21 (R30021) | A | A | B | A |
| Cobalt 31 (R30031) | A | A | B | A |
| Aluminium Alloys | | | | |
| A356 (A13560) | A | A | A | A+ |
| C355 (A33550) | A | A | A | A+ |
| Tool steels | | | | |
| A-2 (T30102) | B | B | B | B+ |
| H-13 (T20813 | B | B | B | B+ |
| Copper Alloys | | | | |
| Gunmetal (C90500) | A | C | A | B+ |
| Beryllium copper 10C (C82000) | A | C | A | B+ |

A-Excellent, B-Good, C-Poor

### 2.6.2 Aluminium Alloy (A356)

Based on table 2.0, aluminium alloy (A356) is a most suitable material that can be used for making a shell mold for complex shape propeller hub. Aluminium alloy (A365) is a member of the 3xxx series of aluminium-silicon (Al-Si) Alloys which is one of the most prevalent types of casting alloys. A365B contains 92.05% aluminium, 75 silicon, 0.2 % iron, 0.2% copper, 0.35% magnesium, 0.1 % zinc and 0.1 % manganese (Tinto n.d.). The strength qualities of this alloy are often improved by subjecting it to heat treatment. The material (A356) is utilized extensively in the production of a wide variety of marine, electrical and many other industry (Anon n.d.-a). The process of preparing melting and pouring molten aluminium alloy was carried out using aluminium alloy A356 (Areo et al. 2019).

### 2.6.3 Ceramic shell mould for non-ferrous alloy.

In investment casting, a ceramic shell mould is a popular type of mould. It can be used to cast a non-ferrous like copper, bronze, brass, titanium and aluminium. The shell mould is an important part of the investment casting process. . It needs a high strength and have a good surface finish on the outside layer. Jones states that he found that the shells made of pottery by colloidal binders have very low green strengths which are prone to cracking during wax removal and handling. Then, Jones and Leyland also stated that they found that the green strength of the ceramic shell mould could be increased by adding the soluble organic polymers (Pattnaik et al. 2012). In addition, the uses of recycled ceramic material that obtained from the ceramic layered moulds which contains the aluminosilicates can also greatly reduce the production costs in the investment casting foundries (Soroczynski et al. 2019). Aluminium alloys which also a non-ferrous material are used a lot in the industry and have become a valuable material because of the properties such as lightweight, strong, resistant to corrosion, conductivity and also formability. The strength and durability of aluminium alloys vary widely. This is not just because of the different pasrts of each alloy but also because of how they are heated and manufactured. Its strength can be adjusted to the applications needs by modifying the alloys composition (Author 2012).

### 2.6.4 Ceramic shell mould strength and performance

Due to the need to use controlled the moisture removal, making the mould takes a long time. At the moment, it takes between 24 and 72 hours, based on the part. Drying and strength development are the most important rate-limiting factors for the industry when it comes to reducing lead times and producing costs (Jones and Yuan n.d.). Therefore, one of the most important aspects that need to ensure the proper operation of the investment casting process is the strength and performance of the shell (Yameng and Zhigang 2018).

## 2.7 Summary

Since investment casting process are considered as a accurate production method for components that have a complicated design and need a surface finish and also a precision dimensional. So, there a a technique of shell moulding to create the components. To better understand shell moulding in investment casting, information and knowledge from all previous studies that are relevant to this study have been compiled in this chapter, along with references to the theory. The information obtain will help with the development of a shell with a suitable material that can provide a shell moulds strength.

The issue is that zircon are almost all foundries uses it as a primary coat or as a stucco because of zircon have an excellent of functionability. At the same time, zircon is much pricey. So, from the literature a new development of ceramic shell mould by using other material that can substitute a zircon is widely researched. Therefore, this thesis also attempts to initiate a new development of material which is the uses of aluminium silicate as a refractory powder and a sodium silicate as a binder for a slurry in making a shell mold for complex shape propeller hub.

In order to solve the problem that was described before , there is an oppoetunity for research to examine, explore and create a new approach that is integrated and effective for shell mould investment casting. The shell mould is aimed toward designed with the most apppropriate material, the lowest cost material and reasonable accuracy. This is the main focus of this thesis. The following chapter 3 shall discuss the proposed in detail.

# CHAPTER 3

# METHODOLOGY

## 3.1 Overview of the methodology.

Investment casting has been widely utilized for centuries. It is well-known for manufacturing components with exceptional surfacetextures, precise dimensions and complex shapes. This chapter discusses the appropriate planning and methods used in this research to ensure that all specified objectives are met. This chapter will examine and describe in detail the utilized material, fabrication method and also the relevant experimental testing and analysis of this research. The existing material for shell mold will be determined in this chapter and the shell mold will fabricated using an investment casting process.

In order to build the shell mold, currently it takes between 24 and 72 hours to manufacture moulds because controlled moisture removal is required for water-based colloidal gelation on each coat. Therefore, a suitable material also needs to be considered which to prevent flaws in the shell mould making (handling stages) and casting processes, the green and fired strength of the material must be increased. The investigation begins with the preparation and testing of the raw materials.

## 3.2 Proposed Methodology

### 3.2.1 Project Workflow

A flowchart is a visual guide that will assit in comprehending the project management plan that you are attempting to put into action. It is really necessary to have a strong flowchart in order to have a successful conclusion for the next job to be success. There are a wide variety of strategies and pieces of information to improve its work process. The data from successive project streams such the investigation conducted for a large number of journals, research projects and book publications may be improved by a top and high efficiency project. The technique for the examination is carried out while making use of the required parameter and perspective in addition to the positives and negatives. After the previous development has been implemented effectively, the final step will be executed. Figure 1.2 illustrate an effective project management workflow.

### 3.2.2 Flowchart of Project

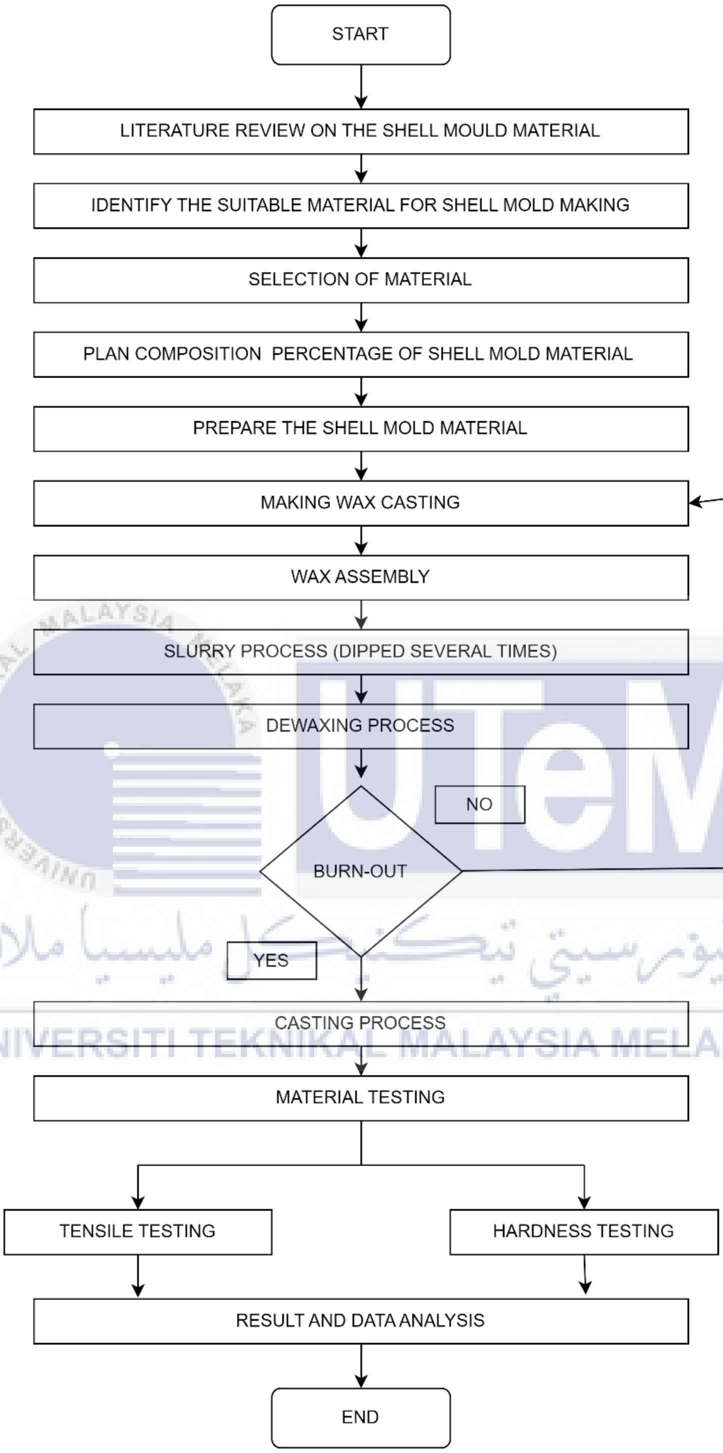



Figure 1.2: Project management workflow

## 3.3 Experimental Setup of Investment Casting

### 3.3.1 Making of Wax Pattern

Wax is heated to the appropriate temperature to create a molten wax. Wax is then poured into the mould section to form a wax layer. The single piece wax model is an exact replica of the casting. After the wax has completely cooled, open the mould and start the process over again, starting with pouring the hot wax ang going on until the wax has cooled completely. This method is carried out multiple times for the tree that will serves as the mould for the shell. Making of the wax pattern are as shown in the figure 1.3.



