MOULD DESIGN AND MECHANICAL ANALYSIS OF THE CASTED MATERIAL

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MOULD DESIGN AND MECHANICAL ANALYSIS OF THE CASTED MATERIAL

MOHD AZUAN BIN ABU SHAH

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with
Manufacturing Engineering

Faculty of Mechanical Engineering
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UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Mould design and mechanical analysis of the casted material*" is written by *Mohd Azuan Bin Abu Shah*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

MR. JASRI BIN MOHAMAD

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering with Manufacturing Engineering.

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STUDENT'S DECLARATION

I declare that this report titled "*Mould design and mechanical analysis of the casted material*" is my result of my own research except as stated in the references. This thesis/report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Date : 06 DECEMBER 2010

Dedicated, truthfully for supports,
encouragements and always be there during hard times, to
my beloved family.

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ABSTRACT

This report is an outcome of the work carried out in doing and completing final year project, mould design and mechanical analysis of the casted material. Objectives of this project is to design and fabricate the mould for tensile test specimen, following ASTM E8 standard and to study the mechanical properties of the casted materials and its comparison with effect of the cooling rate between water, oil and air. Materials that have been used for mould is mild steel and for casted material is aluminum alloy. Overall, this project was run based on four main steps; design using Solid Work, running a simulation on Master CAM, fabricates using CNC Milling Machine, and finally casting process. Each sample was then tested by Rockwell hardness in order to study the effect of the cooling media to the hardness of casted material for all three cooling media, water, oil and air. It project was done by testing at the outer surface and inner surface of the casted aluminum alloys. The higher value for outer surface hardness test is 49.10 HRB and the higher value for inner surface hardness test is 37.72 HRB. The result shows the hardness of casted material immersed in water has higher value compared to oil and air. Water has proved to be the best mediums for cooling rate compare to oil and air medium. The hardness of aluminium increases with the increasing of cooling rate. Cooling rate decreases with distance from the quenched end, and the hardness also decreases.

ABSTRAK

Laporan ini ialah satu hasil kerja dijalankan dalam melakukan dan menyiapkan projek tahun terakhir, membentuk reka bentuk dan analisis mekanik bahan dicor. Tujuan dari projek ini adalah untuk merancang dan membuat cetakan untuk spesimen uji tarik, mengikuti ketetapan ASTM E8 dan untuk mempelajari sifat mekanik bahan dicor dan perbandingannya dengan kesan kadar penyejukan antara air, minyak dan udara. Bahan-bahan yang telah digunakan untuk cetakan adalah keluli lembut dan bahan dicor adalah paduan aluminium. Secara keseluruhan, projek ini dijalankan berdasarkan empat langkah utama; mereka bentuk menggunakan *Solid Work*, menjalankan simulasi menggunakan perisian CAM, mereka menggunakan mesin kisar CNC, dan akhir sekali adalah proses tuangan. Setiap sampel yang diuji oleh kekerasan Rockwell untuk mempelajari pengaruh media pendinginan untuk bahan dicor untuk ketiga-tiga media pendinginan iaitu melalui air, minyak dan udara. Projek ini telah dijalankan dengan melakukan pengujian pada permukaan luar dan permukaan dalam dari gabungan aluminium dicor. Nilai yang tertinggi untuk ujian kekerasan pada permukaan luar ialah 49.10 HRB dan nilai tertinggi untuk ujian kekerasan permukaan dalam ialah 37.72 HRB Keputusan kajian menunjukkan kekerasan bahan dicor direndam dalam air mempunyai nilai lebih tinggi berbanding dengan minyak dan udara. Air telah terbukti menjadi media terbaik untuk membandingkan kadar penyejukan diantara minyak dan medium udara. Kekerasan aluminium meningkat dengan meningkatnya kadar penyejukan. Kadar penyejukan berkurangan dengan jarak dari menghilangkan akhir, dan kekerasan juga berkurangan.

.

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LIST OF SYMBOLS

mm	Millimeter
MPa	Megapascal
GPa	Gigapascal
%	Percent
HB	Brinell Hardness Number
HR	Rockwell Hardness Number
D	Diameter of Steel Ball
sec	Second
lbf	Pound of Force
σ	Stress
F_0	Minor Load
F_1	Major Load
F	Total Load
ρ	Density
A	Area
V	Volume
e	Depth of Penetration
l	Instantaneous Length
l_o	Original Length
E	Modulus of Elasticity

