UNIVERSITI TEKNIKAL MALAYSIA MELAKA

A NEWLY SPIRAL CHANNEL MECHANISM TO PRODUCE NON-DENDRITIC GRAINS MICROSTRUCTURE OF ALUMINIUM ALLOY FOR SEMI-SOLID PROCESSING

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BACHELOR OF MANUFACTURING ENGINEERING

TECHNOLOGY (PROCESS AND TECHNOLOGY)

WITH HONOURS

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in fulfilment of the requirements for the degree of Bachelor of Manufacturing

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Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I hereby that this thesis entitled Design & Develop a Device to Transform Dendritic to the Spherical Microstructure of Aluminium Alloy for Semi-solid Processing is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :

Name : MUHAMMAD HAFIZ BIN ABD RAHIM

Date : 28/1/2022

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

Signature :

Supervisor Name : TS. DR. HANIZAM BIN HASHIM

Date : 28/1/2022

DEDICATION

Alhamdulillah, this study I humbly dedicated to my beloved parents and families that continually provide their moral and financial support. To my supervisor, Ts. Dr Hanizam Bin Hashim for his guidance and encourage me to develop this research. To all my friend for helping me in this particular.

ABSTRACT

The purpose of this thesis presents grain dendritic microstructure form change into non-dendritic microstructure form in the aluminium alloy (A356) for semi-solid metal processing. In this situation, one of the ways employed to generate a nearly spherical shape is the cooling slope. The explanation for this operation is the challenge of managing the process and air entrapment, the cost, the water cooler's need maintenance, and parameters that directly impact the microstructure. The aim of this study, to fabricate a new design spiral channel. Next, to compare the spherical factor between spiral channel casting and direct casting, and to analyze microstructure using the T-test method. Initially, create two spiral channel design concepts using Catia V5 software and Solidworks software. Analyze and choose the best drawing design to fabricate the spiral channel. The A356 is heated by using a furnace until it reached a temperature of 700˚C. Pouring melted alloy into mold with spiral channel and direct casting. After that, the product needs to do a metallographic procedure. All specimens should be measured using optical microscopy (OM) with iSolution DT software. Analyzed the data to do a T-test analysis. Comparison roundness of grain size between the spiral channel and direct casting. T-test analysis generates by Minitab software show the graph and calculates the p-value. Besides, the effect is non-dendritic for semi-solid metal processing. To achieve the success of the project, the spiral channel can be successfully produced according to the detailed drawing that has been created. In comparison to direct casting, the spiral channel approach produces better globular quality, according to OM observations. Using the Minitab software, the roundness calculations for spiral channel and direct casting were revealed by t-test analysis.

ABSTRAK

Tujuan tesis ini memaparkan perubahan bentuk butiran mikrostruktur dendritik kepada bentuk mikrostruktur bukan dendritik dalam aloi aluminium (A356) untuk pemprosesan logam separa pepejal. Dalam keadaan ini, salah satu cara yang digunakan untuk menghasilkan bentuk hampir sfera ialah ‘cooling slope’. Penjelasan bagi operasi ini ialah cabaran mengurus proses tersebut dan berlakunya udara terperangkap, kos, penyejuk air perlu penyelenggaraan, dan parameter yang memberi kesan secara langsung kepada struktur mikro. Matlamat kajian ini, untuk mencipta ‘spiral channel’ bentuk yang baharu. Seterusnya, untuk membandingkan faktor sfera antara tuangan ‘spiral channel’ dan tuangan biasa, dan untuk menganalisis struktur mikro dengan menggunakan kaedah ‘t-test’. Pada mulanya, cipta dua konsep reka bentuk ‘spiral channel’ dengan menggunakan perisian Catia V5 dan perisian Solidworks. Menganalisis dan memilih reka bentuk yang terbaik untuk membuat ‘spiral channel’. A356 dipanaskan dengan menggunakan ‘furnace’ sehingga mencapai suhu 700˚C. Tuangkan cecair aloi ke dalam acuan dengan gunakan ‘spiral channel’ dan tuangan secara terus. Selepas itu, produk dihasilkan perlu melakukan prosedur metalografi. Semua spesimen hendaklah diukur menggunakan mikroskop optik (OM) dengan gunakan perisian iSolution DT. Menganalisis data untuk melakukan analisis ‘t-test’. Membuat perbandingan kebulatan saiz butiran antara ‘spiral channel’ dan tuangan secara terus. Analisis ‘t-test’ yang dihasilkan oleh perisian Minitab menunjukkan graf dan mengira nilai-p. Selain itu, pemprosesan logam separa pepejal memberi kesan kepda bukan dendritik. Bagi mencapai kejayaan projek, ‘spiral channel’ berjaya dihasilkan mengikut lukisan terperinci yang telah dibuat. Menerusi pemerhatian OM, perbezaan dengan tuangan secara terus, memberi pendekatan ‘spiral channel’ dapat menghasilkan kualiti kebulatan yang lebih baik.

ACKNOWLEDGEMENTS

First of all, I would like to express my gratitude for the blessing given to ALLAH S.W.T so that I can complete this project. I would like to thank my Project Supervisor, Ts. Dr Hanizam Bin Hashim for this encouragement, advice, and ongoing support throughout the final year of the project. I appreciate his guidance from the beginning to the last, which has helped me to understand this report project. Without his assistance, it would be harder to finish this report. I would also like to express my sincere thanks for the time spent correcting my mistakes. Besides, I would like to appreciate all my friends who give me some suggestions ideas during the report progression. The utmost appreciation also goes to my beloved parents Mr Abd Rahim Bin Mahmud and Mrs Siti Rohani Binti Abd Rahim, with their love and moral support. I am keeping strong to go through the challenge that comes to me and keep focus.

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LIST OF SYMBOLS AND ABBREVIATIONS

F	-	Fehrenheit
C	-	Celsius
sec	-	Second
α	-	Alpha
Al	-	Aluminium
$^{\circ}$	-	Angle degree
Wt%	-	Weight percent
OM	-	Optical Microscope
SSM	-	Semi-solid Metal
CS	-	Cooling Slope
NRC	-	New Rheocasting
SSR	-	Semisolid Rheocasting
SEM	-	Scanning Electron Microscopy
SIMA	-	Strain-induced Melt activated
MWCNT	-	Multiwalled Carbon Nanotube
AMMC	-	Aluminum Metal Matrix Composites
ANSI	-	American National Standards Institute
MIT	-	Massachusetts Institute of Technology
MHD	-	Magnetohydrodynamic Stirring
A356	-	7Si-0.3 Mg alloy with 0.2 Fe (max) and 0.10 Zn (max)
T6	-	Solution heat treated then artificially aged
SF	-	Spherical factor
p	-	Average parameter of the grains
A	-	Average area
Mm	-	Millimeter
Rpm	-	Revolution per minute

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CHAPTER 1

INTRODUCTION

1.1 Background

Manufacturing is the process of transforming raw materials, parts, or businesses into finished goods that match client requirements. To produce a product, various manufacturing processes must be combined and worked on the raw material to form the desired shape of a specific product.

Casting is one of the well-known manufacturing methods, with lots of advantages. Meanwhile, aluminium alloys with mechanical solid and properties have gained popularity among cast alloys. However, increasing the mechanical properties of aluminium alloys is a big challenge for technology concerned with the properties of metals and production.

A356 aluminium alloy is made up of 92.05% Aluminium, 7% Silicon, 0.35% Magnesium, 0.20% Copper, 0.20% Iron, 0.10% Mg and 0.10% Zinc. Corrosion resistance, high strength and good weldability are just a few of the benefits of A356 castings. The mechanical properties of casting are determined by its microstructure. The microstructures of the casting determine the mechanical characteristics.

Dendritic is a look like the tree-like structure of crystal formed when the molten metal solidifies. This dendritic has a significant impact on material properties. As a dendritic structure grows, the dendritic grow parallel to the right growing directions. Grains with mold directions close to the direction of heat flow develop faster and block the growth of other grains, resulting in a dendritic microstructure.

1.2 Problem Statement

In recent years, several ways can found to change dendritic form to non-dendritic microstructure. In this case, the cooling slope is one of the means methods that have been used to form an almost globular shape. It is a continuous casting process that uses a low temperature to keep the metal at a consistent temperature near or just above the solidus temperature. Flow is produced by pouring molten metal over to a cold slope and allowing it to assemble and collect in a mold. This method is not suitable for all applications. The reason for this application is the difficulty of controlling the process and air entrapment. Next, the cost to run this experiment is because of the water cooler's need for maintenance. Finally, temperature and angle are the two most important parameters that affect the microstructure directly.

1.3 Research Objective

To finish the Final Year Project, some objectives must be accomplished. The objectives are below:

I. To fabricate a new design spiral channel that is for the casting process.

II. To compare the spherical factor between spiral channel casting and direct casting.

III. To analyze microstructure using the T-test method.

1.4 Scope of Research

In this Final Year Project, the experiment will be conducted at the FTK Manufacturing Process Laboratory. Meanwhile, will be a focus on the design of the spiral channel using CATIAV5 and Solidwork software. Besides, this spiral channel is made of mild steel. The spiral channel fabricates is done by using an Abrasive Water Jet Machine (AWJM), lathe machine (JET GW-144W-3), shearing machine, hand notcher machine, slip roll machine and Metal Inert Gas Welding MIG) for the joining process. The material that is used for casting is an aluminium alloy (A356). Other than that, during casting operation, the A356 is heated using a furnace until it reached a temperature of 700˚C. Pouring melted an A356 into a single cavity mold with a spiral channel and direct casting. The pouring angle for both castings processes is 90˚. The product diameter is 25 mm. Prepare using the standard metallographic procedure such as sectioning with 10 mm diameter length. The grinding process in different grit sizes (600, 800, 1200, 2000) with distilled water. Next, polishing with (6,3,1) micron with diamond paste. Last;y, etching for 3 or 4 seconds with Keller solution. All specimens need to be applied to this procedure before examining the microstructure using optical microscopy (OM). The OM's iSolution DT software automatically measured the spherical factor. Construct the data into a T-test using Minitab software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter gives an overview of the project background and obtains the prior work related to this research. Furthermore, articles, journals, and books related to this research are all provided as the source of the guide. Thus, the literature review will explain the definition of dendritic form and non-dendritic form. This section offers an overview each of subtopic of this project.

2.2 Aluminium alloy casting

Casting alloys are materials used to make form castings, which are aluminium alloys with complicated geometrical shapes. Aluminium alloys are widely used in modern manufacturing and have a wide range of applications. Aluminium castings make up roughly 20–25 percent of annual world aluminium production, with die castings making for approximately 60 percent of the total (Otarawanna & Dahle, 2010). Aluminium castings can be made using almost any casting technique, producing products with a wide range of engineering properties. In addition to the difficulties in eliminating casting defects, casting aluminium alloy has a lower tensile strength.

2.2.1 Properties of aluminium alloy casting

A four-digit numbering system is used for aluminium alloys casting, with a decimal point after the third digit. The Aluminium Association created and maintains this system, which is the most generally used naming convention for aluminium alloys. The Aluminium Association implements ANSI regulations (Musto, 2005).

Grade	Composition (wt%)	Tensile Strength (MPa)	Yield Strength (MPa) 0.2%
1xx.x	99.00% to 99.00% Aluminium	131 - 448	28 - 152
2xx.x	4% to 4.6% Copper	131 - 276	90 - 345
3xx.x	5% to 17% Silicon	117 - 172	66 - 172
4xx.x	5% to 12% Silicon	117 - 172	41 - 48
5xx.x	5% to 12% Magnesium	131 - 448	62 - 152
6xx.x	Not used		
7xx.x	6.2% to 7.5% Zinc	207 - 379	117 - 310
The average value for alloy comparison only			

Table 2.1: Cast aluminium properties

2.2.2 Characteristics of aluminium alloy

- Extremely high operating temperatures.
- Corrosion resistance.
- Excellent hardness.
- Excellent stiffness.
- Good finishing characteristics.
- Full recyclability.

2.2.3 Aluminium alloy production

Bauxite is used to make aluminium alloy casting. This is a naturally occurring mineral containing 15-20% aluminium and is the only one still used in commercial aluminium extraction. The extraction of pure aluminium from bauxite is a complex and energy-intensive process (Musto, 2005).

2.2.4 Aluminium alloy casting application

Because of their poor tensile strength, cast aluminium alloys are rarely employed for structural components. Specialized processing technologies can solve this (Musto, 2005). However, cast alloys are used for the following applications in general:

- Impeller
- Machine tools.
- Casting wheels.

2.2.5 Advantages of aluminium alloy casting

Lower price is one of the benefits of casting aluminium alloys. Second, due to casting flexibility, a wide range of shapes can be produced. Furthermore, due to their poor ductility, some specialized alloys can only be obtained as castings. Finally, parts with minimal post-cast machining can be fabricated (Musto, 2005).

2.3 Permanent mold casting

Permanent mold casting is widely used for producible cast metallurgical quality and complexity. In permanent mold casting, molten metal flows in the form of steel and flows only by gravity. In most cases, permanent mold casting is manufactured by pouring molten metal on top of a die shaped into the shape you want to cast. There are many variations from this simple method of practice in actual casting. This is done to prevent turbulence and premature freezing of the melt while filling the die cavity and optimizing the parts casting conditions (Butler et al., 2016).

To avoid solidification shrinkage voids in the final product, the solidification of the molten metal must be regulated. In addition, the solidification rate is controlled to improve the microstructure of the final casting and find the design requirements (Butler, 2001). When compared to sand and investment casting, the advantages of the permanent mold and semi-permanent mold casting processes are reason piece costs resulting from high production rates achieved. With metal molds (especially water-cooled molds), the lower equipment investment is required when compared to low-pressure and high-pressure die casting (Table 2.2). Furthermore, the use of expendable cores in semi-permanent mold casting allows for a lot of design flexibility. Automotive parts such as aluminium pistons, steering knuckles, brackets, wheels, and pump impellers are specific parts made in the permanent mold method. Zinc, brass, copper, lead, and even grey iron are used to make parts. The varieties of items that can be created are nearly limitless, thanks to the process design flexibility and compatibility with a wide range of metals. Multiple die sets must be used if more effective production rates are needed.

Property	Sand casting	Investment casting	Permanent mold casting	Low-pressure die casting	High-pressure die casting
Cycle time	2	1	3	3	4
Investment cost	4	2	3	2	1
Lead time for prototype/design change	4	2	1	1	1
Process efficiency	1	1	2	4	3
Automation level	2 – 3	1	3	4	4
Post-casting heat treatment	4	4	4	4	1
Casting weldability	2 – 3	3	3	3	1
Quality surface	1	2	3	4	4

Table 2.2: Comparison of casting type

2.3.1 Permanent mold casting process

A thin ceramic coating is applied to the inside surfaces of the two components (cope and drag) of a permanent mold. Before coating, the mold is preheated to 300-500°F (150-260°C). In the mold assembly, the cores are inserted and installed. The mold has been closed. The mold is filled with molten metal. The mold is opened, the casting is removed from it once it has solidified and cooled to the right temperature. The casting is cut away from the gating mechanism. The finishing activities are completed.

2.3.2 Design aspect of permanent mold casting

Permanent molds are produced of carbon steels, grey cast irons, graphite (casting steels and Cast irons), or bronze. Other than that, external cooling (by water or air) can be applied to control solidification and reduce shrinkage defects and internal stress. It is possible to cast parts weighing from 0.1 kg to 70 kg. Next, permanent mold casting section thicknesses may range from 2.5mm to 50mm. Dimensional tolerances range from 0.4mm to 1.5mm, depending on the thickness of the casting section. For dimensions crossing the molds parting line, 0.25mm - 0.75mm allowances are being used.

2.3.3 Advantages of Permanent mold casting

- More durable mechanical properties.
- Low shrinkage and gas porosity.
- Homogeneous grain structure.

2.3.4 Disadvantages of permanent mold casting

- Molds are expensive.
- The casting of high melting point metal into metallic molds has its limitations.
- It is impossible to cast complex shapes.

2.4 Pouring process

Pouring is a foundry procedure that requires the insertion of molten metal into molds to produce castings. Ladles are used to pour molten metal into molds in the pouring section. Molten metal is poured into ladles, which are then manually poured into molds (Joshi & Jugulkar, 2014).

2.4.1 Pouring temperature

The cooling curves for metal solidification suggest a superheated pouring temperature, which leads to an increase in the freezing range time and melt fluidity. Before freezing for solidification, the melt can fill in all parts and corners of the mold. However, the pouring temperature must be monitored and kept within a specified range. It speeds up the metal-mold reaction inside the cavity and increases fluidity, allowing it to enter deeper into gaps and pores in the mold. The outcome is a small sand particle embedded in the metal surface (Kaushik Kumar et al, 2019).

2.4.2 Temperature control

The majority of the casting tasks are performed using aluminium alloys, which have a melting temperature of 660°C. The pouring temperature should be between 700°C and 750°C. Lindberg also claimed that the melting temperature might be as low as 649°C (Ndaliman & Pius, 2007). Applying heat metal to a higher temperature. Then, adjust for a small amount of heat loss during a transfer of molten metal from the furnace to the mold. A pyrometer and the furnace controls are used to keep track of the temperature.

It's crucial to maintain a consistent temperature during the pour to ensure the end products integrity. If the molten metal is extremely hot, the chemical and physical qualities of the casting will be affected, and the casting will not satisfy the needed criteria. Due to solidification, the molten metal will not flow into all of the cavities and apertures of the casting if the temperature is too low. As a result, the temperature is carefully monitored. (Edward, 2017).