Figure 1.3: Pattern Wax Casting

### 3.3.2 Pattern Assembly

In order to construct an assembly, these designs are first mounted on a pouring cup and they are attached to a "tree" which is a central wax stick. Assembly of the wax pattern are as shown in the figure 1.4.


Figure 1.4: Pattern Assembly

### 3.3.3 Production of Ceramic Slurry

In the liquid ceramic slurry process, colloidal silica and zircon flour are being used as the binder and refractory powder. The ratio of the zircon flour and colloidal silica has been set at a fixed ratio of 3:1 (Pattnaik and Sutar 2021) . Then, stir the mixture by using the pedestral drilling mixer.To achieved the required viscocity, use an ASTM 4212 viscosity cup to measure it within 20-30 second. After that, the wax pattern is repeatedly soakings into the ceramic slurry which apply 4,5,6 layer of slurry Taguchi method. This ceramic layer is a crucial process in investment casting. The slurry preparation are as shown in the figure 1.5.



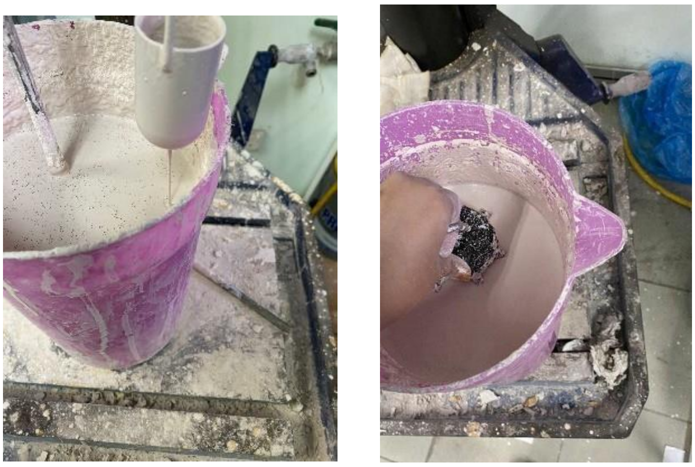


Figure 1.5: Slurry preparation

### 3.3.4 Ceramic Coating Process

Make a process commonly referred to stucco coating. The combination of the stucco material are contribute between two material which is silica sand and also the Plaster of Paris. The composition percentage of stucco are based on table 3.0.The percentage value are based on 1 kg mixture of stucco. Then, apply 4,5,6 layer of stucco based on Taguchi method. Coating process are also a crucial process in investment casting. Then the product was dried out in the open air that is protected from the direct sunlight. The coating preparation are as shown in the figure 1.6.

Table 3.0: Experimental value for stucco coating

| NO. EXPERIMENT | MIXTURE | SILICA SAND | PLASTER of PARIS |
|---|---|---|---|
| 1 | SS1 | 40% | 60% |
| 2 | SS1 | 40% | 60% |
| 3 | SS1 | 40% | 60% |
| 4 | SS2 | 60% | 40% |
| 5 | SS2 | 60% | 40% |
| 6 | SS2 | 60% | 40% |
| 7 | SS3 | 80% | 20% |
| 8 | SS3 | 80% | 20% |
| 9 | SS3 | 80% | 20% |

Figure 1.6: Coating process

### 3.3.5 Dewaxing Process

Traditionally, the dewaxing process has been performed using the autoclave dewaxing and other method. In this study, the dewaxing process is do manually at room temperature and then put the product in the electric ceramic kiln to remove the wax pattern and to reduce the possibility of cracking the shells dring the firing and pouring stages. The temperature will maintain 200 ˚C to 1 hour in the electric ceramic kiln. The dewaxing process are as shown in the figure 1.7.



Figure 1.7: Dewaxing process

### 3.3.6 Preheating Process

Placing the ceramic shell in a wax burnout kiln, the process firing is turned on. It is referred to as the lost wax process from the shell and it consists of baking the shell and melting the wax. The results in a ceramic shell mold is hollow inside. The temperature of baking is 500 C, 600 ˚C, 700 ˚C based on the Taguchi method. Figure 1.8 shown the preheating process.

Figure 1.8: Baking/ Firing Process

### 3.3.7 Casting Process

The ceramic shell is taken out from the wax burnout kiln and molten material is put right into it. After analyzing the working conditions and material qualities, the casting material should be selected. Aluminium alloy A356/ LM25 is chosen to make the propeller hub because it is strong and lightweight in equal measure. The metal heated up to 700˚C and then poured the molten metal into the shell mould and keep the shell mould in the room temperature for cooling. Figure 1.9 shown the casting process.

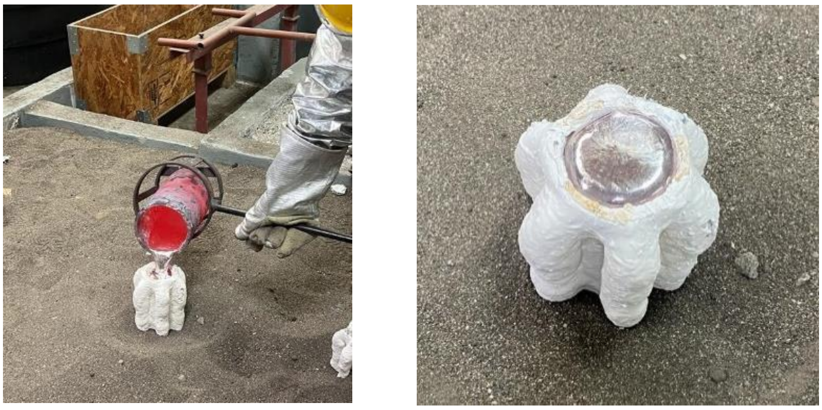


Figure 1.9: Casting Process

### 3.3.8 Knockout Process

After the shell mold has been cast, it undergoes a knockout material removal procedure using chisel, hammer and using a handsaw in order to be cut off into the correct final shape and size. Then, the remaining parts of the casted product have been removed by using a hand saw. Figure 2.0 shown the knockout process and also the cut off the residual parts.

Figure 2.0: Knockout & Cut off Process

## 3.4 Methodology for Optimization

### 3.4.1 Minitab

Minitab is a statistical software package widely used in many industries such as the investment casting for the purpose of analyzing and optimizing process parameters. Within the field of the investment casting, Minitab can be employed to do design of experiments (DOE) and statistical analysis on a crucial process variables including the mould material, layer of the slurry and stucco and also the preheat time. Minitab can be utilized by engineers and researchers to input data and also anaylze the correlations between these factors and the quality that attributes of the cast components. Moreover, minitab assists in visualizing the patterns, forecasting outcomes and eventually supporting well-informed decision making to improve the effectiveness and the quality of the investment casting process.



Figure 2.1: Minitab Statistical Analysis

### 3.4.2 Taguchi Method

The Taguchi technique is a common statistical method that used in engineering and manufacturing which includethe investment casting process. The Taguchi method is utilized in investment casting, a precise method for casting metal to systematically analyze and control various factors that can impact the quality of the final cast product with the aim of optimizing them and improving their overall quality. These factors, reffered to the parameters and variables such as the mixture of material composition, layer and also the preheat time. The Taguchi method approach the minimize the variations, reduce defects and also enhance the overall efficiency and also the reliability of the investment casting. This method is particularly beneficial for obtaining durable and consistent outcomes which improves the quality of the castings in the investment casting process.

“Orthogonal Arrays” (OA) offers a set of experiments that are optimally balanced ,ensuring a minimum level of of an imbalance. The experiment is designed to select the most appropriate orthogonal arrays and allocate the relevant parameters and interactions to their respective columns . Taguchi’s suggestion of utilising linear graphs and triangle tables simplifies the processof identifying parameters. The selection of a particular orthogonal array is determined by the quantity of various factor levels. In this study, it conducted the trials by selecting 3 parameter at 3 levels.Based on the Degree of Freedom calculation, there are 9 set of experiments is stated. Figure 2.2 shows the experimental parameter of investment casting according to the Taguchi orthogonal array.