LIST OF ABBREVIATIONS

AA	Aluminum Association
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Material
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CNC	Computer Numerical Control
FKM	Fakulti Kejuruteraan Mekanikal
HPCC	High Precision Contour Control
HRB	Hardness Rockwell Brinell
ISO	International Organization for Standardization
NC	Numerical Control
RISC	Reduced Instruction Set Computer
RPM	Rotation Per Minutes
UMP	Universiti Malaysia Pahang
V/A	Volume per Surface Area
2D	Two Dimension
3D	Three Dimension

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Casting is a manufacturing process where a solid is melted, heated to proper temperature (sometimes treated to modify its chemical composition), and is then poured into a cavity or mold, which contains it in the proper shape during solidification. Thus, in a single step, simple or complex shapes can be made from any metal that can be melted. The resulting product can have virtually any configuration the designer desires. Since metal casting involves working with metal in its molten form, the process can be dangerous if undertaken by the reckless or ill informed. The melting points of several metals are well above 1,000 degrees Fahrenheit, or 530 degrees Celsius. It is vital that anyone wanting to work with metal casting take all the proper precautions.

Casting has marked advantages in the production of complex shapes, parts having hollow sections or internal cavities, parts that contain irregular curved surfaces (except those made from thin sheet metal), very large parts and parts made from metals that are difficult to machine. Because of these obvious advantages, casting is one of the most important of the manufacturing processes.

Today, it is nearly impossible to design anything that cannot be cast by one or more of the available casting processes. Metal casting requires specialized equipment, knowledge, and some creativity. While metal casting is used on an Industrial level as the process cuts cost and proves to be highly efficient. However, as in all manufacturing techniques, the best results and economy are achieved if the designer understands the various options and tailors the design to use the most appropriate process in the most efficient manner. The various processes differ primarily in the mold material (whether sand, metal, or other material) and the pouring method (gravity, vacuum, low pressure, or high pressure). All of the processes share the requirement that the materials solidify in a manner that would maximize the properties, while simultaneously preventing potential defects, such as shrinkage voids, gas porosity, and trapped inclusions.

Based on that case, the project title was proposed is mould design and mechanical analysis of the casted material. This project involves the designing process, simulation process, fabrication process and analysis process. The project start from design the mould using computer aided design (CAD) software and then simulation using master cam (CAM) software. After that the project continues with fabrication the mould using CNC Milling Machine and next process is mould casting. The finally is mechanical analysis process for the product cast. At the end of the project, all the process method will combine to study and investigate the defects of gases, gating system and mold design and material selection in metal casting and other defects.

1.2 PROBLEM STATEMENT

As in all metal casting process, certain guidelines and design principles pertaining to casting have been developed over many years. Although these principles have been established primarily through experience, analytical methods, process simulation and modeling, and computer aided design and manufacturing techniques have all come into wide use as well, thus improving productivity and the quality of castings and resulting in significant cost savings.

However, products that are produced with casting process still have defective. In most cases a given mold design will produce mostly well with some defective. It is very difficult for a mold to produce no defective parts and some defective ones. There are many defective that are found in products primarily due to gassing, pouring method, size of risers and etc. However, this kind of causes is difficult to control since process of casting is a hands-on process by human itself and not machine where it involves pouring the melted material into mould. Thus, in this project, the system for casting in terms of gating system and risers will be designed and calculated purposely to reduce the defects of part to be casted. Furthermore, the study about the mechanical properties of the casted material has not been an interested topic among researchers. Hence, investigation to the changes of aluminum mechanical properties after the casting process will be examined in this project.

1.3 PROJECT OBJECTIVES

Basically, the specific objectives of this project are:

1. To design and fabricate the mould for tensile test specimen, ASTM E8.
2. To study the mechanical properties of the casted materials by quench the aluminum alloys to different cooling media which are water, oil and air.

1.4 PROJECT SCOPES

This project will be carried out by using specific software and machine in the process of designing and fabricating the mould of casting. The dimension of the casted dog-bone shape for the tensile test specimen will be according to ASTM standard E8 as shown in Figure 2.1 in chapter 2. The material and hardware to be used to carry out this project is listed as follows:

1. Types of material to be used in this project are restricted to only aluminum for the casted material and mild steel as the mould.
2. The design of mould is according to dog-bone shape standard ASTM E8 and it will be done by using Solid Work as the design software.
3. Master CAM software used to simulate the machining process of mould fabrication.
4. Fabrication process of the mould has done by using CNC milling machine.

CHAPTER 2

LITERATURE REVIEW

2.1 TENSILE TESTING SPECIMEN (ASTM E8)

Consider the typical tensile test specimen is shown as Figure 2.1. It has enlarged ends or shoulders for gripping. The important part of the specimen is the gage section. The cross sectional area of the gage section is reduced relative to that of the remainder of the specimen so that deformation and failure will be localized in this region. The gage length is the region over which measurements are made and is centered within the reduced section. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section, and the gage length should be great relative to its diameter (Davis Joseph, 2004).