2.5 Aluminium alloy (A356)

A356 is an aluminium alloy applied in automotive, aerospace and structural applications. Fabricating Aluminum Metal Matrix Composites (AMMCs) using ceramic reinforcements improves the mechanical and surface properties of A356 alloy. A356 alloy has a melting point of 610 degrees Celsius and a density of 2.67 g/cc (Edward, 2017). Aluminium, silicon, and magnesium make up the A356 aluminium alloy, which is a casting alloy. It has exceptional mechanical properties and high ductility and excellent casting properties, and high corrosion resistance. Heat treatment, particularly the T6 heat treatment regime, can greatly improve the mechanical properties of this alloy. The alloy has been widely used to replace steel components in the machinery, aircraft, defence industries and the automotive industry (Vencl et al., 2010). The A356 aluminium alloy has also been used to make composites with ceramic reinforcing particles and fibres like SiC, Al2O3, and others to improve alloy wear resistance. Table 2.3 shows the composition of A356 alloy :

Element	Si	Mg	Ti	Cu	Zn	Fe	Mn	Al
Wt%	6.5	0.2	0.2	0.2	0.1	0.5	0.3	Balance

Table 2.3: Composition of A356

2.5.1 Mechanical properties

Materials mechanical characteristics are those that involve a response with a load. Metals mechanical characteristics dictate a materials application range as well as its expected service life. Material categorization and identification are also aided by mechanical properties.

Mechanical Properties	Metric	English	Comments
Hardness, Brinell	70 - 105	70 - 105	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	112	112	Estimated from Brinell Hardness.
Hardness, Rockwell A	37	37	Estimated from Brinell Hardness.
Hardness, Rockwell B	55	55	Estimated from Brinell Hardness.
Hardness, Vickers	99	99	Estimated from Brinell Hardness.
Tensile Strength, Ultimate	>= 234 MPa	>= 34000 psi	AA
Tensile Strength, Yield	>= 165 MPa @Strain 0.200 %	>= 24000 psi @Strain 0.200 %	AA
Elongation at Break	>= 3.5 %	>= 3.5 %	AA; in 2 in. (50 mm) or 4D
Tensile Modulus	72.4 GPa	10500 ksi	Compressive modulus in is typically about 2% higher for Al alloys
Poissons Ratio	0.33	0.33	
Machinability	50 %	50 %	0-100 Scale (100=best)
Shear Modulus	27.2 GPa	3950 ksi	
Shear Strength	143 MPa	20700 psi	Calculated

Figure 2.1: Aluminium alloy (A356) of mechanical properties

2.5.2 Thermal properties

The sensitivity of materials to temperature variations and heat application is referred to as their thermal characteristics. A solid temperature rises, and its dimensions expand as it absorbs energy in the form of heat. However, different materials react to heat in different ways.

Thermal Properties	Metric	English	Comments
Heat of Fusion	389 J/g	167 BTU/lb	
CTE, linear	21.4 µm/m-°C @Temperature 20.0 - 100 °C	11.9 µin/in-°F @Temperature 68.0 - 212 °F	
	23.2 µm/m-°C @Temperature 20.0 - 300 °C	12.9 µin/in-°F @Temperature 68.0 - 572 °F	
Specific Heat Capacity	0.963 J/g-°C	0.230 BTU/lb-°F	
Thermal Conductivity	151 W/m-K	1050 BTU-in/hr-ft²-°F	
Melting Point	557 - 613 °C	1030 - 1140 °F	
Solidus	557 °C	1030 °F	
Liquidus	613 °C	1140 °F	

Figure 2.2: Aluminium alloy (A356) of thermal properties

2.5.3 Processing properties

Melt Temperature	677 - 816 °C	1250 - 1500 °F	
Solution Temperature	535 - 540.6 °C	995 - 1005 °F	hold at temperature for 12 hr; cool in water at 150 to 212°F
Aging Temperature	152 - 157 °C	305 - 315 °F	hold at temperature 2 - 5 hrs; start with solution heat-treated material
Casting Temperature	677 - 788 °C	1250 - 1450 °F	

Figure 2.3: Aluminium alloy (A356) of processing properties

2.5.4 Microstructure of aluminium alloy (A356)

This is the microstructure of aluminium alloy (A356) obtained by an optical microscope. The morphologies of aluminium alloy (A356) handled by this lab by traditional casting show a dendritic structure, as shown in Figure 2.4.

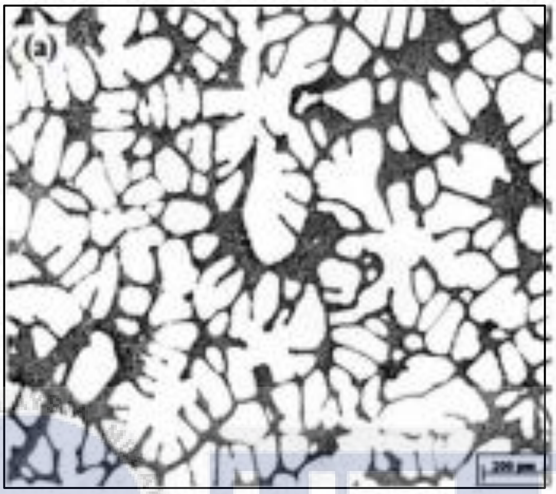


Figure 2.4: Morphology of A356 alloy conventioally cast

2.6 Dendritic grain microstructure form

When an alloy solidifies, the most common structure seen is a dendritic structure. It also shows one of the most complex patterns that develop from dynamical growth processes. It is a branched structure with primary, secondary, tertiary, and finally, higher-order branches, similar to a tree, as shown in Figure 2.5. It's important to know how such a complicated pattern forms and how different dimensions of this dendritic structure develop quantitatively. Besides, growth condition is hard to understand as these range scales evolve.

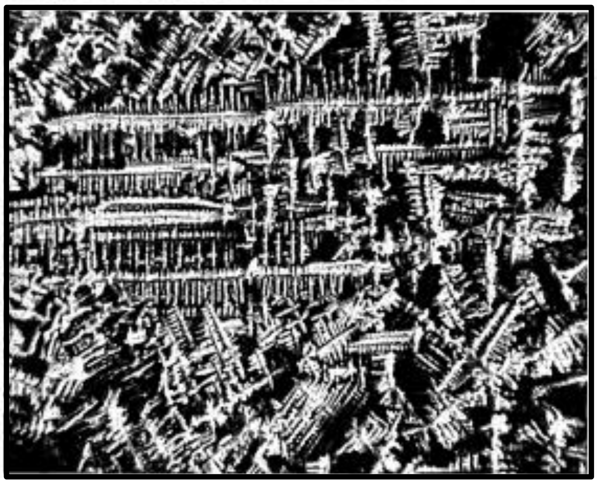


Figure 2.5: Dendritic grain microstructure form

Dendritic structures develop under two different development conditions, each of which differences in how the latent heat of fusion is transferred away from the interface, as shown in Figure 2.6. The latent heat of fusion is released through the colder liquid ahead of the interface, resulting in an equiaxed dendritic crystal from an undercooled melt. Figure 2.6(a) and (b) show that the temperature gradient in the liquid at the interface is negative, whereas it is almost zero in the solid. Furthermore, Figure 2.6(c) shows directional solidification or constrained development, in which a positive temperature gradient is imposed in the liquid to dissipate the latent heat of fusion through the solid (Trivedi & Kurz, 1994).

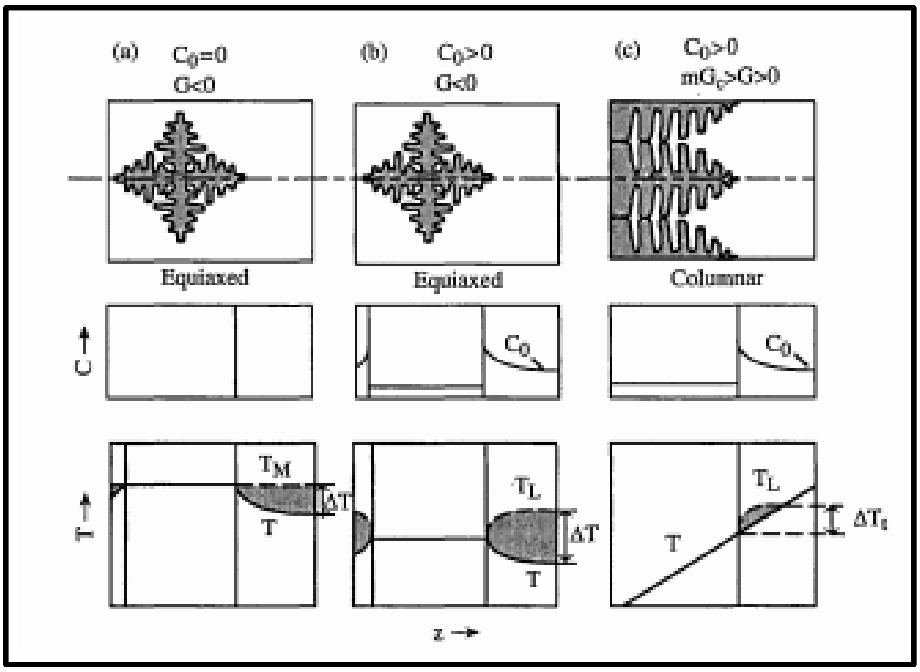


Figure 2.6: Composition and temperature fields are provided along the dendritic axis under (a), (b) and (c) free growth

2.6.1 Solidification microstructure of aluminium alloy (A356)

Several theoretical models for correlating various microstructural features of solidified alloys have been developed in the literature. Given that these models are sophisticated and varied greatly in detail, their predictions can all be arranged in a basic manner. This is performed by finding the characteristic dimensions of drive crystallisation microstructures. "A simple yet surprising relationship exists between the characteristic durations of physical processes. Phenomena and the microstructure properties of solidified alloys," according to the authors. Such correlations reveal the relative importance of various physical processes in defining a certain microstructural scale. Still, they also demonstrate how changes in processing conditions directly influence the biological processes, altering the microstructure scale (Trivedi & Kurz, 1994).

2.7 Non-dendritic grain microstructure form

A purpose of feedstock production will be to produce the material with such a thixotropic microstructure, in which a non-dendritic primary stage with small grain size. consistently in a lower melting point. The non-dendritic feedstock is made by cooling slope (CS), mechanical stirring, magnetohydrodynamic stirring (MHD), spray casting, ultrasonic treatment, liquidus casting and chemical grain refining. To overcome these challenges, simple approaches with inexpensive equipment and operating costs are required (Kumar et al., 2014).

2.7.1 A mechanism for the formation of non-dendritic microstructure

The formation of small near spheroidal particles through forced convection generated by stirring has been suggested as one mechanism to explain the presence of non-dendritic morphology. (The greatest challenge lies in the judicious selection of key process parameters such as pouring temperature, cooling slope angle and cooling slope length, which dictates the final microstructure of the feedstock). The shape and size of the particles change irreversibly over time, which differentiates semi-solid metal slurries from other suspensions. As shown in Figure 2.7, the processes for dendritic fragmentation can be separated into major types (Kumar et al., 2014).

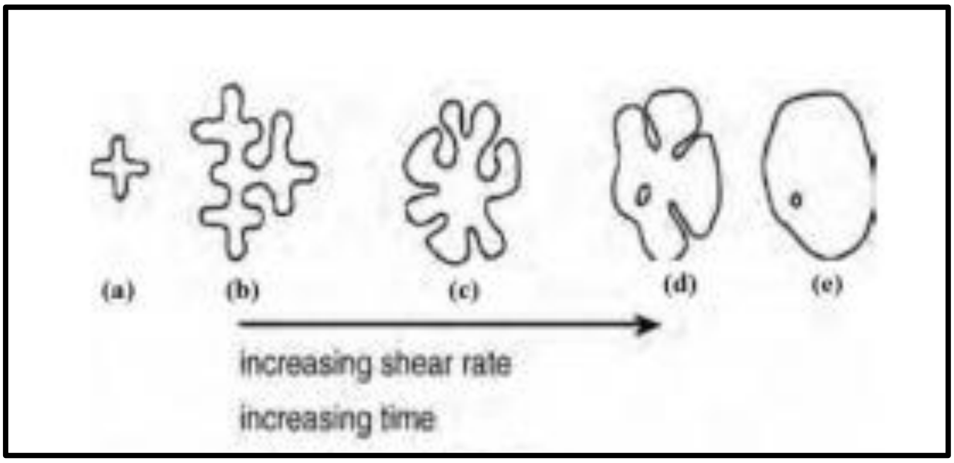


Figure 2.7: The formation of non-dendritic microstructure

2.8 Semi-solid metal processing

Semi-solid metal processing can be divided into two typical approaches, each of which is constrained to both the solid or liquid form. Casting with a range of adjustments, such as gravity, is used in liquid-state processes. Semi-solid metal (SSM) processing, also known as semi-solid metallurgy, was developed by Spencer, Flemings, and collaborators at the Massachusetts Institute of Technology in 1971. This has been claimed that during solidification, dendritic arms "melt" or "break" off. The increased density of the particles produced thus allows for non-dendritic development, resulting in non-dendritic (Wannasin & Thanabumrungkul, 2008). The main difference between semi-solid processing and superheated melt casting is the lower temperature. The known benefits of hardware performance obtained through lower operating temperatures are universally beneficial for all alloys, can be used to dissolve brittle phases, increasing their characteristics, if enables heat treatment. In terms of hardware performance, the lower processing temperature exchanges a molten alloy with a semi-solid slurry. However, further cooling below the liquidus affects the solid/liquid mix and slurry characteristics, affect the end product not just in terms of internal integrity, as well as of microstructure. The fluid motion of the liquid alloy together into mold may lead to the trapping of air and mold gases in the melt, which can cause porosity. The semi-solid slurry smooth flow reduces these defects. The main microstructure change after slurry crystallisation is the exchange of dendritic morphologies with globular form (Czerwinski, 2006).

2.9 Hardware mechanism for non-dendritic grain microstructure

The creation of thixotropic feedstock is an essential step in good SSM processing. Furthermore, based on the condition of the starting material, SSM technologies are divided into two groups. Regulated solidification under controlled conditions or considerable plastic deformation from a liquid alloy. The most effective and extensively used commercial practice tactics are described briefly below (M. N. Mohammed et al, 2013).

2.9.1 Magnetohydrodynamic Stirring

International Telephone and Telegraph (ITT) in the United States devised the magnetohydrodynamic (MHD) stirring technique to make non-dendritic by electromagnetic fields rotate that generate shearing to remove dendritic within a continuous casting mold. When electromagnetic stirring is applied to a melt approaching the freezing point at the surface of the chilled mold, a fluid flow in the semi-solid mushy zone creates the necessary shear stresses for the deformation and melting of dendritic arms to form equiaxed grains in the liquid matrix. After mechanical stirring, just a small percentage of the particles remain in the melt. In the vertical agitation mode, the dendritic near the solidification area is convectively moved to the hotter zone to remelt, and the globular mechanism is controlled by thermal processing of mechanical shearing (M. N. Mohammed et al, 2013).

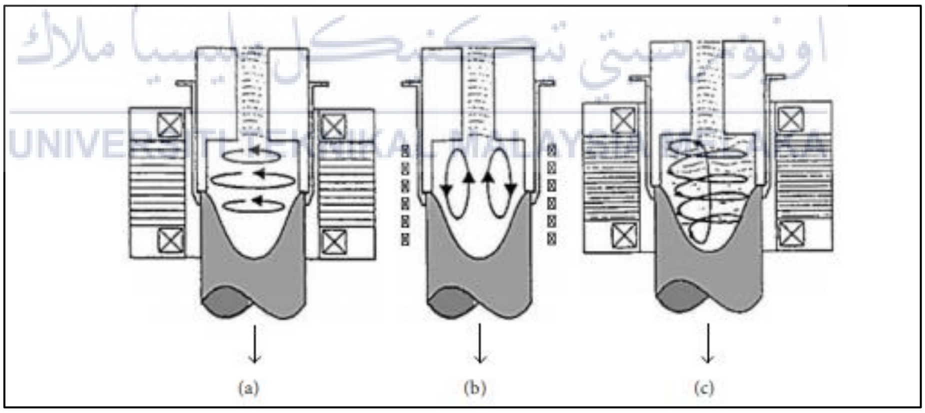


Figure 2.8: Diagram of magnetohydrodynamic stirring

For the past 20 years, MHD stirring has been the most effective and widely used method. Regardless, this MHD stirring has several issues, like solid particles creating entirely round rosettes and nonuniformity of the microstructure in the cross-section of the casting billet, which leads to longer reheating periods. It also covers the struggle of recycling the non-dendritic gates, and even the additional steps needed in feedstock production but also real part processing due to the heating of feedstock required before shaping into parts. all these problems result in increased production costs (M. N. Mohammed et al, 2013).

2.9.2 Cooling Slope

The cooling slope technique is the simplest non-agitation method for generating feedstock with a near-globular solid fraction in a liquid matrix. This is a continuous casting method in which the metal is given a low superheat at a constant temperature. Flow can be generated by pouring molten metal down a cool slope into a mold, or it can be used in conjunction with a shaping process such as rolling. The mechanism of dendritic fragmentation with this approach is based on crystal separation theory. Granular crystal nucleation occurs on the cooling plates contact surface. In contrast, nucleation on the sloping wall takes molten metal into a heating mold owing to fluid movement accelerated by gravity, guaranteeing that the spheroid size is fine. The microstructure of A356 aluminium poured at 620°C and produced using the cooling slope technique is shown in Figure 15 (M. N. Mohammed et al, 2013).