**Taguchi Design**

**Design Summary**

| | |
|---|---|
| Taguchi Array | L9(3^3) |
| Factors: | 3 |
| Runs: | 9 |

Columns of L9(3^4) array: 1 2 3

| | C1-T | C2 | C3 |
|---|---|---|---|
| | MIX | LAYER | TEMP |
| 1 | SS1 | 4 | 500 |
| 2 | SS1 | 5 | 600 |
| 3 | SS1 | 6 | 700 |
| 4 | SS2 | 4 | 600 |
| 5 | SS2 | 5 | 700 |
| 6 | SS2 | 6 | 500 |
| 7 | SS3 | 4 | 700 |
| 8 | SS3 | 5 | 500 |
| 9 | SS3 | 6 | 600 |

Figure 2.2: Design of Orthogonal Array



## 3.5 Parameter of Investment Casting

### 3.5.1 Selection of material

In manufacture of the shell mould, the assembly dipped with an liquid mixture of zircon flour and colloidal silica. Then, coated with the mixture of stucco which contains different percentage of combination between Silica sand and also Plaster of Paris. Zircon flour was chosen in making a slurry because it has a high density which makes it less reactive with molten metals and it is low thermal expansion compared to silica so makes it more stable in size. It also a high thermal conductivity and make it more resistant to thermal shock. The high refractoriness makes it possible to use smaller particles which improve the surface finish (Bundy and Viswanathan 2008). Meanwhile, for the selection material for casting process, Aluminium alloy A365 has been taken to make that shell mold castings. It is an aluminium alloy that have an excellent mechanical strength, ductility, hardness, fatigue strength, fluidity and machinability. This alloy finds employments in a wide variety of industrial applications, including castings for airframes, machine parts, component for aeroplane and missiles and also structural part that need to have a high level of strength.

### 3.5.2 Zircon flour

Zircon flour is a necessary component used in the investment casting process due to its excellent heat resistant characterstic and stability. Zircon flour is produced by carefully processing the material zirconium silicate to powder. This material is highly valued for its excellent heat resistance which makes it an excellent choice for the refractory material used in the ceramic shells for the investment casting moulds. Zircon flour improves the moulds durability and ability to withstand any unexpected changes in temperature during the casting process, ensuring accuracte replication of complicated characteristic in the result of final metal product. Zircon flour is very suitable for invetsment casting applications due to its refractory characteristic and low thermal expansion which provide both precision and durability. Figure 2.3 shows the zircon flour that been used in this study. The zircon flour are used in the ratio of 3:1 with the colloidal silica.


Figure 2.3: Zircon Flour



### 3.5.3 Colloidal Silica

Colloidal silica is also an important material used in investment casting as it used as a binding agents for forming a ceramic shells. A colloidal silica solution is a substance that consisting of fine silica particles which dispersed in a liquid medium usually water. A colloidal silica is combined with refractory materials, including the zircon flour or with other additives to create a slurry during the invesment casting process. The slurry is then applied onto the wax pattern which result in the formation of a ceramic shells by a sequence of immersions and coatings. Colloidal silica functions as aa an adhesive which increasing the the strength and durability of the ceramic shell ensuring its ability to withstand the high temperatures during the casting procedure. Colloidal silica enhances the rigidity of the shell as it dries and hardens,providing a precise reproduction of fine details from the wax patterns in the final cast product. Colloidal silica plays a crucial role in the success of investment casting due to its malleability and potential to create a strong ceramic shell mould. The colloidal silica also are used in the ratio of 3:1 with the zircon flour. Figure 2.4 shows the colloidal silica that been used in this study.


Figure 2.4: Colloidal Silica



### 3.5.4 Silica Sand

Silica sand is also an important component in the investment casting process as it assists in building the ceramic shells that surrounds the pattern wax design. The use of silica sand as a stucco in investment casting perfoms a distinct function during the beginning phases of the ceramic shells mould formation. Stucco, which consists a combination of silica sand and other additives material is used to add the first layer to the ceramic shell by applying it onto the wax pattern. The ceramic shell coarse and granular texture enables effective layering which is important for establishing its basic structure. The silica sand enhances the strength and durability of the mould when the plaster of Paris layer dries and hardens. Moreover, the specific composition of silica sand ensures excellent refractory properties, allowing the ceramic shell to withstand the difficult circumstances of the investment casting process. This will leads to the manufacturing of complex and precisely engineered metal components. The amount of silica sand are used in the amount of 40 % , 60 % and also 80 % of 1kg amount stucco to combined with the plaster of Paris. Figure 2.5 shows the silica sand that been used in this study.




Figure 2.5: Silica Sand

### 3.5.5 Plaster of Paris

Plaster of Paris is also necessary in the early stages of the mould development when it is used as stucco in investment casting. Refractory material such as silica sand are commonly mixed with the other material to form a stucco mixture. The stucco, which is put onto the wax pattern acts as the primary layer for making a ceramic shell mould. Plaster of Paris enables an invisible and consistent coating due to its viscosity and ability to hold onto complex characteristic. During the process of solidification, the ceramic shell develops a solid base, which enhances its overall strength. The stucco, which is strengthened by the bonding properties of the plaster creates the initial layers that are necessary for the stages of investment casting. This guarantee a strong shell mould that capable of reproducing small details in the final metal casting. The amount of plaster of Paris are used in the amount of 60 % , 40 % and also 20 % of 1 kg amount stucco to combined with the plaster of Paris. Figure 2.6 shows the plaster of paris that been used in this study.


Figure 2.6: Plaster of Paris



### 3.5.6 Ingot material of molten metal (Aluminium Alloy A356/LM25)

The selection of ingot material such as aluminium alloy A356 or also known as LM25 in investment casting is important for the whole casting process. A356 , an aluminium alloy are frequently utilized due to their exceptional ability to be cast and their strong mechanical characteristic. These alloys demonstrated exceptional fluidity in their molten state, enabling them to accurately fill complicated mould details in investment casting. Furthermore, it have advantageous solidification properties, reducing the probability of flaws like porosity. The used of aluminium alloy A356 have an excellent mechanical characteristicsin the final metal castings product including excellent strength and resistant to the corrosion. Due to their relatively low melting points, aluminium alloy A356 are very suitable for investment casting since it can be easily and effectively melted and poured into the ceramic shell moulds. The use of A356 ingot in investment casting in investment casting enables the manufacturing of better, complicated metal components with the exceptional dimensional precision and also the mechanical functionality. The amount of ingots used for one ceramic shell mould is approximately 2 kilograms. Table 4.0 shows the chemical composition of the A356. Figure 2.7 shows the ingot of aluminium alloy LM25 that been used in this study.

Table 4.0: Chemical composition of A365/LM25

| ELEMENT | % |
|---|---|
| Cu | 0.1 |
| Mg | 0.2-0.6 |
| Si | 6.5-7.5 |
| Fe | 0.5 |
| Mn | 0.3 |
| Ni | 0.1 |
| Zn | 0.1 |
| Pb | 0 |
| Sn | 0.1 |
| Ti | 0.2 |
| Al | Bal |


Figure 2.7: Ingot of Aluminium Alloy A356 /LM25.

## 3.6 Process Parameters

### 3.6.1 Selection on Process Parameters

In this particular investigation, there are three process parameters that are taken into a consideration which is the preheat temperature, preheat time and pouring temperature.

### 3.6.2 Dewaxing Temperature

Before pouring the molten metal into the shell mould , the mould is often heated to prevent the thermal shock that might result from the rapid cooling of the metal. Just before the pour, the shell is heated to a temperature of 200 ˚C in order to remove any wax residues and to cause the binder to become more rigid.

### 3.6.3 Preheat Time

The amount of time necessary to heat or burn off the shell in order to get rid of any wax residue and make the binder firm up prior to pouring the molten metal. The burnout in two stages strategy was selected. This part of the burnout process begins with the temperature of room temperature form 25 ˚C for a period of 30 minutes and is then followed by increase in temperature to 500 ˚C , 600 ˚C, 700 ˚C. As soon as the maximum temperature was attained, the mould was subjected to heat for a period of half an hour. For at least two hours, ensure that the temperature remains at the optimum level.

### 3.6.4 Pouring Temperature

When doing an investment casting, the temperature of the molten metal as it is poured into the shell might vary substantially depending on the alloy that is being utilized. Ceramic moulds used in investment casting can withstand temperature above 816˚ C which contributes to an increase of their strength. Pouring temperature for the majority of aluminium alloys is 750˚C. When casting into the ceramic shell, these temperatures ensure that the pouring processes are as effective as they possibly can be and that cooling method are as smooth as the possibly can be. The higher the temperature at which the liquid is poured, the greater the amount of shrinkage that occurs and the longer it takes for the liquid to become a solid.

### 3.6.5 Selection on Mechanical Properties



Mechanical properties are the physical properties substance exhibits when subjected to forces. Mechanical properties include the elasticity modulus, tensile strength, elongation, hardness and fatigue limit. In this study, the following mechanical propeties that was tested are the tensile strength , elongation , hardness and porosity.

#### 3.6.5.1 Tensile strength

Conducting tensile testing or experiments on specimens by using an universal testing machine which can provide data for analysis to evaluate the effectiveness of the experiment. This study involves 21 tensile test specimen based on ASTM B557M. The illustrated of the specimen are shown as in the Figure 2.8. The specimen will be subject under a ultimate tesnsile testing machine with the load 100kN as shown as in the Figure 2.9. The stress-strain curve will be obtained from the test and then will be plotted and analysed in the chapter 4.

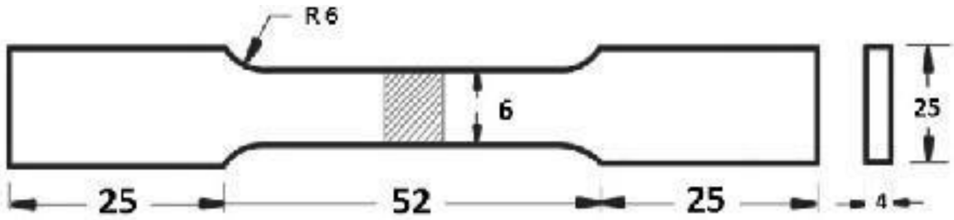



Figure 2.8: Dimension of the tensile test specimen based on ASTM B557M.