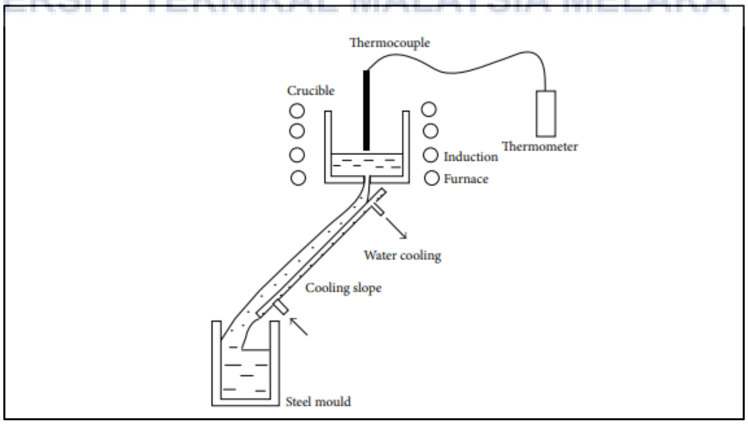


Figure 2.9: Diagram of cooling slope

This procedure is not suited for many operations due to the following factors: gas interruption, slurry contamination from chemical reactions, and oxidation. It's also tough to keep track of the procedure. The microstructure may be affected by the slope and degree of the cooling slope. The major variables that have a substantial impact are molten metal heating and die composition. (M. N. Mohammed et al, 2013). This process method is commonly performed with various parameters that have been used to obtain globular morphologies.

2.9.3 Mechanical Stirring

This techniques feedstock might be employed straight in a semi-solid slurry condition for near-net shaping of components by rheocasting or thixoforming. The feedstock is completely solidified, then warmed to a semi-solid state before being molded by either injecting it into a die or molding it. Using the thixocasting and thixoforming techniques, forging into the desired shape is also possible. Intense agitation of the superheated molten metal during solidification causes dendritic arm deformation and melting, which leads to the production of equiaxed grains in the liquid matrix. These grains will be remelted because the bulk liquid surrounding them still includes discrete regions of superheated liquid. There are only a few particles remaining in the molten metal. These superb particles are made by cooling molten metal for a specified length of time to solidify it into tiny and non-dendritic microstructures. In a liquid matrix, well-rounded particles are generated when high solidification rates are coupled with high shearing rates. Nonetheless, that technique is hardly suitable for some industrial needs due to the formation of rosettes and solid particles. Furthermore, there is a risk of gas interruption and slurry contamination due to chemical processes including oxidation caused by stirring. Next, the stirrer can erode, especially with high melting point alloys. Finally, problems involved industrial-scale process control (M. N. Mohammed et al, 2013).

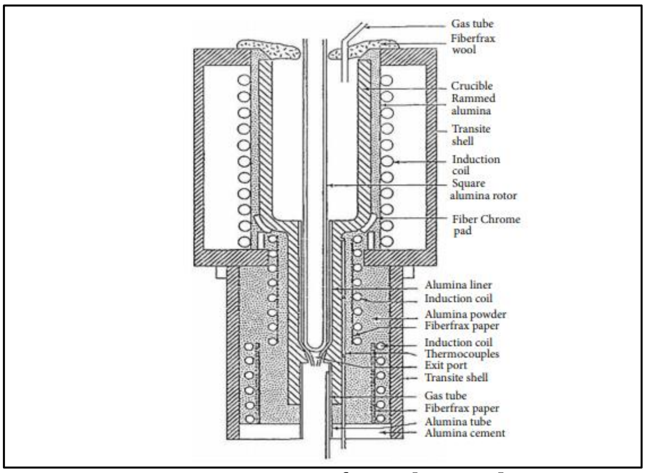


Figure 2.10: Diagram of mechanical stirring

2.10 Conclusion

From this chapter can conclude that aluminium alloy casting can produce a difficult shape that is required. Mostly aluminium alloy casting is used in automotive industries fabrication. Permanent mold casting is one of the types that can offer more durable mechanical properties, low shrinkage and low gas porosity. Furthermore, the pouring process is an important step that needs to consider such as temperature control. The material selection for this project is an aluminium alloy (A356). Otherwise, this aluminium alloy (A356) processing and mechanical properties have an excellent material that can develop applications required based on purpose, especially in aircraft, replacement machinery tools, and many others. SSM is typically separated into two techniques, each of which is limited to either the solid or liquid state. The primary distinction between semi-solid and superheated melt casting is the lower temperature. The lower processing temperature trades a molten alloy for a semi-solid slurry in terms of hardware performance. Further cooling below the liquidus, on the other hand, alters the solid/liquid mix and slurry characteristics, affecting the finished product not only in terms of internal integrity but also of microstructure. These flaws are reduced by the semi-solid slurry's smooth flow. Dendritic growth occurs when a crystallites edge or corner is selected for development. This development path is typically linked to a certain like-tree form. There are many ways and methods to convert the formation of dendritic grain microstructure to non-dendritic grain microstructure such as magnetohydrodynamic stirring, cooling slope and mechanical stirring. It knows the approach and process that can produce non-dendritic microstructure over a year.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The technique of the study to fulfil the specified objectives is explained in-depth in this chapter and illustrated by a flowchart. It is based on the preceding chapters research and literature review. To complete the literature review, sources from books, journals, articles, and websites were gathered. This chapter is important because it will explain each process that must be followed to complete the item from start to finish. This section will describe how the spiral channel concept was used to transform a dendritic form into a non-dendritic form. Characterizations of the final product using established methods available.

3.2 Planning Process

To complete this spiral channel project, there should be a process planning before this project begins to ensure the product can be completed within the time frame given. The most important aspect of the planning process should be designed before it is applied to ensure that it runs smoothly and without failures. Additionally, process planning can be used as a guide to ensure that the process is followed step by step. Furthermore, this planning process is beneficial to this project because it prevents errors or issues with the process. This medium can also help make sure that time constraints are met in the most positive way possible.

3.3 Process Flow Diagram

A process flow diagram (PFD) graphically represents a process in detail, commonly referred to as a flowchart. These are some of the methods used in industrial engineering to solve a problem. This technique has been used in every industry to show the projects overall flow. This PFD is commonly used in industry when it is good to prove the relationship between significant components while excluding minor parts.

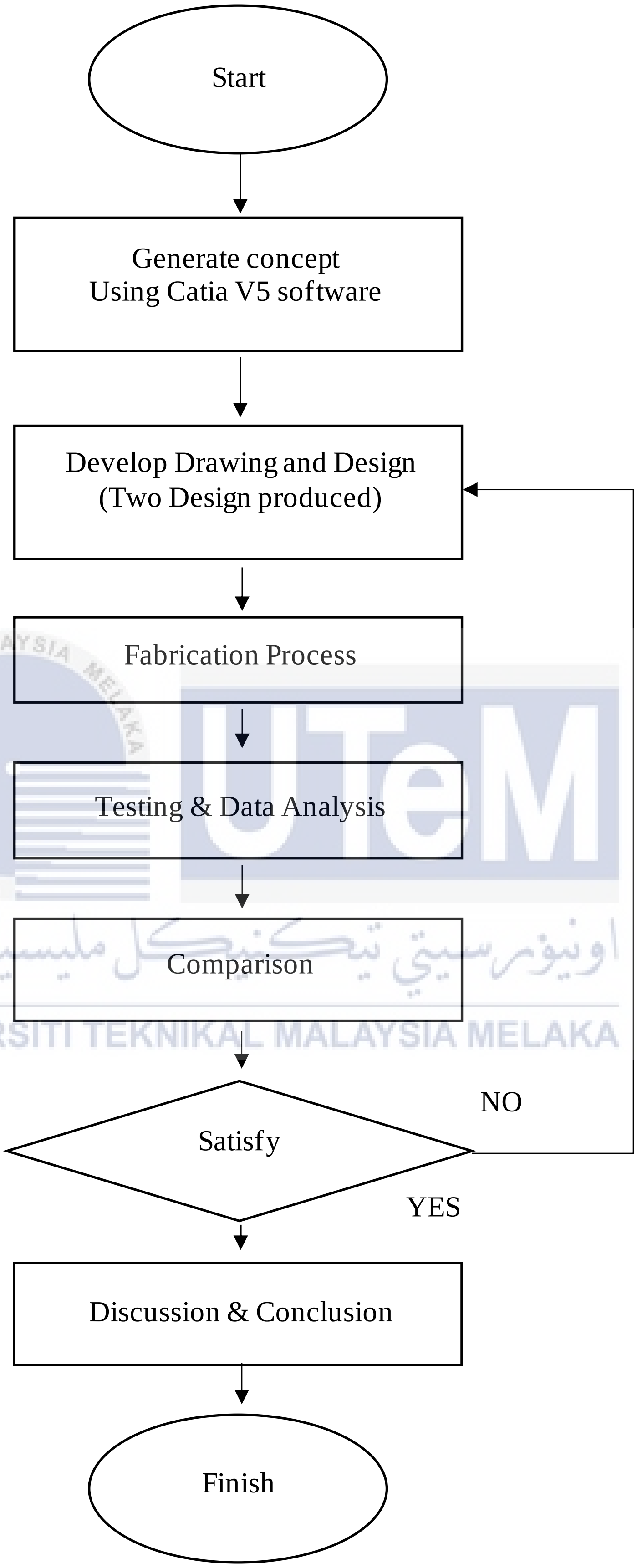


Figure 3.1: Process flow diagram

3.4 Project Design

To ensure the success of the project, creating this spiral channel was divided into several phases. The first phase involves designing and drawings a new idea using the CATIA V5 software. The next step includes processing raw material with precise dimensions to cut the materials. Once completed, the next is also fabricated in sections and with minor modifications. The fourth phase is the assembly of each part. Lastly, the spiral channel needs to do testing and collect some data. Other than that, a comparison is required of the results between dendritic and non-dendritic to create a discussion.

3.4.1 Phase 1: Design a spiral channel

The main objective of this phase is to create new several designs. In this section, all designs needed to focus on how non-dendritic can from. So many concepts were sketched before the final design was chosen. Following that, this design was sketched using the CATIA V5 software. This drawing aims to ensure that the manufacturing process is carried out perfectly. Additionally, it is important to ensure that all components seem to be well. Table 3.1 shows several design concepts.

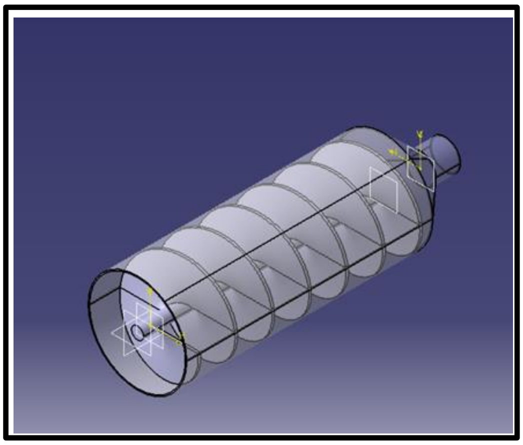
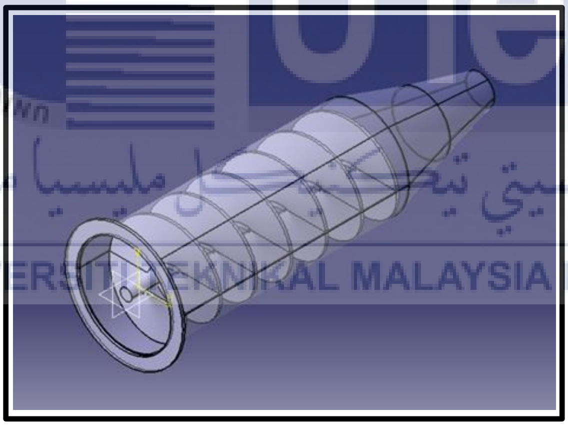
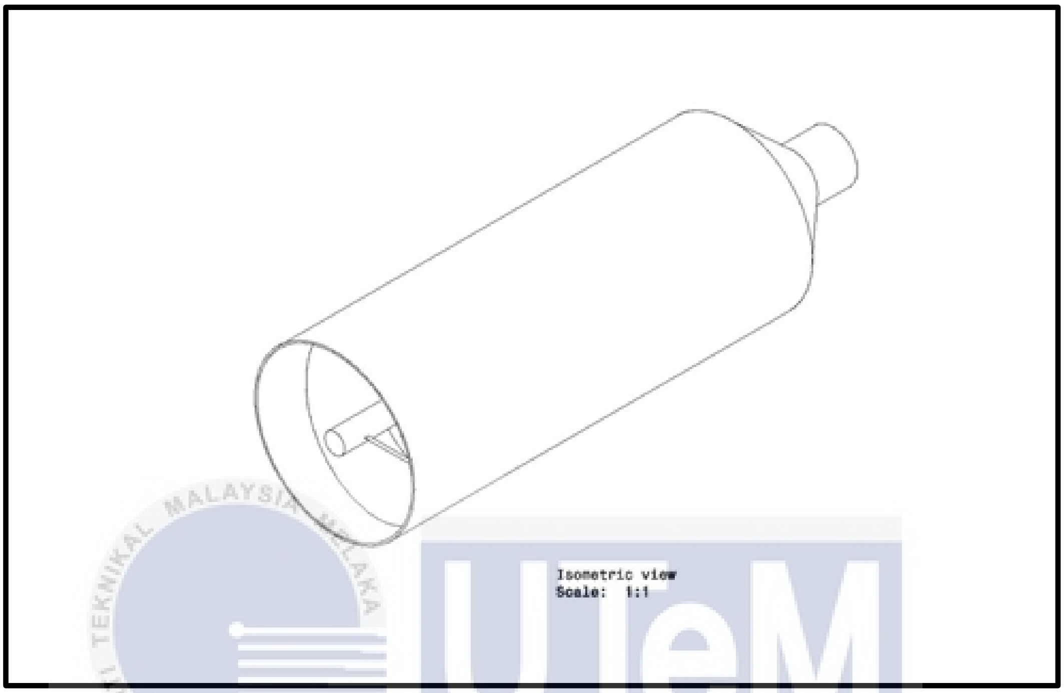
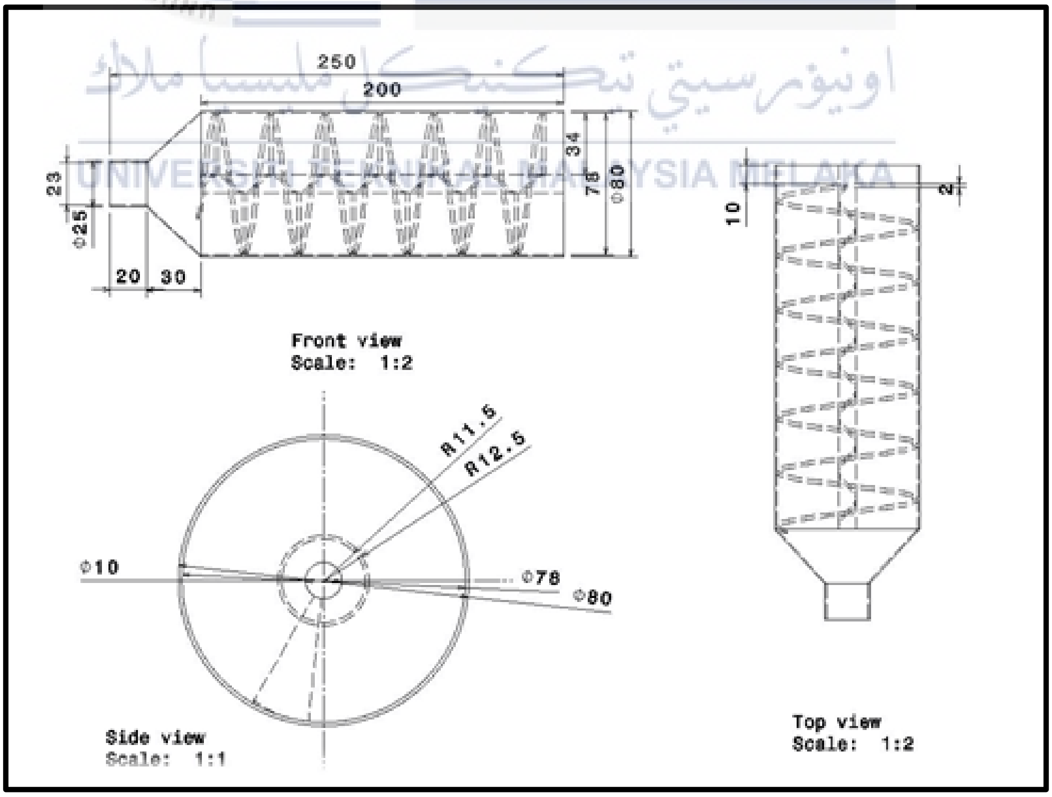
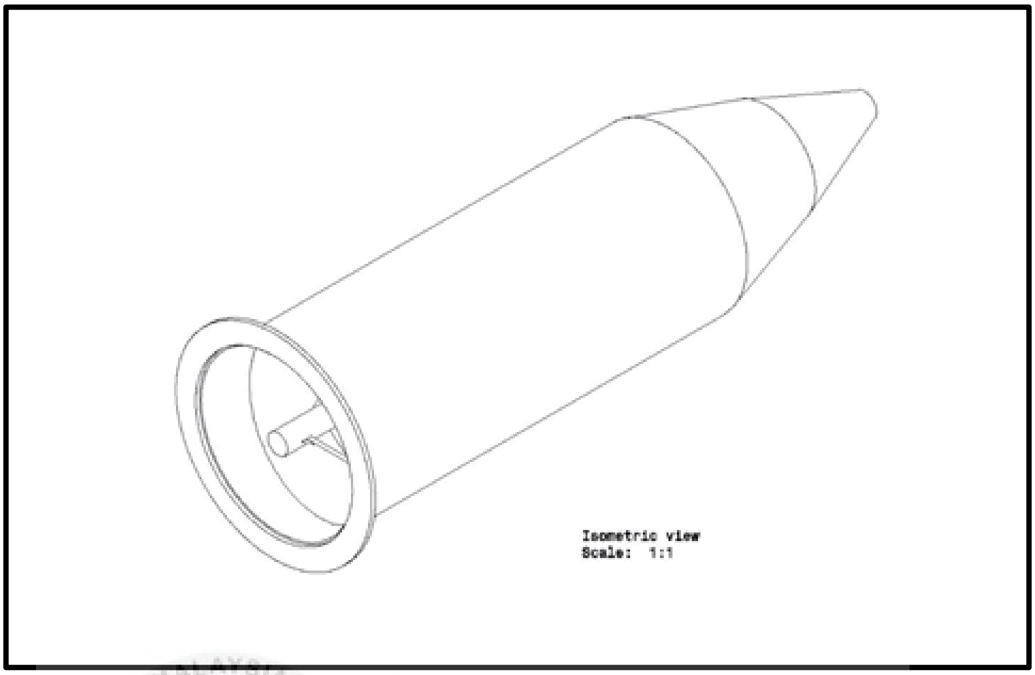
No	**Design / Parts**	**Material**
1	 Figure 3.2: Drawing A of spiral channel	Mild Steel Sheet & Rod
2	 Figure 3.3: Drawing B of spiral channel	Mild Steel Sheet & Rod

Table 3.1: Design concept

3.4.2 Drawing dimension

No	Drawing
1	 

2



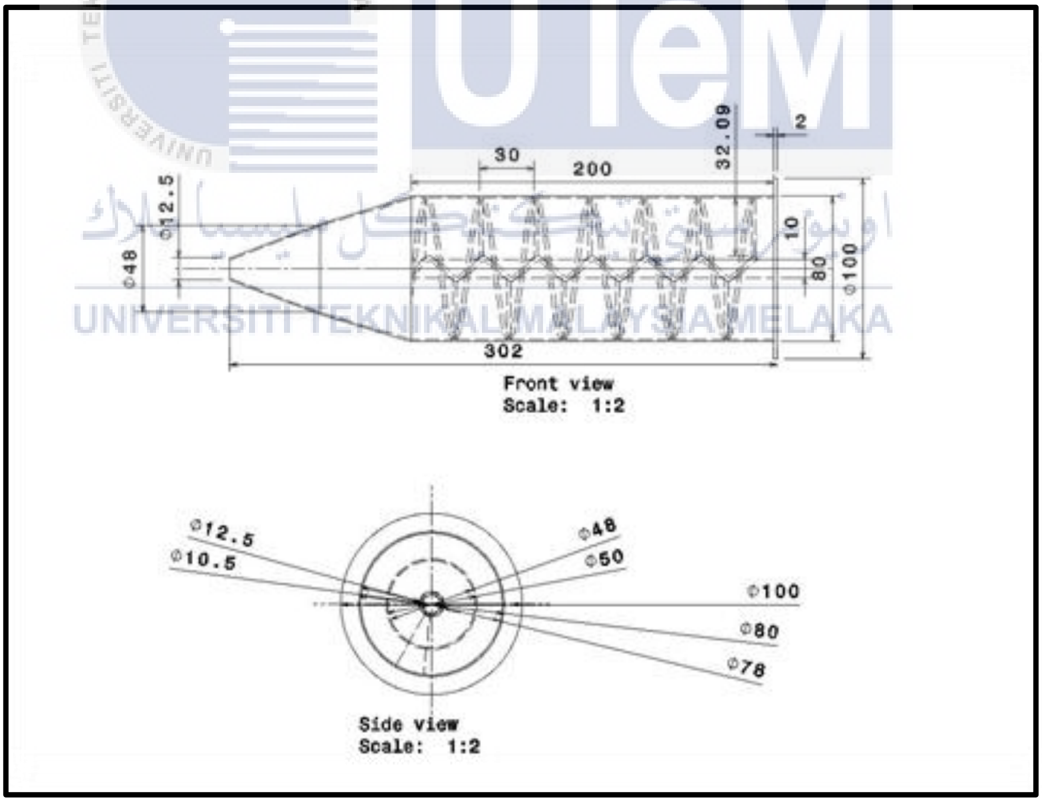


Table 3.2: Several drawing design of spiral channel

3.5 Raw material

Almost everything we use is made up of a variety of basic materials. Maintaining raw material inventory is crucial since it is the most significant component of the list for every production unit. A raw material, also known as a feedstock, unprocessed material, or primary commodity, is a fundamental substance used to make commodities, finished products, energy, or intermediate resources utilized as feedstock for future finished products. (Krishna, 2010).

3.5.1 Aluminium alloy (A356)

Aluminium that was obtained from the casting lab in factory 1 at Fakulti Teknologi Kejuruteraan Mekanikal Pembuatan (FTKMP). The aluminium alloy that will be used in this research is A356. The quantity of aluminium that will be used to create enough specimens for testing. The composition of this aluminium alloy is given in Table 3.3. A356 aluminium casting alloy is utilized for aviation components, pump housings, impellers, blowers, and structural castings where great strength is required. A356 aluminium casting alloy is a suitable choice for intricate and complex castings that demand lightweight, pressure tightness, and outstanding mechanical characteristics due to its exceptional castability.

Composition	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
A356	6.5	0.2	0.2	0.2	0.5	0.1	0.1	0.2	Balance

Table 3.3: Composition of aluminium alloy (A356)

3.5.2 Mild steel sheet

Figure 3.4 shows the mild steel sheet who have got from Fakulti Teknologi Kejuruteraan Mekanikal Pembuatan (FTKMP). This material is used to develop a device called a spiral channel. Dimension thickness needs to be considered for doing this project. A mild steel sheet will be measured and cut based on the design that has been set. Mild steel is a low-carbon version of carbon steel. Mild steels typically have a carbon level of 0.05

percent to 0.25 percent by weight, whereas higher carbon steels have a carbon content of 0.30 percent to 2.0 percent, depending on the source. If any additional carbon was added to the steel, it would be classed as cast iron. Table 3.4 shows the chemical composition of mild steel (Darlas, 2009).

Carbon	0.16 percent – 0.18 percent
Silicon	0.40 percent maximum
Manganese	0.70 percent – 0.90 percent
Sulphur	0.040 percent maximum
Phosphorus	0.040 percent maximum

Table 3.4: Mild steel composition

Mild steel provides several advantages, including low cost, ease of welding, and machinability. In sulphide solutions, the mild steel has a strong resistance to nitric and chloride corrosion. These plates have high tensile, yield, mechanical, ductility, hardness, toughness, and other properties. It's very easy to work within a high-temperature environment, and it's resistant to chloride crossing and cracking stress.

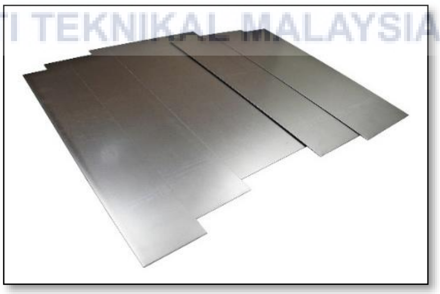


Figure 3.4: Example of mild steel sheet

Figure 3.5: Example of mild steel rod

3.6 Parameter

A general characteristic that represents an engineering condition is referred to as an engineering parameter. An opposition between these criteria is defined as a technical contradiction. (Thompson, 2015).

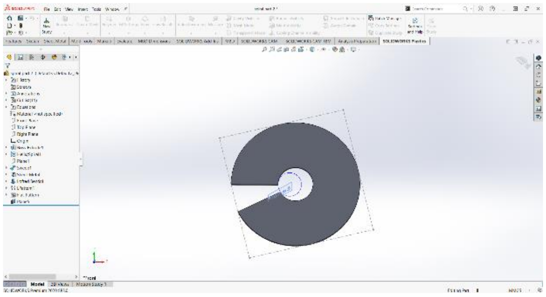
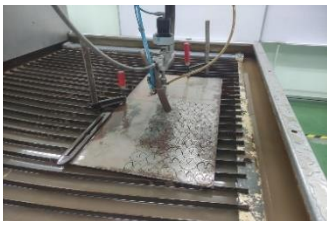
3.6.1 Temperature

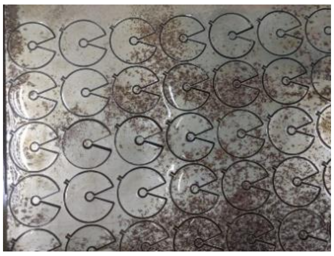
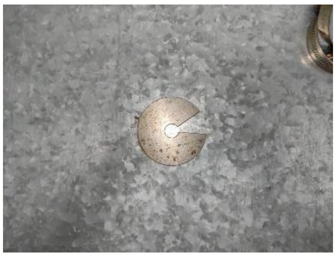
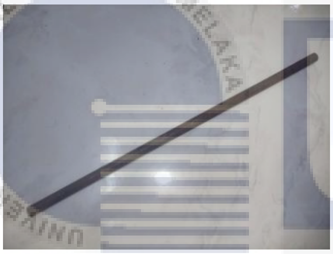
A thermocouple was used to measure the pouring temperatures of the Aluminum alloy castings. The point of every tool was involved in making contact with the molten metal in the base of the pouring ladle. For each casting, temperature measurements were collected and recorded. Firstly, the temperature sample is recorded when the molten metal is put into mold for the first time. Next, is taken after the mold is filled. The average of these two measurements was used to calculate the temperatures for the specific casting. The molten metal was poured and allowed to solidify and freeze. (Ndaliman & Pius, 2007)

3.6.2 Angle

The flow of molten metal into mold can be described as the pouring angle of molten metal. The molten metal was again mixed thoroughly, and the time it took for the mold to fill up was adjusted for different specimens to produce different casting sizes. This pouring temperature is 650 degrees Celsius, and the pouring angle is 60 degrees. (Ndaliman & Pius, 2007)

3.7 Procudure of the fabrication spiral channel

1.	 	Construct the design sheet metal to get flatten dimension using Solidwork software. Checking the drawing dimension and save as a DXF file. Next, transfer the file to the machine computer and make starting hole for the required pattern. Preview the routes of the pattern.
2.	 	Dimension thickness mild sheet metal used is 1 mm. Place the workpiece on the work table and secure it using fixtures. Make sure the routes are acceptable before starting the machine.

3.	 	Isolate the work piece and remove burr to get a perfect surface using pedestal grinder.
4.	 	Measure the mild steel rod with a diameter of 10 mm according to the drawing. Cutting the rod using a steel hand saw. Repeated this process several times to get two samples. Furthermore, to eliminate rust on the rod by doing turning process to achieve great surface roughness.

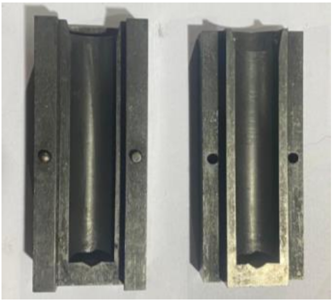
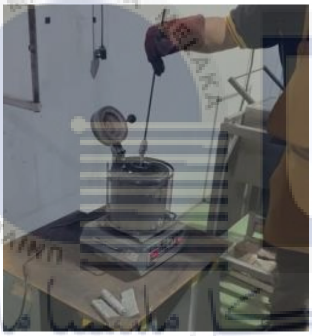
5.	 	The plate needs to be spirally shaped first before starting to assemble. For joining between spiral and rod are using welding process. Type of welding to perform this project is Metal Inert Gas Welding (MIG).
6.	 	Fabricate the casing spiral channel by selecting the raw sheet metal with size 1 mm that has been prepared. Start the measurement according to the drawing. After that, cut sheet metal pieces using a shearing machine to obtain the measured. Next, a hand notcher machine is performed to achieve the desired cutting finish. Used slip roll machine to form cylinder and cone shape.

7.	 	Assemble all part to get final spiral channel product with joining by welding process. When the product completed assemble, spiral channel needed to rub process to getting better surface. The sandpaper is used (400, 1200, 2000) size. Lastly, spray the spiral channel with black colour for final touch and look neat.

Table 3.5: Procedure of the fabrication spiral channel

3.8 Procedure of casting

1.		The Aluminium will be cut into small pieces to easier the process of melting the Aluminium Alloy (A356).

2.	 	Prepared the mold and set up the furnace. Make sure the spiral channel is in dry condition to avoid moisture before starting the process.
3.		Aluminium alloy (A356) will be heated to a $700^{\circ}C$ melting point temperature inside the furnace.
6.		The molten aluminium alloy (A356) then will be poured into the mold with the spiral channel. The pouring angle is 90 degrees. Repeated the process without a spiral channel for direct casting.

7.	 Casting with Spiral Channel  Direct casting	This is the product result after being removed from the mold.

Table 3.6: Procedure of casting

3.9 Procedure of Metallographic

The proper preparation of metallographic specimens to evaluate microstructure and content needs a strict step-by-step procedure. Sectioning, grinding, polishing, etching and microscopic analysis are the steps in order. To show precise microstructures, specimens must be cleaned regularly and the process for reporting must be properly performed. The study of the structure of metals and alloys is known as metallography. For general purpose examination, optical microscopy serves. (S, Prof Sunggook Park et al, 2015)

3.9.1 Sectioning

The product bond should be measured in length first and divided into 10 specimens. Each specimen is cut to the length of 10 mm. Perform the process for both bonds. The product was cut using a steel hand saw. During the cutting process, need to proper force control and keeping steady are important in all sectioning specimens. A reasonable doing that is to avoid bond break or crack which can be affected. After the operation is done, the specimens must be marked.

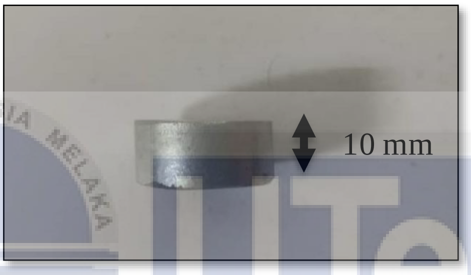


Figure 3.6: Specimens with length 10 mm

3.9.2 Grinding

Grinding is a process step of mechanical specimen preparation for microscopic inspection. The analysis is founded on the operation of increasingly finer grain size to eliminate surface till the right outcome is reached. The goal of the grinding stage is to eliminate material approaching the region of interest and to clear damage from cutting.

3.9.2.1 Fine Grinding

The grinding stages aim is to create an at first flat surface that is devoid of scratches. Each stage operation must be carefully performed. Grinding can be done wet or dry with grit sizes of (400, 600, 800, and 1200). Wet grinding is commonly used in fine grinding to eliminate heating-related negative effects such as transformation. It also provides keep a great sharp edge. Distilled water must be applied during the process to lubricate the removal product. Grinding properly requires rotating the specimen by 90° between steps while keeping the grinding angle consistent at each stage.

Figure 3.7: Metallographic polishing machine

3.9.3 Polishing

Polishing requires the use of diamond abrasives, which are the most expensive and produce the greatest results. Beginning with 6-micron and 3-micron diamond paste on a Nylon-cloth. Moderate the speed of the metallographic machine with a rotation rate of 160 - 200 rpm. Lastly, for precision work by used Napped Microcloth with 1-micron diamond paste to reach a better result. Before moving on to the next stage, the sample must be cleaned and thoroughly dried. Make sure the specimens keep safe and secure from undesirable scratching.

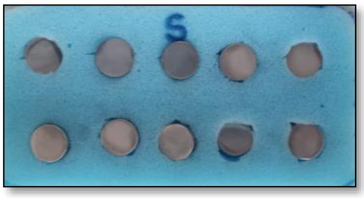


Figure 3.8: Specimens with spiral channel

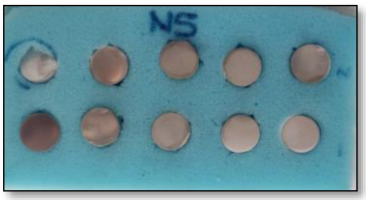


Figure 3.9: Specimens with direct casting

Stage	Abrasive	Lubricant
Fine Grinding 	400, 600, 800, 1200	Distilled Water
Rough Polishing 	6 and 3-micron Aluminum Oxide with Nylon cloth	6 and 3-micron Diamond paste
Final Polishing 	1-micron Aluminum Oxide with Napped Microcloth	1-micron Diamond paste

Table 3.7: General flow sheet for stages of specimen preparation

3.9.4 Etching

Etching is a technique used to emphasise and, in certain cases, identify microstructural characteristics. Etching happens when a chemical is applied to the surface of a specimen due to different rates of action of the different stages present and their orientation. The etching process is completed by applying the right method to the surface of the specimen for 3 or 4 seconds. The chemical for this process is Keller solution. The sample is instantly rinsed with distilled water and air-dried.

3.9.5 Microscopic Analysis

The specimen is positioned on the microscope's stage such that it is surface at the right angle towards the optical axis. Optical Microscopy (OM) is used for detailed examination. A metallurgical microscope does have a lens system that allows for various magnifications (100X to 200X). The roundness of grain size number was determined using the OM automated iSolution DT programme. Take a photo of each specimen at the appropriate zoom and properly mark each specimen. To achieve valid results, up to ten specimens were tested with each stage.