Figure 2.9: Tensile test

#### 3.6.5.2 Hardness

When a solid object is subjected to a compressive force, the amount of change that occur in its strength is referred to as the object hardness once the casting process is complete. Metals for instance are more difficult to work with than other types of materials such as plastics. Hardness on a macroscopic scale is often determined by the existence of clear molecular connections. However, the behavior under the pressure is more complicated. There are several different types of hardness measure including scratch hardness, hardness identation and rebound hardness. The Rockwell hardness testing method was utilised in order to obtain an accurate reading of the material hardness. In this study, the HRB will use for the testing because of the material use is aluminium alloy. Aluminiumalloy is categorized in the B scale as shown in the Figure 3.0. The sample will be located under the hardness testing machine, the the steelball will compress within 15 sec and the result will occur at the screen as shown in the Figure 3.1. The type of indenter use in this testing method is ball indenter as shown in Figure 3.2. Moreover, the total force that been applied for this hardness testing based on the B scale is 980.7 N (100kgf).



| ROCKWELL SCALE INFORMATION | | | |
|---|---|---|---|
| SCALE | TYPICAL APPLICATIONS | PENETRATOR | LOAD (kg FORCE) |
| A | Cemented Carbides, Thin Steels, Shallow case-hardened steel | Brale | 60 |
| B | Copper Alloys, Soft Steels, Aluminium Alloys, Malleable Iron | 1/16" Ball | 100 |
| C | Steel, Cast Irons, Pearlitic Malleable Iron, Titanium, Deep case-hardened Steel, other materials harder than B100 | Brale | 150 |
| D | Thin Steel, Medium case-hardened Steel, Pearlitic Malleable | Brale | 100 |
| E | Cast Iron, Aluminium & Magnesium Alloys, Bearing Metals | 1/8" Ball | 100 |
| F | Annealed Copper Alloys, Thin Soft Sheet Metals | 1/16" Ball | 60 |
| G | Phosphor Bronze, Beryllium Copper, Malleable Irons. Upper Limit G92 to avoid Ball Distortion | 1/16" Ball | 150 |
| H | Aluminium, Zinc, Lead | 1/8" Ball | 60 |
| K | Bearing Metals and other soft or thin Materials including Plastics. Use smallest Ball and heaviest Load avoiding Ball Distortion | 1.8" Ball | 150 |
| L | | 1/4" Ball | 60 |
| M | | 1/4" Ball | 100 |
| P | | 1/4" Ball | 150 |
| R | | 1.2" Ball | 60 |
| S | | 1.2" Ball | 100 |
| V | | 1/2" Ball | 150 |

Figure 3.0: Rockwell scale information

Figure 3.1: Rockwell hardness testing




Figure 3.2: Ball indenter 1.5875 mm (1/16”)

### 3.6.5.3 Porosity

The porosity can be seen by using the field-emissions scanning electron microscope (FE-SEM) to examine the microstructure of the inner and also the outer of the surface microstructre of the specimens. The field-emissions scanning electron microscope (FE-SEM) can be seen as shown in Figure 3.3.

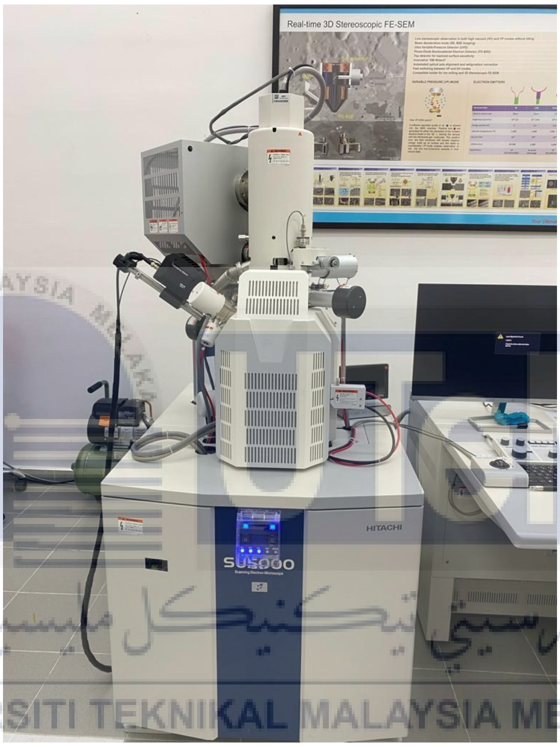





Figure 3.3: Field-emissions scanning electron microscope (FE-SEM) machine

## 3.7 Summary

The proposed methodology main goal is to less time-consuming and reliable without compromising the accuracy of the findings. These methods are also can be utilized in the manufacturing of shell mold for complex shape propeller hub in the future. The ultimate purpose of the technique is not to obtain the highest possible level of accuracy but rather to improve the effectiveness of the product. The product goes through the annealing process after the first phase which is investment casting the followed by material testing to establish the level of the strength and also hardness of material. The recommended process and methodology discussed in this chapter will be demonstrate, verify and further validate the suggested process and methodology presented in this chapter.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

This chapter is presents the result and analysis of the process parameter shell mold for complex shape propeller hub. It is important to note the goal of this case study to demostrate the proposed methodology, regardless limit material that can be use. Case studies are presented to illustrate how the investment casting technique may be utilized when manufacturing a shell mould. The proposed over the method is used to produce a medium range quality of shell mould. During the fabrication of the shell mold through using the technique of invesment casting for the purpose of this study, the three factor that suggest by using the Taguchi is applied. Table 5.0 shows the findings of an experiment on the investment casting especially focusing on the process parameters of the Taguchi L9 orthogonal array. The experiment measured the Ultimate Tensile Strength and Rockwell Hardness Testing (HRB). In this study, there are consists of two experiment whch is experiment 4 and also experiment 7 that have failed two times during after dewaxing process in the manufacturer of ceramic shell mould. This occur due to unbalanced of parameter of mixture and layer of the experiment.

The process optimisation in investment casting involves an organised method to determine the most effective combination of materials and their corresponding percentages, with the goal of improving the overall efficiency of the casting process and simultaneously reducing the costs of the production. The process parameters that involves during the experimental are type of mixture, number of layers and also the preheat temperature.

Table 5.0: Findings of an experiment on the investment casting for Taguchi L9 orthogonal array.

| EXPT. NO. | TYPE OF MIXTURE | LAYER | PREHEAT TEMPERATURE | ULTIMATE TENSILE STRENGTH | ROCKWELL HARDNESS (HRB) | ELONGATION |
|---|---|---|---|---|---|---|
| 1 | SS1 | 4 | 500 | 153.96 | 15.07 | 2.6328 |
| 2 | SS1 | 5 | 600 | 158.71 | 5.20 | 2.5170 |
| 3 | SS1 | 6 | 700 | 134.42 | 15.07 | 2.8293 |
| 4 | SS2 | 4 | 600 | - | - | - |
| 5 | SS2 | 5 | 700 | 164.58 | 14.77 | 2.8895 |
| 6 | SS2 | 6 | 500 | 176.71 | 9.50 | 2.5725 |
| 7 | SS3 | 4 | 700 | - | - | - |
| 8 | SS3 | 5 | 500 | 193.88 | 14.67 | 4.8832 |
| 9 | SS3 | 6 | 600 | 170.92 | 7.57 | 2.6510 |

## 4.2 Comparison result between for average of different experiment for Ultimate Tensile Strength (UTS) , Rockwell Hardness (HRB) and Elongation.

### 4.2.1 Ultimate Tensile Strength (UTS)

Table 6.0 shows the result average of Ultimate Tensile Strength (UTS) meanwhile the Figure 3.4 shows the comparison of Ultimate Tensile strength (UTS) of different experiment . Ultimate tensile strength is the maximum stress of a material that being tested can withstand the applied load. the Based on the chart , experiment 8 gives a highers value of maximum stress. It is important to consider that the material being tested, the testing environment and also the specimen geometry can give an impact on the tensile test results.