Figure 3.10: Observing the microstructure of grain size number

3.10 T-test Analysis

The t-test is a dataset that includes being used to see whether there is a mean difference between two groups that may be related in some way. It is most commonly used when the sets of data have a normal distribution. A t-test requires three crucial data values to be calculated. Which are the number of data values for each group, mean and standard deviation. This T-test method is used after optical microscopy (OM) has been used to examine the grain size microstructure of all accessible specimens. The t-test is used to analyse the data collected by the roundness of grain microstructures. The iSolution DT software auto-generated data must be compiled into the Minitab software. The data is divided into two columns, spiral channel and direct casting, to determine the roundness difference on the graph. To see if the spiral channel and direct casting is statistically significant, the p-value is used to calculate the probability of comparing two samples. Typically, a significance level (α or alpha) of 0.05 performs effectively. If the lower probability is against the null hypothesis, this might be used as evidence.

3.11 Spherical factor

The spherical factor (SF) is a measure of how nearly a grain microstructures roundness matches that of a complete sphere. The highest value of (SF) achieved is 1, which is the numerical shape value of a sphere. The spherical factor of a particle, as described by Wadell in 1935, is the ratio of the surface area of a sphere with the same volume as the provided grain microstructure to the surface area of the grain microstructure (Wadell, 2016). The SF of grain size microstructure is calculated using equation.

$$SF = 4\pi \frac{A}{p^2}$$

Where (p) is the grain's average perimeter and (A) is the grain's average area. Every roundness that isn't a sphere has a spherical factor of less than 1 (Wadell, 2016). When SF is less than 0.3, the structure is dendritic (ABDULRAHMAN et al., 2019).

3.12 Conclusion

From this section, A356 is the aluminium alloy that will be employed in this study, according to this chapter. Based on the design, a mild steel sheet will be measured and cut. Mild steel is a low-carbon version of carbon steel. Low cost, ease of welding, and machinability are just a few of the benefits of mild steel. The procedure that has been implemented for all operational processes to make this project a success. A systematic step-by-step approach is needed for the proper preparation of microscopy specimens for the evaluation of microstructure. The steps are as follows: sectioning, grinding, polishing, etching, and microscopic analysis. To demonstrate specific microstructures, specimens should always be cleaned constantly, and the reporting process must be followed correctly. First, the length of the product bond must be evaluated and split into ten samples. Examined specimens using (OM) with iSolution DT software to measure and obtain data. perform T-test analysis based on the data obtained to make results and conclusions.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

From this chapter, this section will show the aluminium alloy (A356) microstructure at the end of this project. The outcomes will be measured depending on roundness grain size and collected the data for each specimen. Choosing the area of the grain need to consider first before capturing the photography. This part will discuss and analyze the comparison between the spiral channel casting and direct casting using the T-test analysis method.

4.2 Design Selection

This section shows the design that needs to be selected to produce the non-dendritic microstructure. Two designs were created by Catia V5 software and Solidwork software to achieve the main objective of this project. Furthermore, a second design was selected due to the expected criteria needed after doing a discussion and analyzed. A reasonable, longer path of the melted aluminium on the spiral channel can cut off more the dendritic fragmentation before entering the mold. Other than that, the length dimension is the primary purpose for this selection. The length for the second design is 320mm, compare with the first design, which is 250mm in length. The elongation of this design is the main factor during the pouring process and can give the excellent changing of the dendritic microstructure to non-dendritic microstructure. Figure 4.1 shows the drawing design with dimensions is selected.

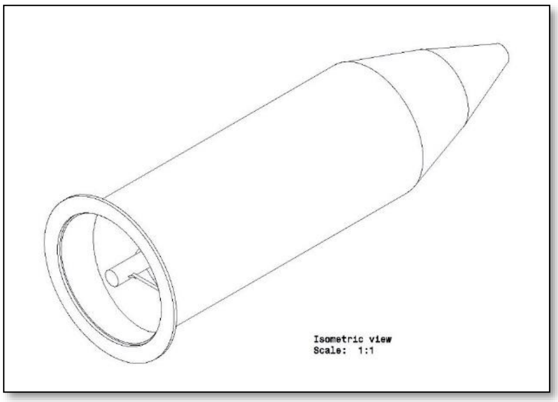


Figure 4.1: Isometric view of spiral channel

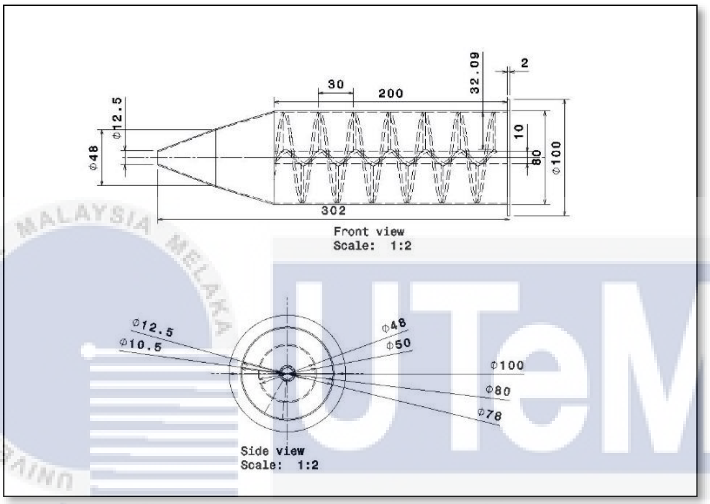
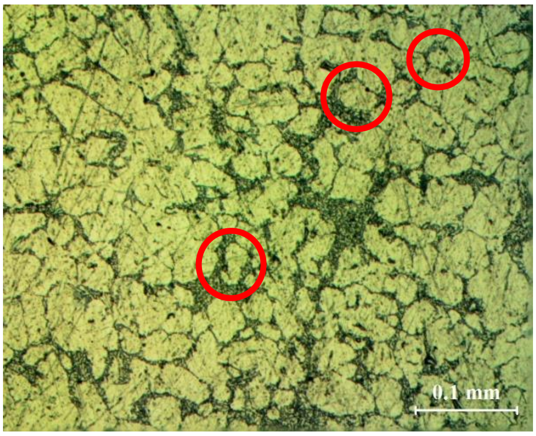
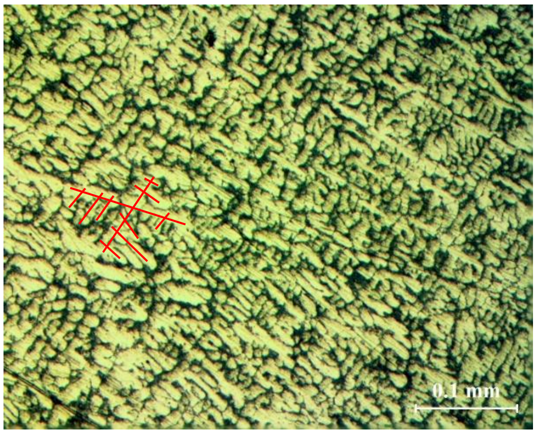
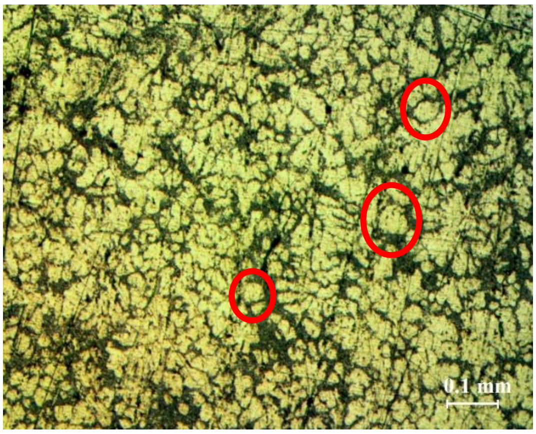


Figure 4.2: Second drawing of spiral channel with front view and side view

4.3 Comparison between grain microstructure dendritic and non-dendritic

The scope of this review focuses on critical features of dendritic and non-dendritic growth. In the examination of typical length scales, a qualitative image of the key microstructure formation is presented (Trivedi & Kurz, 1994). To compare this microstructure, the data that has been generated from Optical Microscopy (OM) with an iSolution DT software require to construct the T-test analysis. This method can be done with Minitab software.

4.3.1 Comparison roundness of grain size between the spiral channel casting and direct casting

No	Casting with Spiral Channel	Direct Casting
1.	 Specimen 1	 Specimens 1
2.	 Specimens 2	 Specimens 2
3.	 Specimens 3	 Specimens 3

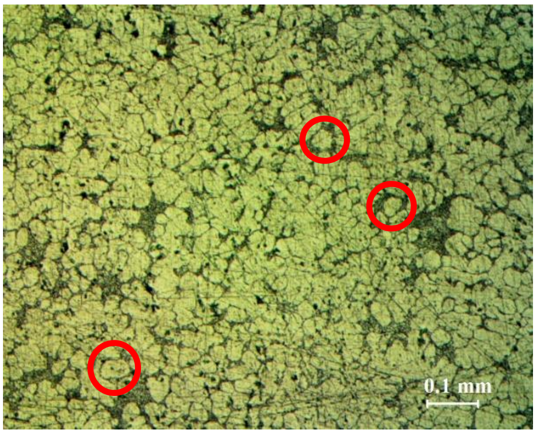
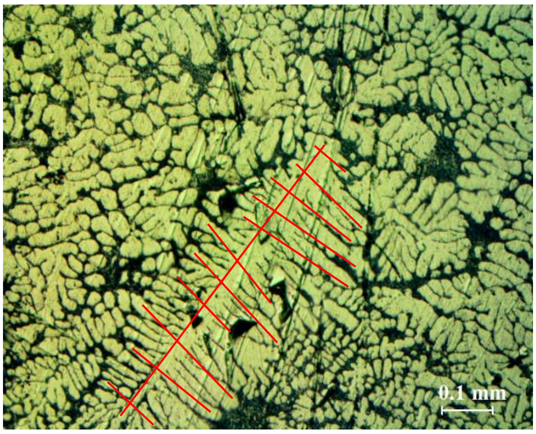
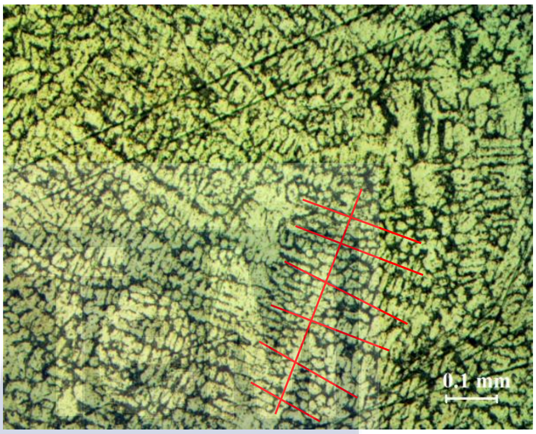
4.	 Specimens 4	 Specimens 4
5.	 Specimens 5	 Specimens 5

Table 4.1: Comparison roundness of grain size between with spiral channel casting and direct casting

4.4 T-test analysis results

This section, beginning with the fundamentals of the two-sample t-test on whether or not it is a statistically significant difference in average roundness between spiral channel casting and direct casting. The boxplot graph and summary statistics for the spiral channel and direct casting are shown in the image below.

Method

μ_1: population mean of SPIRAL CHANNEL

μ_2: population mean of DIRECT CASTING

Difference: $\mu_1 - \mu_2$

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
SPIRAL CHANNEL	150	0.7493	0.0621	0.0051
DIRECT CASTING	150	0.3632	0.0482	0.0039

Estimation for Difference

Difference	95% CI for Difference
0.38616	(0.37354, 0.39879)

Test

Null hypothesis H_0: $\mu_1 - \mu_2 = 0$

Alternative hypothesis H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
60.21	280	0.000

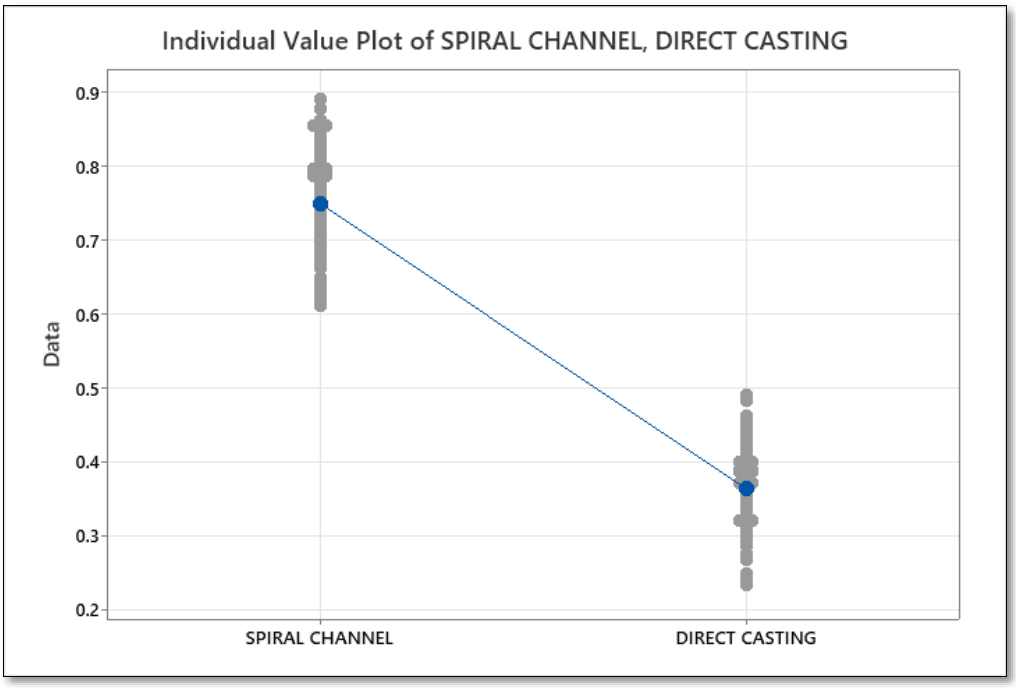


Figure 4.3: Individual value plot graph of the spiral channel and direct casting

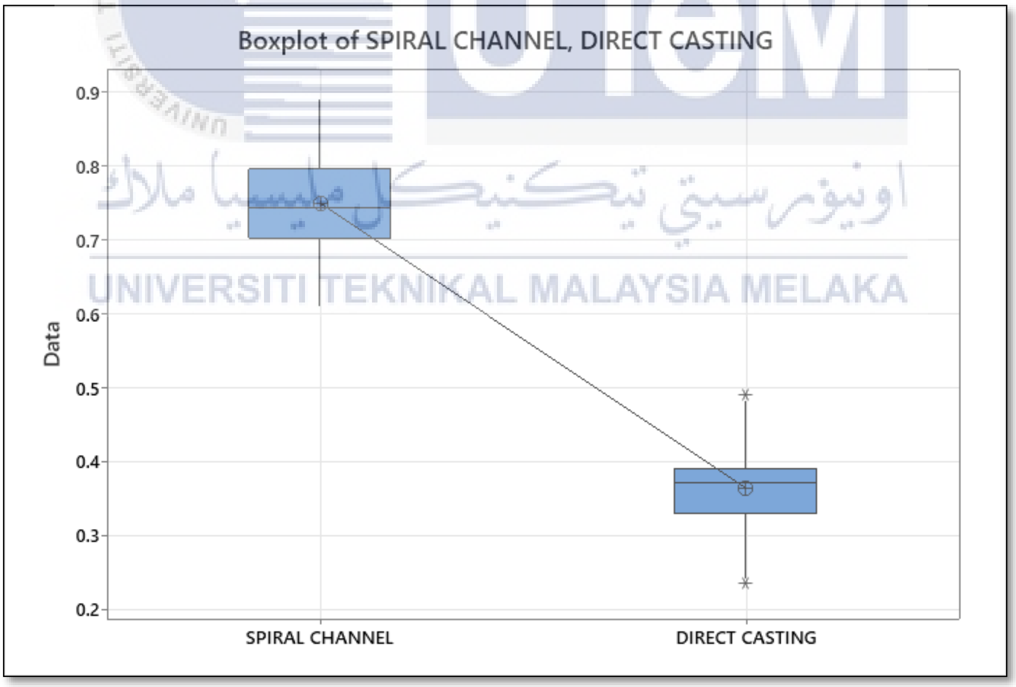
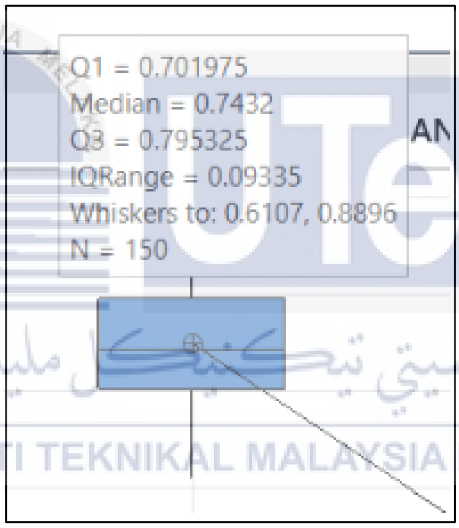
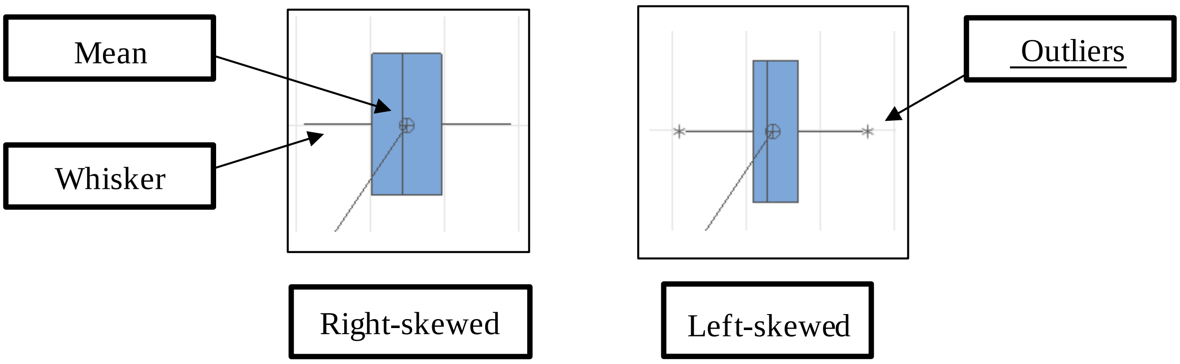


Figure 4.4: Boxplot graph between of spiral channel and direct casting

Based on the graph boxplot, the spiral channel has a better roundness grain size compared with direct casting. This can be evidenced by the mean of the spiral channel which is 0.7493 mm higher than direct casting with a (0.3632 mm). The spiral channel median of roundness grain size is 0.7432. Most of the roughness grain size get from the specimens is between 0.701975 and 0.795325. Other than that, some grain size has a low roundness of 0.6107 and high roundness of 0.8896. The sample size (N) for both operation castings was the same with an (N = 150). For the data more than 20, the normal distribution can be performed normal distribution. For the spiral channel, the boxplot seems to the right-skewed but the direct casting boxplot looks left-skewed. The direct casting shows a few items fail. The outliers (*) that came from the direct casting boxplot may be cause affected the microstructure.





4.5 Effect non-dendritic for semi-solid metal processing

For SSM to form successfully, a non-dendritic microstructure with the right amounts of liquid fraction is necessary. Once shear forces are applied, near-globular grains flow through each other fast, lowering the viscosity and causing the material to act as a liquid. When shear forces are applied to dendritic microstructures, such as in typical castings, the liquid becomes trapped between dendrite arms, blocking them from constantly moving and increasing the material's viscosity. SSM processing requires solid near-globular particles with a large transitional zone from solidus to liquidus. Slurries with these microstructures exhibit thixotropic properties, meaning they have time flow and shear characteristics (M. N. Mohammed et al, 2013). This has been proposed that dendritic arms are severed during solidification. As a result of the higher density of the particles formed, non-dendritic development occurs, resulting in non-dendritic. SSM is processed at a lower temperature. The lower processing temperature replaces a molten alloy with a semi-solid slurry, resulting in well-known improvements in hardware performance. These flaws are reduced by the semi-solid slurry's smooth flow (Czerwinski, 2006).

4.6 Conclusion

This chapter illustrates the design that must be chosen to achieve the non-dendritic microstructure. A fair, long journey of the molten aluminium on the spiral channel can reduce dendritic fragmentation before entering the mold. The elongation of this design is the most important component during the pouring process and can provide an excellent change from dendritic to non-dendritic microstructure. The spiral channel has a greater roundness grain size than direct casting, according to the graph boxplot. This is demonstrated by the spiral channel mean, which is 0.7493 mm bigger than direct casting. The median roundness grain size of the spiral channel is 0.7432. Aside from that, some grain sizes have low roundnesses of 0.6107 and high roundnesses of 0.8896. SSM processing involves the use of solid near-globular particles with a wide transitional zone between solidus and liquidus. It has been suggested that during solidification, dendritic arms are severed. Non-dendritic development happens due to the higher density of the particles generated, resulting in non-dendritic. Because of the decreased processing temperature, a molten alloy is replaced with a semi-solid slurry, resulting in well-known increases in hardware performance.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

The conclusion of the finding will be discussed in this chapter. Using SSM processing with the spiral channel, it is possible to conclude the roundness of grain size microstructure of an A356. Aside from that, the problem that developed throughout the experiment can be discussed, and additional work can be recommended.

5.2 Conclusion

According to the findings of this study, A356 is a material that has been employed in the spiral channel method. SSM processing is generally divided into two methods, each of which is restricted to the solid or liquid state.

I. To achieve the success of the project, the spiral channel can be successfully produced according to the detailed drawing that has been created. This spiral channel is made of mild steel because its mechanical features, such as high melting point, make it very nice to work in a high-temperature condition, as well as its ease of welding, machinability, and affordable cost.

II. In comparison to direct casting, the spiral channel approach produces better globular quality, according to OM observations. This is evidenced by the fact that some grain sizes have low roundness of (0.6107 mm) and high roundness of (0.8896 mm).

III. Using the Minitab software, the roundness calculations for spiral channel and direct casting were revealed by t-test analysis. According to the graph, the spiral channel has a higher average roundness (0.7493 mm) than direct casting, which has a lower average roundness (0.3632 mm). A p-value of ($0.000<0.05$) indicates that the spiral channel and direct casting are statistically significant.

5.3 Recommendation

Based on this study, various changes can be performed to ensure that the experiment achieves better globular grain microstructure results. Firstly, this method has characteristics that can be used, such as the pitch length of the spiral channel and the pouring angle before entering the mold. Before starting casting operation, avoid exposure to moisture and oxygen by keeping the spiral channel clean at all times. This will produce rust on the spiral channel, which will affect grain size. microstructures. The production of metallographic samples needs a deep commitment to a step-by-step procedure. The steps are as follows: sectioning, grinding, polishing, etching, and microscopic observation. To reveal accurate microstructures, samples must always be cleaned regularly and the preparation method must be followed precisely. To observe and measure grain size microstructure manually near the desired region in the analyzed microscope, it is important to first understand the usage of iSolation DT software.

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APPENDICES

Appendix 1: Project planning: gantt chat for PSM 1

Project Activity	Weeks														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	15/3-19/3	22/3-26/3	29/3-2/4	5/4-9/4	12/4-16/4	19/4-23/4	26/4-30/4	3/5-7/5	17/5-21/5	24/5-28/5	31/5-4/6	7/6-11/6	14/6-18/6	21/6-25/6	28/6-2/7
Choose and confirm project title															
Collecting data and information															
Problem statement and objectives															
Chapter 1 : Introduction															
Find and research article															
Chapter 2 : Literature Review															
Chapter 3 : Methodology															
Fill the log book															
Compile a report															
Submit a report to the supervisor and panel															
Presentation PSM 1															

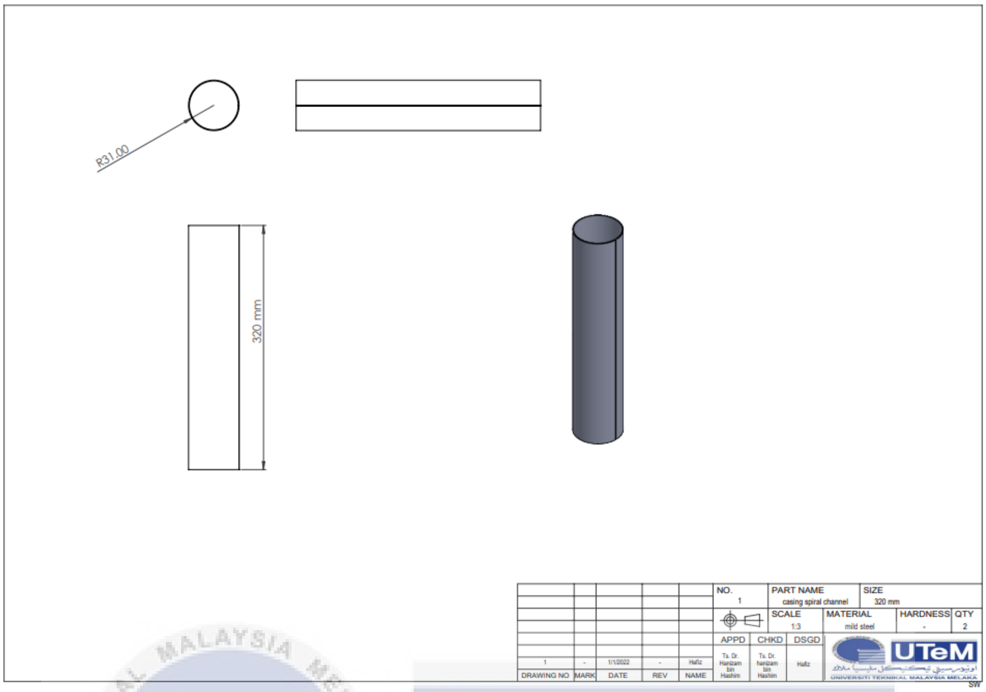
Planning		Actual	

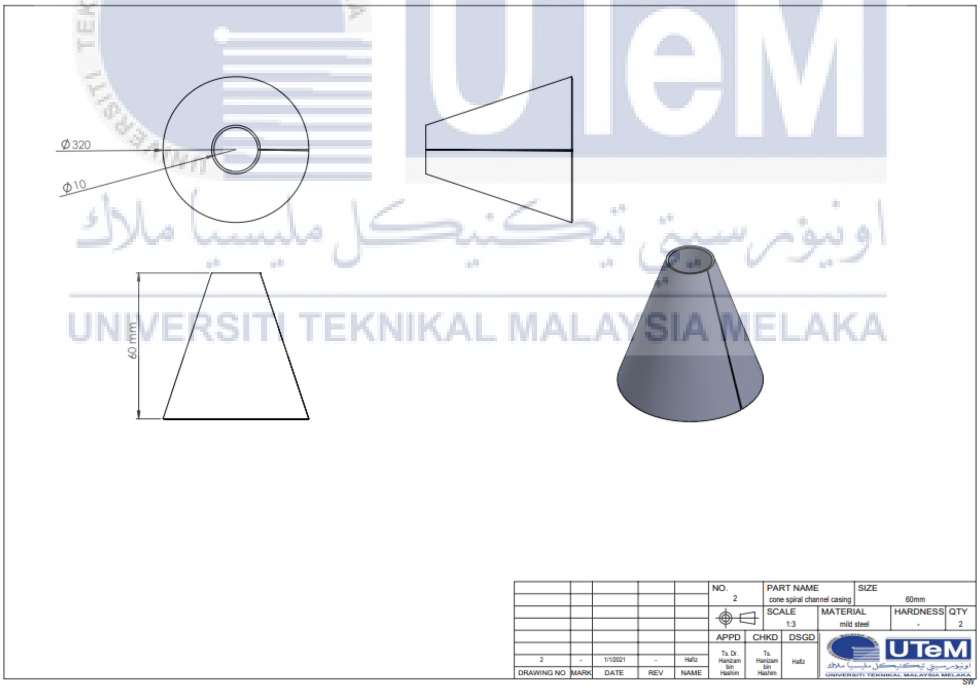
Appendix 2: Project planning: gantt chat for PSM 2

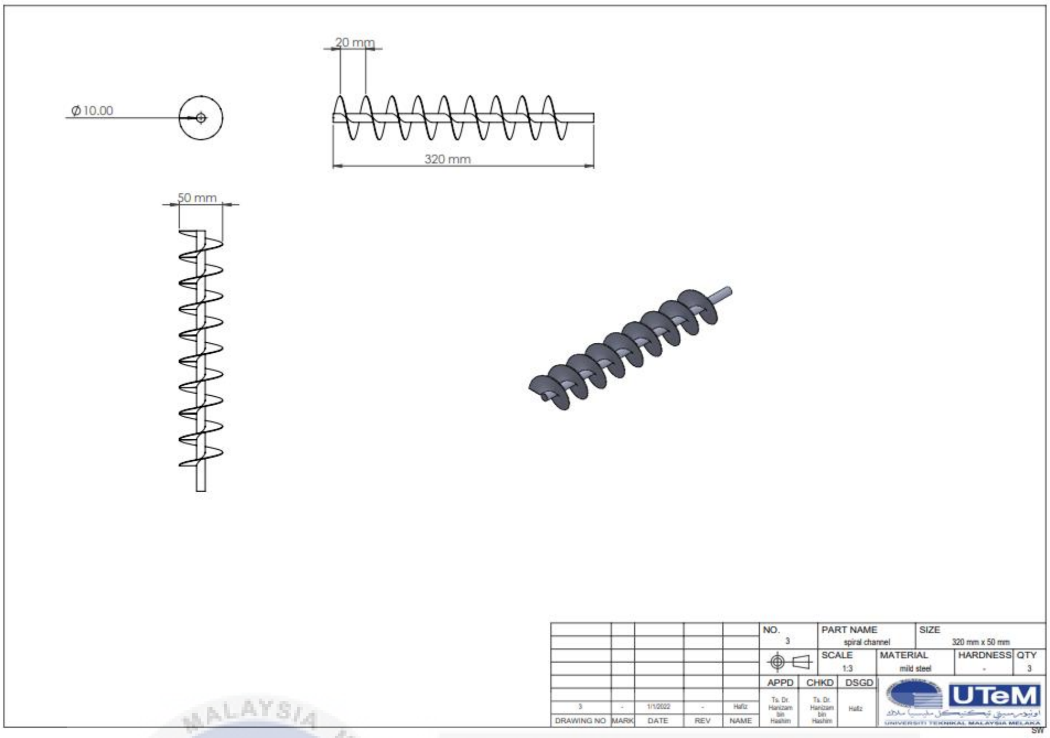
Project Activity	Weeks														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	11/10 - 15/10	18/10 - 22/10	25/10 - 29/10	1/11 - 5/11	8/11 - 12/11	15/11 - 19/11	22/11 - 26/11	29/11 - 3/12	6/12 - 10/12	13/12 - 17/12	20/12 - 24/12	27/12 - 31/12	3/1- 7/1	10/1- 14/1	17/1- 21/1
Fabricate the spiral channel															
Casting operation															
Metallographic process															
Starting collecting data															
Chapter 4 : Result & Discussion															
Chapter 5 : Conclusion & Recommodation															
Compile all chapter															
Fill the log book															
Submit report															
Preparation slide															
Presentation PSM 2															

Planning		Actual	

Appendix 3: Detail Drawing






Ø10.00
20 mm
320 mm
50 mm
NO.
3
PART NAME
spiral channel
SIZE
320 mm x 50 mm
SCALE
1:3
MATERIAL
mild steel
HARDNESS
-
QTY
3
APPD
CHKD
DSGD
Ts. Dr. Hanizam bin Hashim
Ts. Dr. Hanizam bin Hashim
Hafiz
3
-
1/1/2022
-
Hafiz
DRAWING NO
MARK
DATE
REV
NAME
SW

Appendix 4: Data analysis specimens with spiral channel

Experiment 1

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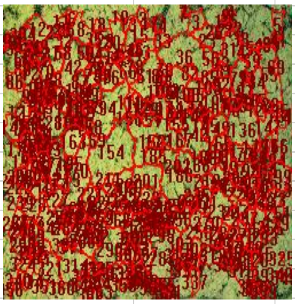
OSCOPY IMAGE ANALYSER REPORT

I TEKNIKAL MALAYSIA MELAKA



Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0	0.0305	0.0097	0.0083	0.7396	0.7387	0.025
2	0	0.0227	0.0077	0.0066	0.7377	0.7897	0.0159
3	0	0.0197	0.0066	0.0062	0.8142	0.8971	0.014
4	0	0.0395	0.0142	0.0111	0.6107	0.695	0.045
5	0.0006	0.1167	0.0339	0.0292	0.734	0.675	0.3084
6	0.0001	0.0448	0.0148	0.0125	0.7016	0.7354	0.0565
7	0.0014	0.1697	0.0527	0.0423	0.6354	0.6247	0.6453
8	0.0001	0.0574	0.0195	0.0155	0.6297	0.6735	0.0868
9	0	0.0378	0.0126	0.0103	0.662	0.6986	0.0386
10	0	0.0175	0.0061	0.0055	0.8247	0.9077	0.0111
11	0.0002	0.0664	0.0209	0.0168	0.6251	0.6289	0.1018
12	0.0003	0.0809	0.0255	0.0213	0.638	0.6619	0.164
13	0	0.023	0.0069	0.0063	0.7587	0.7543	0.0144
14	0	0.0221	0.0066	0.0063	0.7925	0.8021	0.0144
15	0.0004	0.0841	0.0265	0.0226	0.7134	0.7136	0.1843
16	0.0001	0.0443	0.0141	0.0128	0.8017	0.8148	0.0592
17	0.0001	0.0442	0.0135	0.0116	0.6405	0.6626	0.0489
18	0.0001	0.0464	0.0148	0.0129	0.7215	0.7459	0.0605
19	0	0.0254	0.0075	0.0074	0.8562	0.8471	0.0198
20	0	0.0402	0.0107	0.0105	0.6292	0.6562	0.0403
21	0.0001	0.0513	0.0167	0.0147	0.7374	0.7775	0.0787
22	0.0006	0.1088	0.0329	0.028	0.6944	0.6737	0.2822
23	0	0.0242	0.0086	0.0069	0.6483	0.7277	0.0174
24	0.0002	0.0698	0.0204	0.0193	0.7328	0.7434	0.1341
25	0	0.0379	0.0123	0.0105	0.7181	0.7432	0.0403
26	0	0.0299	0.0098	0.0087	0.7816	0.8073	0.0273
27	0	0.0203	0.0061	0.0059	0.8025	0.828	0.0129
28	0.0001	0.0479	0.0154	0.0137	0.7545	0.7814	0.0677
29	0	0.0339	0.0112	0.0104	0.8224	0.872	0.0389
30	0	0.0197	0.0063	0.006	0.8099	0.8608	0.013
Mean	**0.0001**	**0.0492**	**0.0155**	**0.0133**	**0.7256**	**0.7513**	**0.0889**
Min	**0.0000**	**0.0175**	**0.0061**	**0.0055**	**0.2332**	**0.2094**	**0.0095**
Max	**0.0014**	**0.1697**	**0.0527**	**0.0423**	**0.9159**	**0.9330**	**2.3340**
Std.Dev.	**0.0003**	**0.0342**	**0.0104**	**0.0084**	**0.0718**	**0.0793**	**0.1295**