Table 6.0: Result of Average Ultimate Tensile Strength (UTS)

| EXPERIMENT | SPECIMEN 1 | SPECIMEN 2 | SPECIMEN 3 | AVERAGE |
|---|---|---|---|---|
| 1 | 198.500 | 141.000 | 122.375 | 153.9583 |
| 2 | 138.875 | 165.875 | 171.375 | 158.7083 |
| 3 | 145.750 | 109.375 | 148.125 | 134.4167 |
| 4 | - | - | - | - |
| 5 | 172.000 | 152.375 | 169.375 | 164.5833 |
| 6 | 164.375 | 170.500 | 195.250 | 176.7083 |
| 7 | - | - | - | - |
| 8 | 184.875 | 204.375 | 192.375 | 193.8750 |
| 9 | 162.750 | 170.000 | 180.000 | 170.9167 |

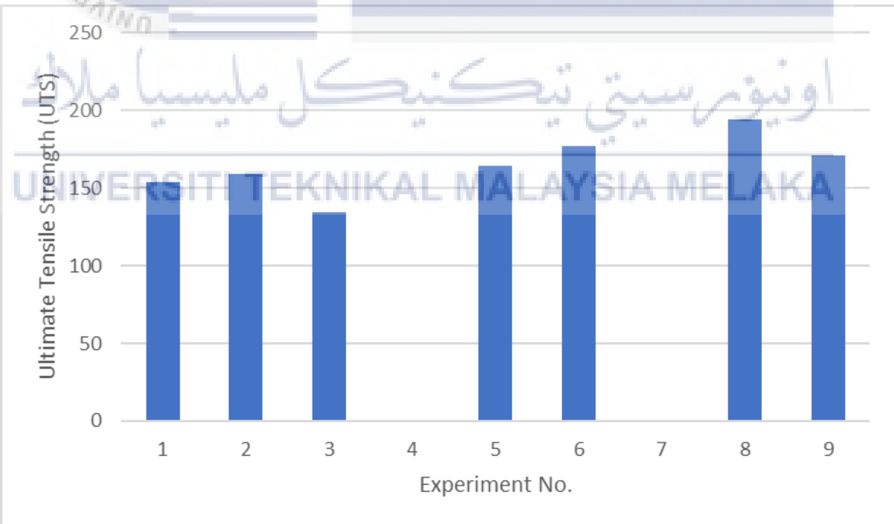



Figure 3.4: Comparison of Ultimate Tensile Strenght (UTS) of different experiment

### 4.2.2 Rockwell Hardness (HRB)

Table 7.0 shows the result of average for rockwell hardness meanwhile Figure 3.5 show the comparison of Rockwell hardness (HRB) of different experiment. Based on the chart , experiment 1 and experiment 3 gives a highers value of hardness.

Table 7.0 : Result of Average Rockwell Hardness (HRB)

| NO.EXPERIMENT | POINT 1 | POINT 2 | POINT 3 | AVERAGE |
|---|---|---|---|---|
| 1 | 18.4 | 10.9 | 15.9 | 15.07 |
| 2 | 8.6 | 2.4 | 4.6 | 5.20 |
| 3 | 16.6 | 12.1 | 16.5 | 15.07 |
| 4 | - | - | - | - |
| 5 | 12.1 | 13.7 | 18.5 | 14.77 |
| 6 | 11.3 | 8.2 | 9.0 | 9.50 |
| 7 | - | - | - | - |
| 8 | 19.9 | 13.9 | 10.2 | 14.67 |
| 9 | 9.7 | 2.7 | 10.3 | 7.57 |



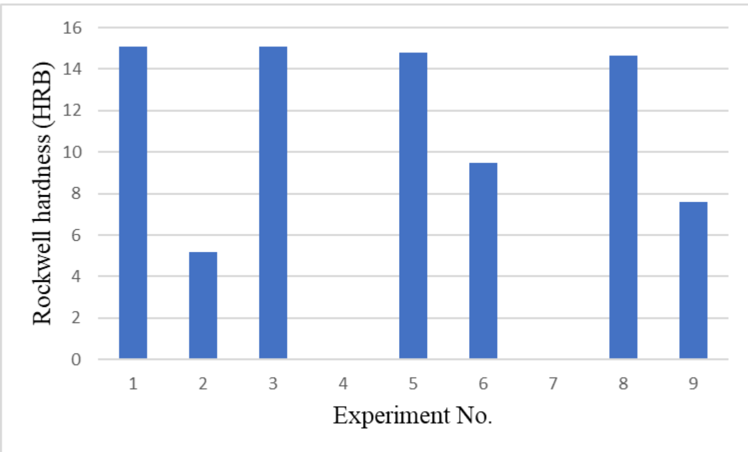



Figure 3.5: Comparison of Rockwell hardness (HRB) of different experiment

### 4.2.3 Elongation

Table 8.0 shows the result of avearge for the elongation of tensil testing meanwhile f igure 3.6 show the comparison of elongation of different experiment during tensile testing. In tensile testing, elongation is the amount of strecth or deformation of a material undergoes before it begins fracture and breaking under tensile forces. It is a gauge of material ductiliy can withstand plastic deformation before it breaking. During a tensile testing, elongation is frequently measured at the fracture or at the maximum load points. It gives a significant information about a materials behavior under the tension especially with regard to its capacity for deformation before it breaking. The higher value of elongation are usually considered to be more ductile meanwhile the lower value of elongation are thought as a brittle material. A ductile material are appropriate for some applications where toughness and deformation capacity are crucial since they can absord large amounts of energy and undergo significant deformation before breaking. So, based on the chart in Figure 3.6, experiment 8 gives highest elongation value during the experiment.

Table 8.0 : Result of Average Elongation of Tenstile Testing

| EXPERIMENT | SPECIMEN 1 | SPECIMEN 2 | SPECIMEN 3 | AVERAGE |
|---|---|---|---|---|
| 1 | 2.5525 | 2.5920 | 2.7540 | 2.6328 |
| 2 | 2.8360 | 2.4370 | 2.2780 | 2.5170 |
| 3 | 2.8130 | 2.1960 | 3.4790 | 2.8293 |
| 4 | - | - | - | - |
| 5 | 2.4825 | 2.6810 | 3.5050 | 2.8895 |
| 6 | 2.1150 | 2.6005 | 3.0020 | 2.5725 |
| 7 | - | - | - | - |
| 8 | 3.9865 | 6.1380 | 4.5250 | 4.8832 |
| 9 | 2.5870 | 2.4720 | 2.8940 | 2.6510 |



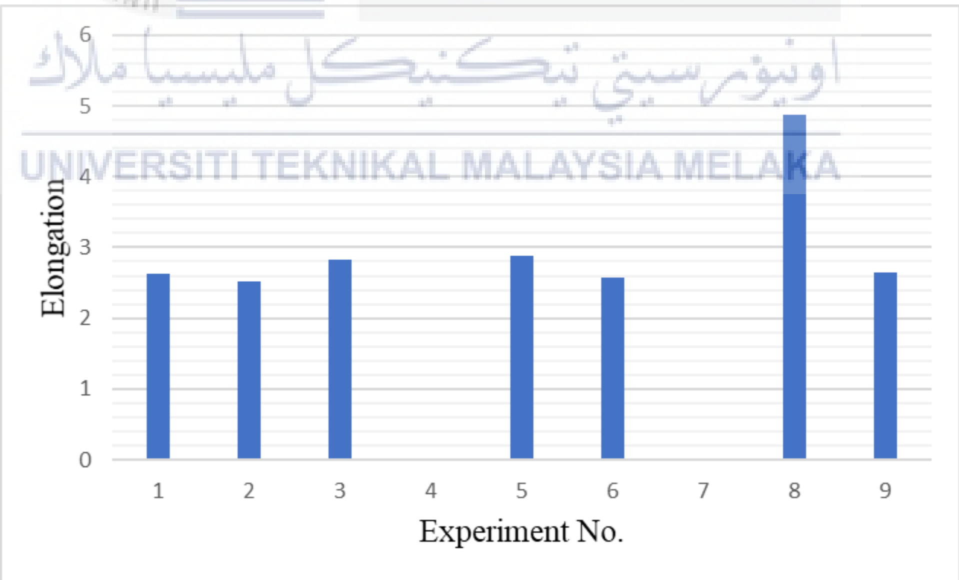



Figure 3.6: Comparison of Elongation of different experiment during the tensile testing

### 4.3 Taguchi Analysis

In the Taguchi analysis method, the term "signal" refers to the desired value or mean for the output characteristic meanwhile the term "noise" refers to the undesired value for the output characteristic. The Taguchi method involves developing a set of experiments to systematically modify the input variables at different levels then measuring the mean performance of the output characteristic. The analysis is also to identify the suitable combination of input factor levels which contributes to the desired mean output. Taguchi uses the Signal-to-Noise (S/N) ratio as a metric to quantify feature deviates from its ideal value. There are multiple signal-to-noise ratios (S/N ratios available with the smaller value being preferred depending on the specific characteristic.

#### 4.3.1 Tensile (Specimen 1), Tensile (Specimen 2), Tensile (Specimen 3) versus Type of Mixture, Layer and Preheat Temperature

Based on the experimental data from tensile testing, the Taguchi method is a statistical method used to optimize the processes by reducing variability. The Taguchi method is use in this experiment data to determine the best combination of Type of Mixture, number of layer and also preheat temperature that gives best result in the highest Ultimate tensile strength. Based on the table 9.0, the data show the response table of means for Ultimate Tensile Strength for every combination of type of mixture, number of layer and also preheat temperature. The delta value represents the difference between the maximum and also the minimum mean values for each factor. The rank values in indicate the ranking of factor according to their influence on the Ultimate Tensile Strength. Based on the table 9.0, it is obvious that the type of mixture has a more important effect on the Ultimate Tensile strength compared to other factors.

Table 9.0 Response Table of Means for Ultimate Tensile Strength

| Level | Type of Mixture | Number of Layer | Preheat Temperature ℃ |
|---|---|---|---|
| 1 | 149.00 | 154.00 | 174.80 |
| 2 | 170.60 | 172.40 | 164.80 |
| 3 | 182.40 | 160.70 | 149.50 |
| Delta | 33.40 | 18.40 | 25.30 |
| Rank | 1 | 3 | 2 |

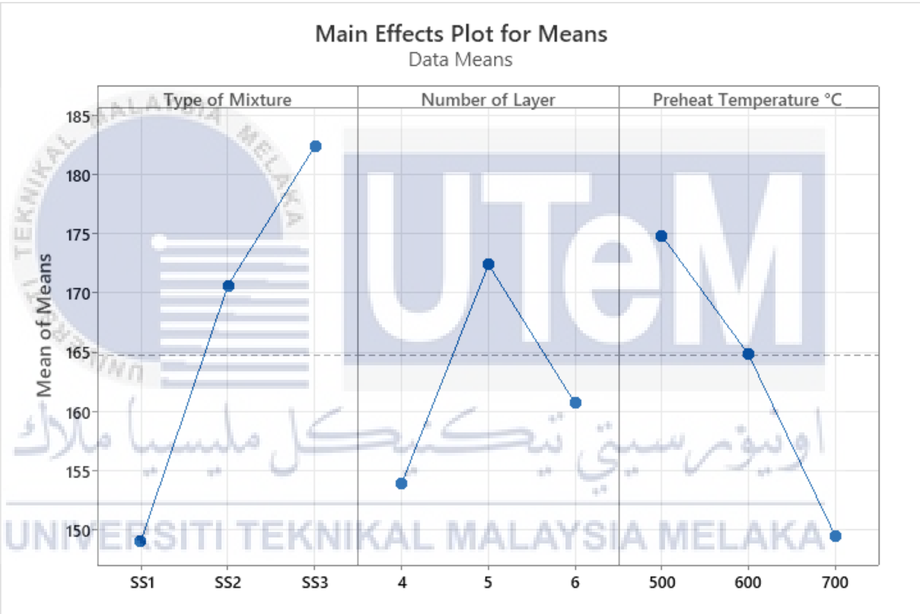



Figure 3.7: Main effect Plots for Mean Ultimate Tensile Strength values

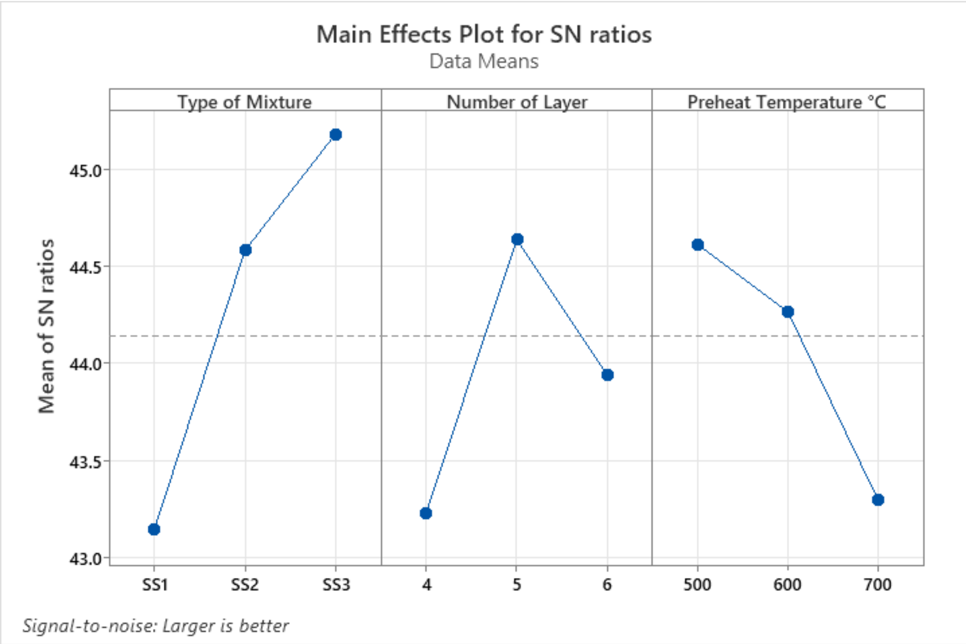



Figure 3.8: Main effect Plots for SN ratio Ultimate Tensile Strength values

### 4.3.2 Elongation (Specimen 1), Elongation (Specimen 2), Elongation (Specimen 1) versus Type of Mixture, Number of Layer and Preheat Temperature

Based on the experimental data from tensile testing, it also can produce a data for elongation. The Taguchi method is use in this experiment data to determine the best combination of type of mixture, number of layer and also preheat temperature that gives best result in the elongation. Based on the table 10.0, the data show the response table of meansfor elongation for every combination of type of mixture, number of layer and also preheat temperature. The rank values in indicate the ranking of factor according to their influence on the elongation. So, based on the table 10.0, it is obvious that the type of mixture also an important effect on the elongation compared to other factors.

Table 10.0: Response Table of Means for Elongation

| Level | Type of Mixture | Number of Layer | Preheat Temperature ℃ |
|---|---|---|---|
| 1 | 2.660 | 2.633 | 3.363 |
| 2 | 2.731 | 3.430 | 2.584 |
| 3 | 3.767 | 2.684 | 2.859 |
| Delta | 1.107 | 0.797 | 0.779 |
| Rank | 1 | 2 | 3 |

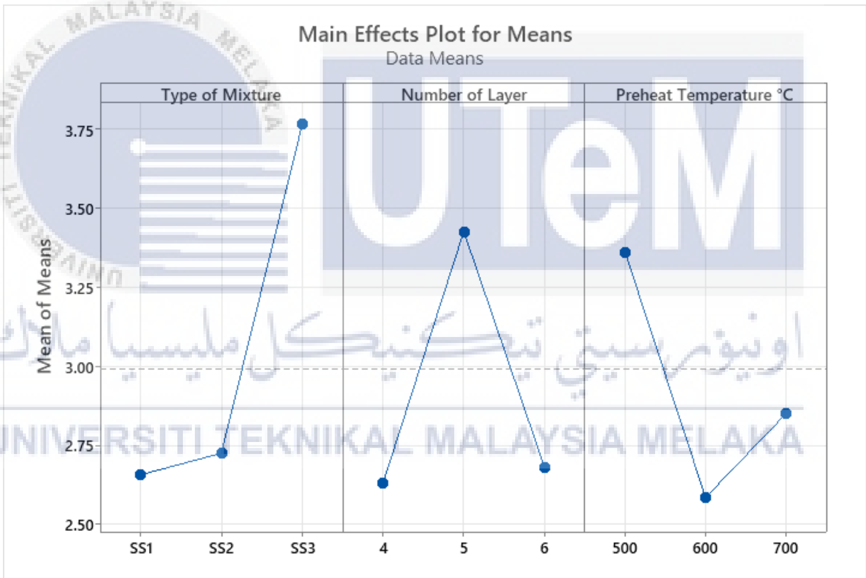



Figure 3.9: Main effect Plots for Mean Elongation values

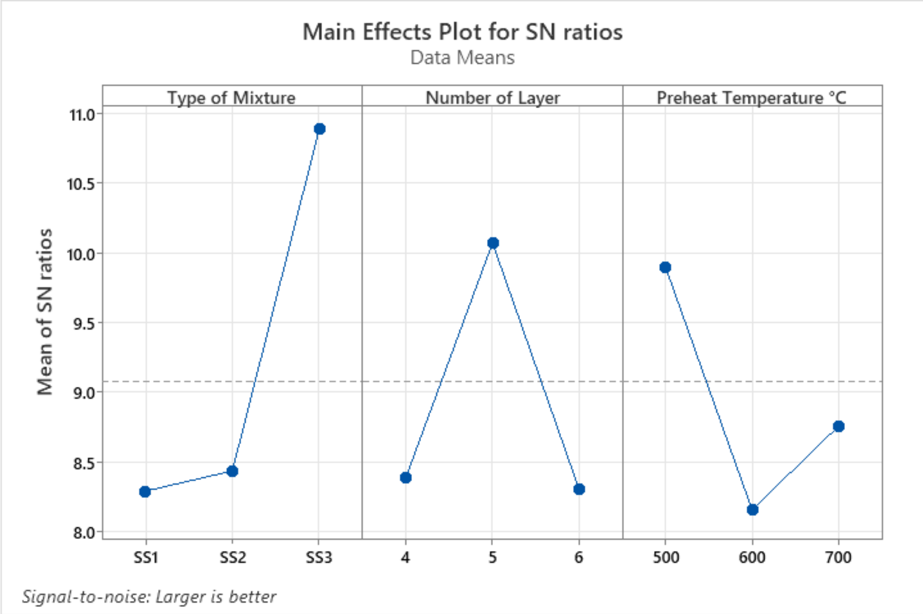



Figure 4.0: Main effect Plots for SN ratio Elongation values

### 4.3.3 Hardness (Specimen 1), Hardness (Specimen 2), Hardness (Specimen 3) vs Type of Mixture, Number of Layer and Preheat Temperature

Based on the analysis of data of Rockwell hardness in table 11.0, it seems the preheat temperature give a big effect on the hardness. This indicates that the preheat temperature gives a big influence of the Rockwell hardness between another factor. Means while the number of layers is the second important thing to determine the hardness and also the type of mixture.