Experiment 2

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT

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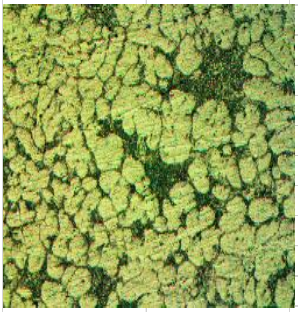
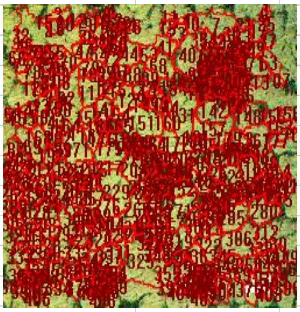


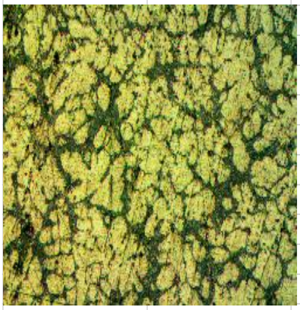


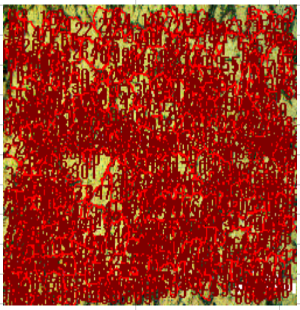
Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0.0002	0.0646	0.0209	0.0167	0.6182	0.639	0.025
2	0.0083	0.4057	0.1148	0.1029	0.7699	0.699	0.95
3	0.0018	0.1837	0.0555	0.0486	0.7286	0.7093	0.2119
4	0.0001	0.0438	0.0152	0.0129	0.7151	0.783	0.0149
5	0.0001	0.0556	0.0191	0.0157	0.6356	0.7106	0.0223
6	0.0002	0.0685	0.0223	0.0189	0.6868	0.7208	0.0323
7	0.0001	0.0559	0.0169	0.0154	0.7327	0.7419	0.0213
8	0.0001	0.0565	0.0162	0.0153	0.7002	0.7136	0.0211
9	0.0003	0.0727	0.0211	0.0196	0.786	0.7539	0.0348
10	0.0014	0.1579	0.0525	0.0424	0.645	0.6775	0.1613
11	0.0005	0.0994	0.0294	0.0265	0.7435	0.7245	0.0634
12	0.0059	0.3533	0.0998	0.0873	0.725	0.6616	0.6852
13	0.0002	0.0599	0.0203	0.0178	0.7662	0.8179	0.0285
14	0.0003	0.0734	0.0238	0.0217	0.7843	0.8233	0.0424
15	0.0003	0.0764	0.0256	0.0209	0.6707	0.7062	0.0395
16	0.0032	0.2371	0.0768	0.0641	0.6928	0.7076	0.3694
17	0.0014	0.1576	0.0522	0.0433	0.6935	0.72	0.1689
18	0.0001	0.0576	0.0189	0.0159	0.6771	0.715	0.0228
19	0.0007	0.1144	0.0362	0.0316	0.7266	0.7403	0.0898
20	0.0062	0.3867	0.103	0.0894	0.7384	0.6245	0.7182
21	0.0003	0.0714	0.0236	0.0206	0.698	0.7576	0.0381
22	0.0016	0.1797	0.0519	0.0454	0.7182	0.6733	0.1854
23	0.001	0.132	0.0408	0.0372	0.7826	0.7843	0.1246
24	0.0002	0.0542	0.0179	0.0163	0.8223	0.8585	0.0239
25	0.0003	0.071	0.0244	0.0207	0.7095	0.7735	0.0387
26	0.0007	0.1085	0.0333	0.0305	0.795	0.788	0.0836
27	0.0005	0.0955	0.0282	0.0271	0.8525	0.8229	0.0659
28	0.0002	0.0545	0.0191	0.0161	0.7008	0.7811	0.0235
29	0.0001	0.0559	0.0189	0.0158	0.6984	0.7422	0.0224
30	0.0006	0.1046	0.0336	0.0291	0.6839	0.7231	0.076
Mean	**0.0012**	**0.1236**	**0.0377**	**0.0329**	**0.7232**	**0.7365**	**0.1468**
Min	**0.0001**	**0.0438**	**0.0152**	**0.0129**	**0.6182**	**0.6245**	**0.0149**
Max	**0.0083**	**0.4057**	**0.1148**	**0.1029**	**0.8525**	**0.8585**	**0.9500**
Sum	**0.0369**	**3.7080**	**1.1322**	**0.9857**	**21.6974**	**22.0940**	**4.4051**
Std.Dev.	**0.0020**	**0.0996**	**0.0274**	**0.0239**	**0.0540**	**0.0555**	**0.2327**

Experiment 3

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT
UNIVERSITI TEKNIKAL MALAYSIA MELAKA





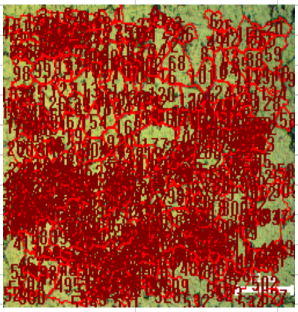
Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0.0003	0.0742	0.0227	0.0199	0.7412	0.7268	0.1433
2	0	0.0338	0.0112	0.01	0.7889	0.8265	0.0362
3	0	0.0192	0.0066	0.0058	0.7459	0.826	0.0123
4	0.0001	0.0477	0.0145	0.0134	0.7033	0.7451	0.0655
5	0.0008	0.1457	0.0394	0.0321	0.6649	0.5648	0.3717
6	0.0001	0.0481	0.0154	0.0136	0.7581	0.7741	0.0667
7	0.0001	0.0407	0.0131	0.0119	0.7887	0.8157	0.0509
8	0.0001	0.0437	0.0143	0.0122	0.7204	0.7501	0.0544
9	0	0.0366	0.0116	0.0098	0.7236	0.7211	0.0351
10	0	0.0301	0.0106	0.0089	0.6899	0.7719	0.0286
11	0	0.0379	0.0122	0.0105	0.7309	0.7443	0.0397
12	0.0001	0.0426	0.0143	0.0123	0.6932	0.7563	0.0546
13	0	0.0208	0.0066	0.0061	0.8028	0.8277	0.0135
14	0	0.0192	0.0063	0.0056	0.7789	0.811	0.0114
15	0.0002	0.0603	0.0191	0.0171	0.8001	0.7982	0.1058
16	0	0.037	0.0122	0.0109	0.8005	0.8327	0.0433
17	0	0.0318	0.0105	0.0091	0.7307	0.7693	0.0299
18	0.0003	0.0756	0.0239	0.0207	0.7096	0.7248	0.1545
19	0	0.0342	0.0112	0.0096	0.7257	0.7569	0.0338
20	0.0002	0.0571	0.0189	0.0163	0.7492	0.7779	0.0963
21	0	0.0231	0.0076	0.007	0.8513	0.8812	0.0178
22	0.0001	0.054	0.0159	0.0141	0.737	0.7068	0.0721
23	0	0.0228	0.0076	0.0067	0.7345	0.7953	0.0163
24	0.0001	0.0392	0.0129	0.0115	0.7902	0.8214	0.0478
25	0.0002	0.0613	0.0178	0.0171	0.8042	0.7888	0.1063
26	0	0.023	0.0074	0.0068	0.7711	0.8175	0.0167
27	0	0.0264	0.0083	0.0082	0.8896	0.9176	0.0242
28	0	0.0151	0.0052	0.0047	0.7969	0.8757	0.008
29	0.0001	0.0548	0.0169	0.0147	0.7559	0.7354	0.0785
30	0.0008	0.1425	0.0355	0.0321	0.6884	0.5873	0.371
Mean	**0.0001**	**0.0466**	**0.0143**	**0.0126**	**0.7555**	**0.7749**	**0.0735**
Min	**0.0000**	**0.0151**	**0.0052**	**0.0047**	**0.6649**	**0.5648**	**0.0080**
Max	**0.0008**	**0.1457**	**0.0394**	**0.0321**	**0.8896**	**0.9176**	**0.3717**
Sum	**0.0036**	**1.3985**	**0.4297**	**0.3787**	**22.6656**	**23.2482**	**2.2062**
Std.Dev.	**0.0002**	**0.0309**	**0.0079**	**0.0067**	**0.0501**	**0.0738**	**0.0893**

Experiment 4

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

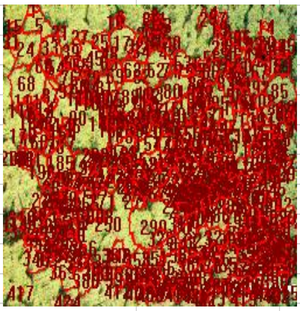
Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0	0.0276	0.0092	0.0081	0.7149	0.7833	0.0239
2	0.0001	0.0467	0.0151	0.0134	0.7703	0.7944	0.0653
3	0	0.0159	0.0057	0.0049	0.7355	0.8408	0.0089
4	0.0001	0.0543	0.0168	0.0156	0.8357	0.8264	0.0879
5	0.0001	0.0485	0.0155	0.0137	0.7755	0.7845	0.068
6	0.0005	0.1043	0.0297	0.0261	0.7615	0.6879	0.2465
7	0	0.0299	0.009	0.009	0.8777	0.8884	0.0294
8	0.0011	0.1535	0.0419	0.0384	0.7429	0.6777	0.5317
9	0.0001	0.0422	0.0132	0.012	0.7694	0.783	0.0519
10	0.0001	0.0606	0.0176	0.0158	0.7021	0.6872	0.0902
11	0	0.0169	0.0058	0.0053	0.8053	0.8855	0.0102
12	0	0.0245	0.0088	0.0069	0.6114	0.6936	0.0173
13	0.0001	0.0465	0.0147	0.0133	0.7906	0.8025	0.0642
14	0	0.0178	0.006	0.0053	0.772	0.8355	0.0104
15	0	0.067	0.0034	0.00236	0.69	0.781	0.0124
16	0.0001	0.0506	0.0159	0.0141	0.7835	0.7764	0.0718
17	0	0.0339	0.0107	0.0099	0.8326	0.8422	0.0357
18	0	0.0176	0.0059	0.0055	0.8615	0.9087	0.0109
19	0.0002	0.079	0.0219	0.0187	0.6843	0.6151	0.1259
20	0	0.0304	0.0097	0.0089	0.8354	0.8429	0.0287
21	0	0.0302	0.0082	0.0078	0.6756	0.6683	0.022
22	0	0.0356	0.0117	0.0102	0.7382	0.7741	0.0375
23	0	0.0332	0.0101	0.0094	0.8048	0.7966	0.0318
24	0	0.0211	0.0069	0.0066	0.8412	0.901	0.0156
25	0	0.0238	0.0078	0.0069	0.739	0.7829	0.0172
26	0	0.0206	0.0065	0.006	0.795	0.8233	0.0133
27	0.0003	0.0835	0.0249	0.022	0.6881	0.6867	0.1745
28	0	0.0192	0.0064	0.0056	0.7724	0.8118	0.0115
29	0	0.0195	0.0063	0.0058	0.8282	0.8571	0.0123
30	0	0.0189	0.0058	0.0056	0.8422	0.8565	0.0114
Mean	**0.0001**	**0.0424**	**0.0124**	**0.0111**	**0.7692**	**0.7898**	**0.0646**
Min	**0.0000**	**0.0159**	**0.0034**	**0.0024**	**0.6114**	**0.6151**	**0.0089**
Max	**0.0011**	**0.1535**	**0.0419**	**0.0384**	**0.8777**	**0.9087**	**0.5317**
Sum	**0.0028**	**1.2733**	**0.3711**	**0.3332**	**23.0768**	**23.6953**	**1.9383**
Std.Dev.	**0.0002**	**0.0306**	**0.0083**	**0.0075**	**0.0632**	**0.0759**	**0.1033**

Experiment 5

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0	0.0298	0.0098	0.0082	0.6908	0.7248	0.0247
2	0.0001	0.0422	0.0134	0.0122	0.7929	0.8112	0.0539
3	0	0.0312	0.0101	0.0086	0.7358	0.7499	0.0272
4	0	0.0276	0.0097	0.0082	0.7111	0.7889	0.0244
5	0.0016	0.1874	0.053	0.0456	0.7219	0.6497	0.7495
6	0.0001	0.0519	0.0155	0.0137	0.717	0.7058	0.0683
7	0.0006	0.1024	0.0308	0.0278	0.7861	0.7581	0.2799
8	0.0001	0.0489	0.0152	0.0134	0.7315	0.7387	0.0651
9	0.0003	0.0785	0.0234	0.0205	0.7207	0.6992	0.1525
10	0.0001	0.0451	0.0139	0.0131	0.8345	0.8336	0.0618
11	0	0.0284	0.0092	0.0086	0.8258	0.866	0.0267
12	0.0001	0.0457	0.0137	0.0126	0.7464	0.7515	0.0577
13	0	0.0185	0.0064	0.0057	0.7963	0.8694	0.0118
14	0	0.0369	0.0118	0.0099	0.6816	0.7012	0.0358
15	0	0.0241	0.0073	0.007	0.8456	0.8385	0.0177
16	0	0.0211	0.0072	0.006	0.6965	0.7534	0.0133
17	0.0002	0.0597	0.0186	0.0167	0.7949	0.7854	0.1008
18	0.0001	0.0462	0.0139	0.0124	0.6851	0.6967	0.0553
19	0.0002	0.066	0.02	0.0179	0.7568	0.7443	0.1163
20	0	0.0223	0.0067	0.0063	0.8009	0.8	0.0144
21	0	0.0273	0.0083	0.0078	0.7879	0.8034	0.0223
22	0	0.0209	0.007	0.0064	0.8206	0.8711	0.0148
23	0	0.0202	0.0066	0.0061	0.8248	0.8674	0.0136
24	0	0.0301	0.0092	0.009	0.8393	0.862	0.0293
25	0.0008	0.1331	0.0361	0.0334	0.786	0.7002	0.4033
26	0	0.0269	0.0081	0.0078	0.8536	0.8494	0.0223
27	0	0.027	0.0085	0.0079	0.7991	0.8251	0.0228
28	0	0.0287	0.0081	0.0081	0.7946	0.7965	0.0239
29	0	0.0369	0.0116	0.0106	0.7601	0.7926	0.0411
30	0	0.0284	0.0091	0.0084	0.8536	0.8646	0.0257
Mean	**0.0001**	**0.0464**	**0.0141**	**0.0127**	**0.7731**	**0.7833**	**0.0859**
Min	**0.0000**	**0.0185**	**0.0064**	**0.0057**	**0.6816**	**0.6497**	**0.0118**
Max	**0.0016**	**0.1874**	**0.0530**	**0.0456**	**0.8536**	**0.8711**	**0.7495**
Sum	**0.0043**	**1.3934**	**0.4222**	**0.3799**	**23.1918**	**23.4986**	**2.5762**
Std.Dev.	**0.0003**	**0.0369**	**0.0102**	**0.0089**	**0.0536**	**0.0638**	**0.1510**

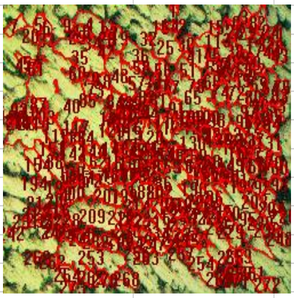
Appendix 5: Data analysis specimens with direct casting

Experiment 1

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



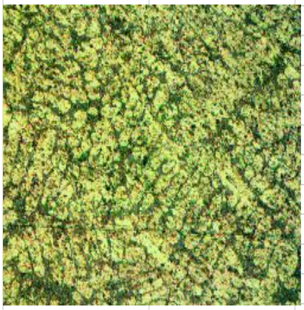
Measurements (Data + Statistics)