Table 11.0: Response Table of Means for Rockwell Hardness (HRB)

| Level | Type of Mixture | Number of Layer | Preheat Temperature ℃ |
|---|---|---|---|
| 1 | 11.778 | 15.067 | 13.078 |
| 2 | 12.133 | 11.544 | 6.383 |
| 3 | 11.117 | 10.711 | 14.917 |
| Delta | 1.017 | 4.356 | 8.533 |
| Rank | 3 | 2 | 1 |

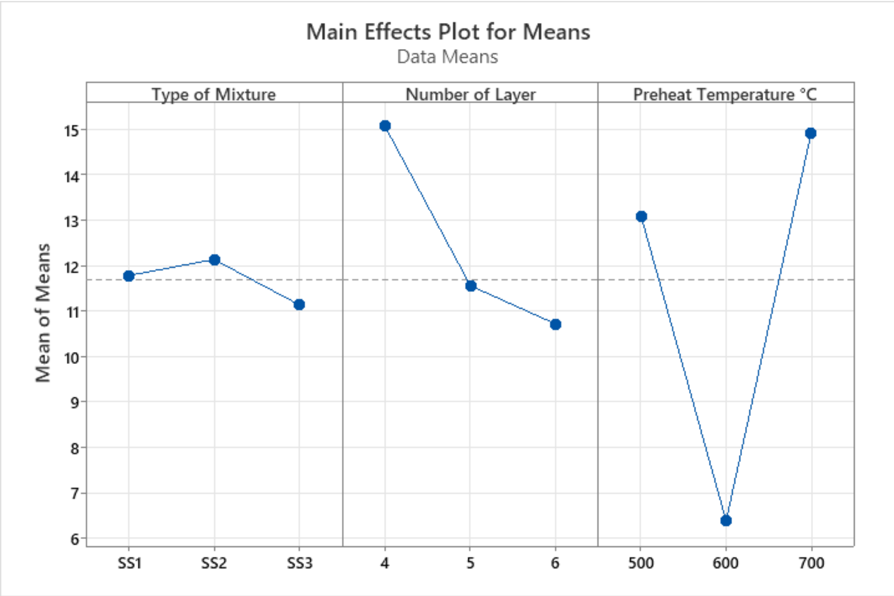



Figure 4.1: Main effect Plots for Mean Hardness values



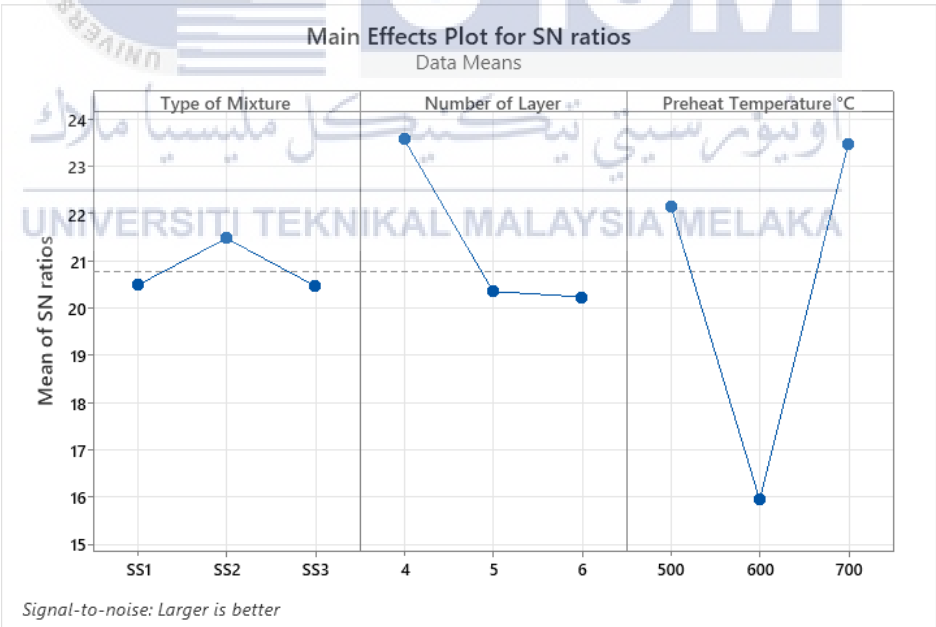



Figure 4.2: Main effect Plots for SN ratio Hardness values

## 4.4 Comparison result between experimental data and main factor parameter of investment casting

### 4.4.1 Ultimate Tensile Strength, Rockwell Hardness (HRB), Elongation vs Type of Mixture, Number of Layer and Preheat Temperature.

The table 12.0 below shows the results data of an experiment conducted in order to investigate the effect of factor of type of mixture, number of layer and also preheat temperature for investment casting on the Ultimate Tensile Strength, Rockwell hardness (HRB) and also the elongation. The delta row in the table shows the differences between the mean values for each level and overall mean. The rank column shows the ranking of each level for each item which one is being the highest rank. Based on the table, it is clearly showing the type of mixture gives an effect in Ultimate Tensile Strength, Rockwell hardness and also the elongation. Meanwhile, the number of layers does not give a significant effect on the type of testing.

Table 12.0 Response table for means of the Ultimate Tensile strength, hardness and elongation.

| Level | Type of Mixture | Number of Layer | Preheat Temperature ℃ |
|---|---|---|---|
| 1 | 54.49 | 57.22 | 63.76 |
| 2 | 61.84 | 62.45 | 57.93 |
| 3 | 65.76 | 58.03 | 55.76 |
| Delta | 11.27 | 5.24 | 8.00 |
| Rank | 1 | 3 | 2 |

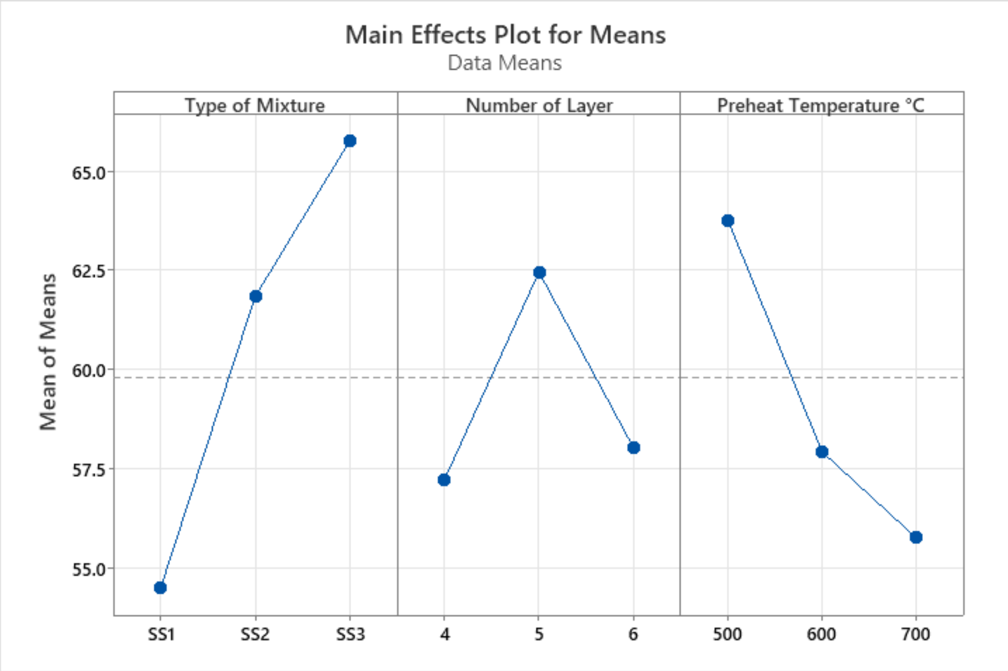



Figure 4.3: Main effect Plots for Mean Ultimate Tensile strength, hardness and elongation.