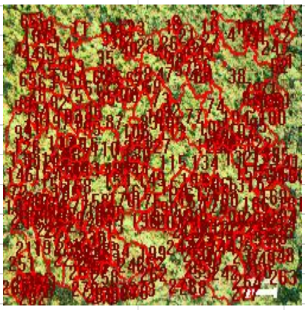
Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0.0006	0.1344	0.0453	0.0279	0.3806	0.4031	0.2815
2	0.0012	0.1754	0.057	0.0399	0.4899	0.5009	0.5752
3	0.0003	0.1082	0.0365	0.0216	0.348	0.3703	0.1683
4	0.0001	0.0517	0.0204	0.0118	0.3337	0.4158	0.0506
5	0.0018	0.2757	0.0696	0.0485	0.4487	0.3707	0.8493
6	0.0018	0.2967	0.0885	0.0482	0.2955	0.2777	0.8376
7	0.0001	0.058	0.0217	0.0133	0.3714	0.4409	0.0642
8	0.0002	0.0685	0.0263	0.0162	0.3621	0.4476	0.0949
9	0.0029	0.2947	0.1083	0.0612	0.32	0.3692	1.3494
10	0.0109	0.9223	0.2175	0.1182	0.2915	0.2175	5.0347
11	0.0005	0.1139	0.0425	0.0258	0.3711	0.435	0.2414
12	0.0018	0.2295	0.0784	0.0487	0.3799	0.4109	0.8539
13	0.0001	0.0678	0.025	0.0136	0.2971	0.3442	0.067
14	0.0004	0.1027	0.0394	0.0248	0.3985	0.4804	0.2231
15	0.0013	0.2052	0.067	0.0413	0.3695	0.3848	0.6157
16	0.0005	0.1286	0.0492	0.0266	0.2927	0.3516	0.2549
17	0.0009	0.161	0.0588	0.035	0.3528	0.4063	0.4425
18	0.0001	0.0513	0.0193	0.0121	0.3876	0.4635	0.0532
19	0.0025	0.3395	0.0808	0.0571	0.4573	0.3577	1.176
20	0.0001	0.0621	0.0227	0.0144	0.4045	0.4643	0.075
21	0.0011	0.1829	0.0675	0.0385	0.3257	0.3779	0.535
22	0.0011	0.1832	0.0582	0.0383	0.4312	0.4314	0.5284
23	0	0.0326	0.013	0.0082	0.3895	0.4935	0.0243
24	0.0012	0.1813	0.0631	0.0403	0.4	0.442	0.5856
25	0.0017	0.2185	0.0769	0.0478	0.3818	0.4251	0.8243
26	0.0008	0.1412	0.0516	0.0326	0.3968	0.458	0.3846
27	0.0015	0.2022	0.0813	0.0445	0.297	0.3768	0.7132
28	0.0019	0.2581	0.0786	0.0498	0.3874	0.3778	0.8951
29	0.001	0.1629	0.067	0.0366	0.3002	0.3873	0.4836
30	0.0005	0.1253	0.0441	0.0272	0.3814	0.4223	0.268
Mean	0.0013	0.1845	0.0592	0.0357	0.3681	0.4035	0.6184
Min	0.0000	0.0326	0.0130	0.0082	0.2915	0.2175	0.0243
Max	0.0109	0.9223	0.2175	0.1182	0.4899	0.5009	5.0347
Sum	0.0389	5.5354	1.7755	1.0700	11.0434	12.1045	18.5505
Std.Dev.	0.0020	0.1616	0.0383	0.0214	0.0514	0.0605	0.9059

Experiment 2

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT

UNIVERSITI TEKNIKAL MALAYSIA MELAKA





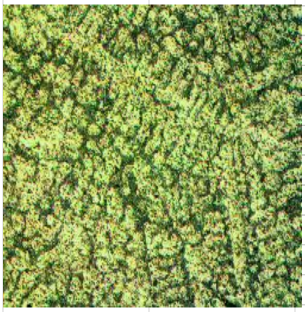
Measurements (Data + Statistics)

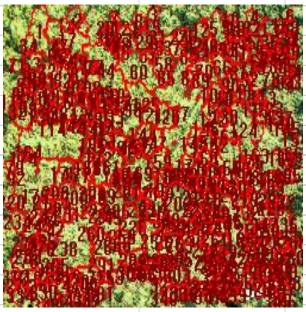
Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0.0066	0.4097	0.1398	0.0917	0.4326	0.4628	0.7553
2	0.0004	0.1132	0.0431	0.0234	0.2898	0.3506	0.0494
3	0.0007	0.1667	0.0536	0.03	0.3072	0.3142	0.0812
4	0.0164	0.8643	0.2534	0.1447	0.3269	0.3007	1.8792
5	0.0004	0.1096	0.0387	0.0246	0.3889	0.4411	0.0546
6	0.0102	0.6011	0.1846	0.1142	0.3719	0.3642	1.1715
7	0.004	0.3366	0.1129	0.0715	0.3924	0.4183	0.4594
8	0.0035	0.3197	0.0976	0.0673	0.4257	0.4314	0.4064
9	0.0064	0.4737	0.1573	0.0908	0.3316	0.3469	0.7403
10	0.0041	0.3787	0.1256	0.0723	0.3279	0.3438	0.4701
11	0.0008	0.1408	0.0508	0.0324	0.4079	0.4627	0.0946
12	0.0019	0.2351	0.0775	0.0492	0.4052	0.4189	0.2177
13	0.0036	0.3504	0.1126	0.0682	0.3669	0.3707	0.418
14	0.0135	0.8267	0.2314	0.1313	0.3171	0.281	1.5481
15	0.0005	0.135	0.0472	0.0272	0.298	0.3457	0.0665
16	0.0006	0.1312	0.0455	0.0285	0.3831	0.4235	0.0733
17	0.005	0.4103	0.1445	0.0803	0.2904	0.3316	0.5796
18	0.0014	0.2037	0.0689	0.0422	0.371	0.3967	0.1601
19	0.0031	0.3346	0.1021	0.0632	0.3839	0.3679	0.359
20	0.0008	0.1446	0.0542	0.0335	0.3849	0.4522	0.1011
21	0.0005	0.1127	0.0414	0.0264	0.3994	0.4664	0.0629
22	0.0005	0.1036	0.0359	0.026	0.4821	0.5492	0.061
23	0.0019	0.2325	0.0807	0.0495	0.3687	0.4066	0.2204
24	0.0017	0.2276	0.0761	0.0475	0.3888	0.4087	0.2024
25	0.0101	0.6689	0.2277	0.1136	0.2486	0.266	1.1578
26	0.0245	1.1691	0.304	0.1768	0.3396	0.277	2.8073
27	0.0011	0.1855	0.0655	0.0385	0.3361	0.3789	0.1336
28	0.0003	0.0855	0.0333	0.0215	0.4142	0.5105	0.0418
29	0.0078	0.6118	0.1867	0.0999	0.2865	0.2748	0.8968
30	0.0002	0.0798	0.0305	0.0186	0.373	0.4493	0.0313
Mean	**0.0044**	**0.3388**	**0.1074**	**0.0635**	**0.3613**	**0.3871**	**0.5100**
Min	**0.0002**	**0.0798**	**0.0305**	**0.0186**	**0.2486**	**0.2660**	**0.0313**
Max	**0.0245**	**1.1691**	**0.3040**	**0.1768**	**0.4821**	**0.5492**	**2.8073**
Sum	**0.1325**	**10.1627**	**3.2231**	**1.9048**	**10.8403**	**11.6123**	**15.3007**
Std.Dev.	**0.0057**	**0.2688**	**0.0741**	**0.0413**	**0.0519**	**0.0721**	**0.6462**

Experiment 3

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT
UNIVERSITI TEKNIKAL MALAYSIA MELAKA





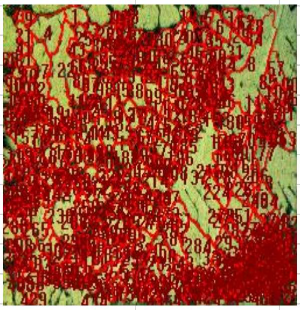
Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0.0013	0.1789	0.0669	0.0414	0.3794	0.4478	0.1538
2	0.0026	0.2912	0.0835	0.0579	0.4614	0.4246	0.3012
3	0.0007	0.1253	0.0463	0.0307	0.4412	0.5126	0.085
4	0.0084	0.6919	0.1629	0.1039	0.3809	0.2913	0.9699
5	0.0007	0.143	0.0516	0.0301	0.3402	0.3859	0.0813
6	0.002	0.2475	0.0797	0.051	0.4105	0.4151	0.2338
7	0.0005	0.1233	0.0463	0.027	0.3388	0.4017	0.0658
8	0.0005	0.1082	0.0417	0.0264	0.3988	0.4851	0.0628
9	0.027	1.4866	0.3278	0.1856	0.3216	0.2225	3.0924
10	0.0043	0.5054	0.1305	0.0742	0.32	0.261	0.4943
11	0.0004	0.1061	0.0409	0.0241	0.3466	0.4201	0.0521
12	0.0061	0.4718	0.1432	0.0885	0.3817	0.3642	0.7035
13	0.0006	0.1229	0.0442	0.0287	0.4207	0.4771	0.0743
14	0.0013	0.195	0.0651	0.0421	0.3834	0.4203	0.1593
15	0.0038	0.3517	0.1123	0.07	0.3885	0.39	0.4405
16	0.0008	0.1648	0.055	0.0335	0.36	0.3833	0.1008
17	0.001	0.1592	0.053	0.0358	0.4591	0.4799	0.1155
18	0.0002	0.0608	0.0261	0.0164	0.3973	0.5359	0.0243
19	0.0015	0.2054	0.0711	0.0443	0.389	0.4228	0.1763
20	0.0002	0.0809	0.0311	0.0191	0.3767	0.4563	0.0329
21	0.0005	0.0979	0.041	0.0252	0.3778	0.4973	0.0571
22	0.0015	0.2183	0.0692	0.044	0.3737	0.3871	0.1736
23	0.0022	0.2353	0.0819	0.0537	0.4293	0.4699	0.2589
24	0.0201	1.0653	0.2382	0.16	0.427	0.3083	2.297
25	0.0029	0.2904	0.0967	0.0614	0.3995	0.4204	0.3391
26	0.0015	0.2224	0.0857	0.0449	0.2741	0.3322	0.1811
27	0.0007	0.1354	0.0546	0.0304	0.3077	0.3911	0.0829
28	0.0002	0.0798	0.0293	0.0194	0.4176	0.494	0.0338
29	0.003	0.3305	0.1089	0.0619	0.3179	0.332	0.3445
30	0.0139	1.0056	0.2713	0.1331	0.2412	0.2042	1.5901
Mean	**0.0037**	**0.3167**	**0.0919**	**0.0555**	**0.3754**	**0.4011**	**0.4259**
Min	**0.0002**	**0.0608**	**0.0261**	**0.0164**	**0.2412**	**0.2042**	**0.0243**
Max	**0.0270**	**1.4866**	**0.3278**	**0.1856**	**0.4614**	**0.5359**	**3.0924**
Sum	**0.1104**	**9.5008**	**2.7560**	**1.6647**	**11.2616**	**12.0340**	**12.7779**
Std.Dev.	**0.0062**	**0.3331**	**0.0728**	**0.0415**	**0.0516**	**0.0836**	**0.7060**

Experimnet 4

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



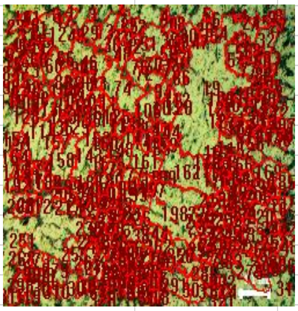
Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0.0224	1.0133	0.3046	0.1691	0.3038	0.289	2.5663
2	0.0035	0.2957	0.1035	0.0675	0.424	0.4671	0.4092
3	0.0025	0.2436	0.0896	0.0565	0.397	0.4591	0.2865
4	0.0173	0.9996	0.2682	0.1485	0.3066	0.2584	1.979
5	0.0015	0.1905	0.0789	0.045	0.3231	0.422	0.1818
6	0.0011	0.1747	0.0638	0.0377	0.3517	0.403	0.1281
7	0.0083	0.5	0.1924	0.1032	0.287	0.3474	0.9557
8	0.0007	0.1443	0.049	0.0316	0.3798	0.4249	0.09
9	0.0033	0.2611	0.1064	0.0654	0.3792	0.4848	0.3844
10	0.0015	0.1909	0.0765	0.0441	0.3334	0.4198	0.1751
11	0.0001	0.0568	0.0228	0.0146	0.4085	0.5177	0.0192
12	0.003	0.2929	0.1054	0.0621	0.3343	0.3854	0.3465
13	0.0007	0.1171	0.0478	0.0301	0.393	0.5065	0.0814
14	0.0015	0.1941	0.0709	0.0445	0.3852	0.4475	0.178
15	0.0019	0.2129	0.0836	0.0498	0.3475	0.4338	0.2232
16	0.0017	0.2128	0.0769	0.0471	0.3714	0.4245	0.1998
17	0.0022	0.2298	0.0924	0.0532	0.3313	0.4193	0.2548
18	0.0358	1.2901	0.3739	0.2137	0.326	0.2971	4.0974
19	0.0002	0.0796	0.0311	0.018	0.3363	0.4129	0.0292
20	0.0015	0.1884	0.0719	0.0437	0.3608	0.4383	0.1719
21	0.003	0.2689	0.099	0.0619	0.3612	0.4347	0.3439
22	0.001	0.1658	0.0551	0.0357	0.3728	0.4135	0.1146
23	0.0003	0.0927	0.0348	0.0222	0.3944	0.4729	0.0443
24	0.0011	0.1727	0.0627	0.0384	0.3625	0.4208	0.1325
25	0.0009	0.1777	0.0586	0.0347	0.3287	0.3522	0.1083
26	0.004	0.3027	0.1139	0.0715	0.3857	0.4609	0.4588
27	0.0034	0.2692	0.0966	0.0663	0.4384	0.5124	0.3946
28	0.0019	0.2294	0.0872	0.0494	0.3191	0.3823	0.2191
29	0.0026	0.2418	0.0902	0.0575	0.3994	0.4725	0.2971
30	0.0001	0.0608	0.0257	0.0143	0.3085	0.4106	0.0184
Mean	0.0043	0.2957	0.1011	0.0599	0.3584	0.4197	0.4963
Min	0.0001	0.0568	0.0228	0.0143	0.2870	0.2584	0.0184
Max	0.0358	1.2901	0.3739	0.2137	0.4384	0.5177	4.0974
Sum	0.1290	8.8699	3.0334	1.7973	10.7506	12.5913	14.8891
Std.Dev.	0.0077	0.2895	0.0810	0.0448	0.0381	0.0626	0.8771

Experiment 5

DIGITAL MICROSCOPY IMAGE ANALYSER REPORT

UNIVERSITI TEKNIKAL MALAYSIA MELAKA



Measurements (Data + Statistics)

Number	Area, mm*mm	Perimeter, mm	Max Length, mm	Equal Circle Diam., mm	Roundness	Roundness-ALT	% Area
1	0.0038	0.3378	0.119	0.0695	0.3353	0.3746	0.4343
2	0.058	2.0952	0.4426	0.2719	0.3686	0.2475	6.6362
3	0.0013	0.1791	0.0688	0.0419	0.3712	0.4478	0.1576
4	0.0028	0.2773	0.0887	0.0603	0.4399	0.4532	0.3265
5	0.0015	0.1788	0.0691	0.0437	0.3977	0.4843	0.1714
6	0.0021	0.2428	0.0867	0.0528	0.3667	0.4137	0.2501
7	0.0037	0.3185	0.1079	0.0693	0.3894	0.4267	0.4312
8	0.003	0.3033	0.103	0.0627	0.3708	0.3959	0.3535
9	0.0033	0.3427	0.1087	0.0649	0.3367	0.3453	0.3781
10	0.0008	0.1661	0.0649	0.0323	0.2483	0.3046	0.0938
11	0.0024	0.2469	0.0883	0.0557	0.3974	0.4469	0.2785
12	0.0003	0.0851	0.0339	0.0201	0.3526	0.4419	0.0364
13	0.002	0.23	0.0828	0.0515	0.3855	0.4366	0.2379
14	0.0023	0.2593	0.0955	0.0549	0.3309	0.383	0.2712
15	0.015	0.8825	0.2324	0.1382	0.3532	0.2924	1.714
16	0.0002	0.073	0.0282	0.0176	0.3855	0.4722	0.028
17	0.0017	0.2055	0.0757	0.0469	0.3811	0.4434	0.1981
18	0.0027	0.279	0.0933	0.0588	0.3827	0.41	0.311
19	0.0053	0.4669	0.1705	0.0824	0.2333	0.2679	0.61
20	0.0008	0.1475	0.0547	0.0335	0.3715	0.4351	0.1008
21	0.0026	0.2599	0.0967	0.0577	0.3577	0.4176	0.2996
22	0.0004	0.1049	0.041	0.023	0.3176	0.3892	0.0477
23	0.0034	0.3619	0.1114	0.0665	0.3262	0.3297	0.3969
24	0.0007	0.1259	0.0478	0.0301	0.3881	0.469	0.0817
25	0.0026	0.3208	0.1117	0.0581	0.2679	0.2946	0.3031
26	0.0026	0.2485	0.0951	0.0575	0.365	0.4393	0.297
27	0.0015	0.1906	0.0739	0.0447	0.3628	0.4438	0.1793
28	0.0031	0.3072	0.1169	0.0628	0.2861	0.3438	0.3546
29	0.0063	0.5082	0.1567	0.0899	0.321	0.3149	0.7256
30	0.002	0.2176	0.0811	0.0504	0.3888	0.4542	0.2284
Mean	**0.0046**	**0.3321**	**0.1049**	**0.0623**	**0.3527**	**0.3940**	**0.5311**
Min	**0.0002**	**0.0730**	**0.0282**	**0.0176**	**0.2333**	**0.2475**	**0.0280**
Max	**0.0580**	**2.0952**	**0.4426**	**0.2719**	**0.4399**	**0.4843**	**6.6362**
Sum	**0.1382**	**9.9628**	**3.1470**	**1.8696**	**10.5795**	**11.8191**	**15.9325**
Std.Dev.	**0.0104**	**0.3664**	**0.0758**	**0.0458**	**0.0462**	**0.0667**	**1.1932**

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

TAJUK: A NEWLY SPIRAL CHANNEL MECHANISM TO PRODUCE NON DENDRITIC GRAINS MICROSTRUCTURE OF ALUMINIUM ALLOY FOR SEMI-SOLID PROCESSING

SESI PENGAJIAN: **2021/22 Semester 1**

Saya **MUHAMMAD HAFIZ BIN ABD RAHIM**

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2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
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MEKANIKAL & PEMBUATAN
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Tarikh: 18 Januari 2022

Tarikh: 18/01/2022

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