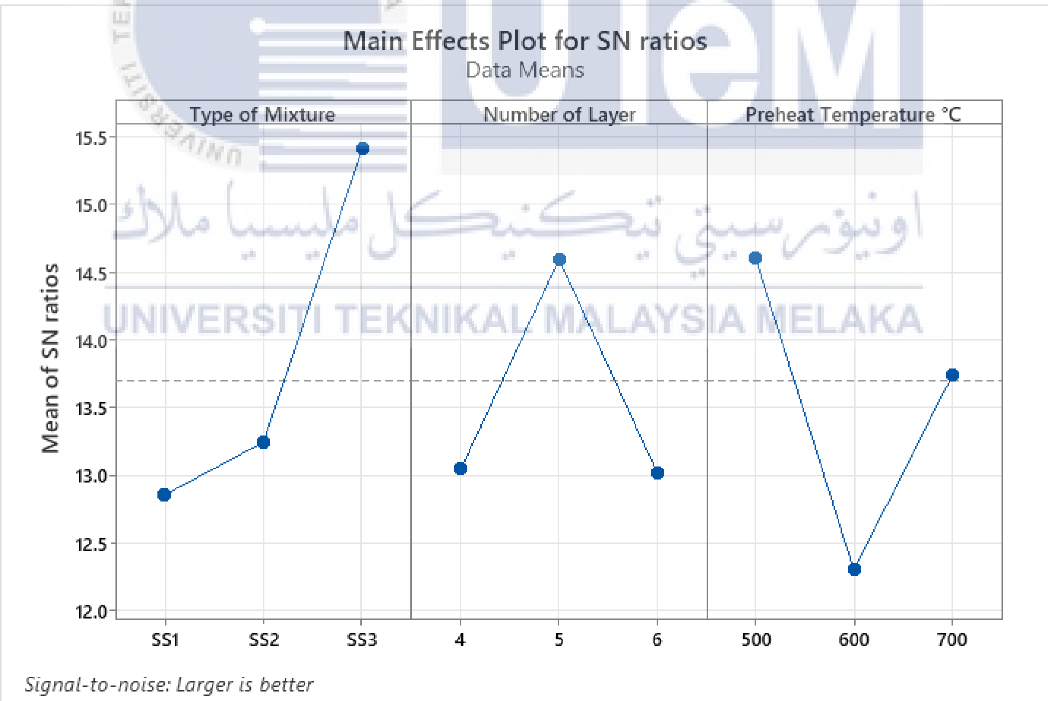





Figure 4.4: Main effect Plots for SN ratio Ultimate Tensile strength, hardness and elongation.

## 4.5 Effect on Porosity

The influence of porosity on tensile properties of selected specimen is shown in the figure 4.5 and figure 4.6. The image shown that the formed of pore that influenced by all three factors of parameter in this experimental which is type of mixture, number of layer and also the preheat temperature.

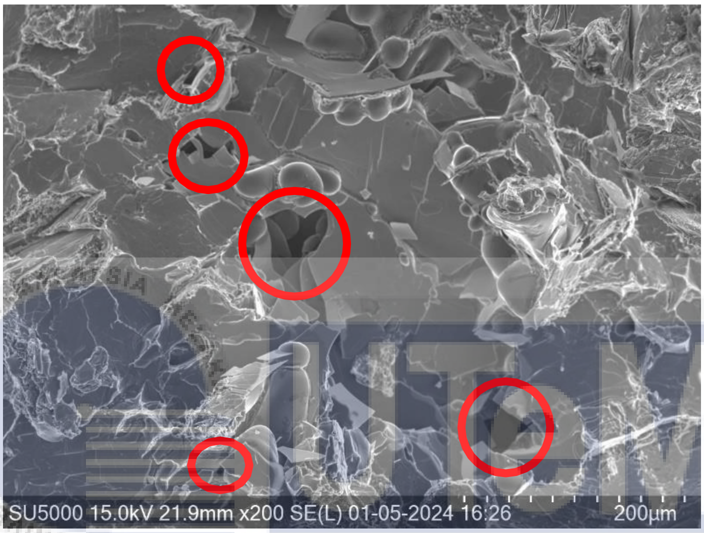



Figure 4.5. The effect of porosity on tensile properties of selected specimen



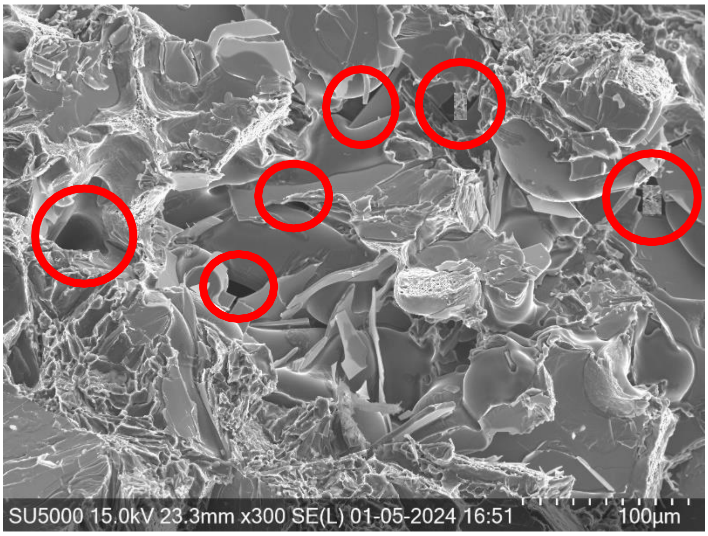



Figure 4.6. The effect of porosity on tensile properties of selected specimen

## 4.6 Summary

After performed the analysis of the experimental data, it can be concluded that the factor parameter is important to know the composition of the material because it is significantly affecting the mechanical properties of the product. Therefore, by using various combination of mixtures it shows the different levels of strength, weakness and also the deformation behavior under a stress. The number of layers also take a role which is essential to optimize the number of layers to get the best performance based on the desired properties and preheat temperature also play an important role in to get the best result. Preheat temperature affects the viscosity, surface characteristic and also and internal stresses of the materials. In the hardness testing, a good preheat temperature can helps minimize the defects and ensure a good outcome. Meanwhile, the excessive preheating may result in a material degradation and affect the mechanical properties. Based on the overall of experimental data, the type of mixture of SS3 is give the best high performance, the five number of layers are suitable in making a ceramic shells mould and also the 500˚C of preheat temperature is significantly to use. By using a lowest number of layers, it can be more cost-effective and less complex to manufacture the product. However, the optimization of the parameters of the investment casting can be customized to fulfill the specific requirements of the propeller hub hence improving the perfomance and also the functionality.

# CHAPTER 5

# CONCLUSION AND RECCOMENDATIONS

## 5.1 Introduction

This chapter will provide a summary of the projects findings which have done based on the objectives to optimize the investment casting parameters for propeller hub to improve the mechanical properties of LM25. The investment casting process is an important role in manufacture a complex shape of product such as the propeller hub, which directly impact the structural integrity and also the performance. Propeller hubs which are the critical components connecting the blades to the engine in the marine propulsion systems require the outstanding mechanical properties. So, to improve the mechanical properties of LM25 by strategically modifying the important parameters. The result of this project not only provide the significant insights into the complexities of investment casting for the marine components but also establish a basis for continued progress in the manufacture of the product.

## 5.2 Conclusion

The objective of this research is to optimize the parameter of the investment casting process for propeller hub ceramic shells. The project involves the finding of the best combination of the mixture composition, number of layer and also the oreheating temperature. From the result analysis and also discussion, the combination of type of mixture SS3 which is contains the 80% of silica sand and also 20% of plaster of Paris, the five number of layers and also on the other hand 500˚C of preheat temperature is the optimum value setting parameter that can give a good data for ultimate tensile strength, Rockwell hardness and also for the elongation. From the Taguchi analysis, it is that the three factor are most influential factor in the manufacture of the ceramic shell mould by using the investment casting process. However, we also need to understand the nature of aluminium alloy in in investment castings to optimize their advantage as a high quality of engineering materials.

Overall, this this successfully contributes to the understanding of the investment casting casting process and the analysis of the data gathered to propose an optimized parameter to produced a ceramic shell propeller hub. However, this project offers an important improvement to both the manufacturing process and also the perfomance of the crucial components.

## 5.3 Recommendations

For the purpose of this study, there are only three parameter used such as the combination type of mixture, number of layer and also the preheat temperature. Not only these three factors can be optimize but there are another factor can be optimize. Several suggestions can be proposed to enhance this reseach. Here is the suggested recommendation:

a) Optimization the ratio of binder mixing , the pouring time and and also the preheat time.

b) Take note of the effect of the stirring method.

c) Observe the microstructure to get a better properties of material.

d) Include the study of combination of the high cooling rates, grain refinement ti obtain the optimum properties in the investment casting LM25.

e) Investigate the use of an additives in the type of mixture that can enhance the crack resistance, minimize the shrinkage and also improve the surface finish.

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# APPENDICES

## APPENDIX A Turnitin Result

PSM ALIA

ORIGINALITY REPORT

| 11% | 8% | 4% | 5% |
|---|---|---|---|
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

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APPENDIX B Gantt Chart PSM 1

| Gantt chart for PSM 1 | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Task project | Plan/Actual | Week | | | | | | | | | | | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| 1 | Registration of PSM title. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |
| 2 | Briefing and explanation of PSM by supervisor. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |
| 3 | Drafting and writing of Chapter 1. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |
| 4 | Drafting and writing of Chapter 2. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |
| 5 | Drafting and writing of Chapter 3. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |
| 6 | Drafting and writing of Chapter 4. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |
| 7 | Submission of report to supervisor and panels. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |
| 8 | Slide preparation and presentation PSM 1. | Plan | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | |

APPENDIX C Gantt Chart PSM 2

| Gantt chart for PSM 2 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Task project | Plan/Actual | Week | | | | | | | | | | | | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | PSM 2 briefing | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 2 | Making a Pattern Wax | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 3 | Make a slurry Preparation | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 4 | Dewaxing Process | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 5 | Baking / Firing Process | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 6 | Pouringthe molten metal | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 7 | Specimen Testing& Analyze the data | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 8 | Writing a fullreport | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 8 | Report submission | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |
| 8 | Presentation PSM 2 | Plan | | | | | | | | | | | | | | | |
| | | Actual | | | | | | | | | | | | | | | |