There are various ways of gripping the specimen, some of which are illustrated in Figure 2.3. The end may be screwed into a threaded grip, or it may be pinned; butt ends may be used, or the grip section may be held between wedges. The most important concern in the selection of gripping method is to ensure that the specimen can be held at the maximum load without slippage or failure in the grip section. Bending should be minimized (Davis Joseph, 2004).

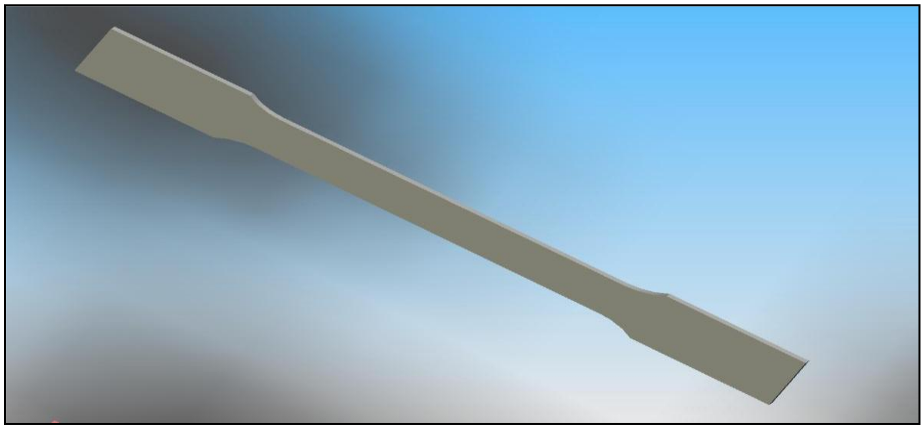


Figure 2.1: Specimen for tensile test

Source: Davis Joseph, 2004

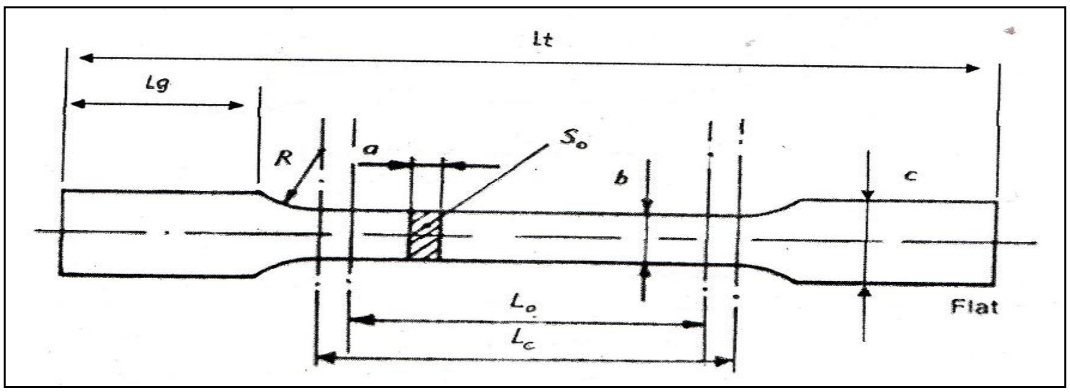


Figure 2.2: Specimen preparation according to ASTM specifications

Source: Davis Joseph, 2004

Table 2.1: Detail Dimension for Tensile Test Specimen

No.	Item	Dimension
1	Lt, Total Length	Min 8" (20.32cm)
2	Lg, Grip Length	Min 2" (5.08cm)
3	Lo, Gauge Length	2.000" ± 0.0005" (5.08 ± 0.0127cm)
4	Lc, Parallel or Reduce Section	Min 2.25" (5.715cm)
5	R, Radius	Min 0.5"
6	a, Thickness	0.2" (0.4cm)
7	b, Gauge width	0.500" ± 0.01" (1.27 ± 0.0254cm)
8	c, Grip width	Approx. 0.75" (1.905cm)

Source: Davis Joseph, 2004

2.2 ENGINEERING DESIGN

Engineering design is defined as the process of devising a system, component, or process to meet desired needs. It is a decision-making process in which the basic sciences, mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objective and criteria, synthesis, analysis, construction, testing and evaluation (Hyman, 1998).

Engineering design is more advanced version in problem solving technique that many people use routinely. The general procedure for solving real everyday problem is straightforward. A problem is encountered, information about the problem is obtained, alternate solutions are formulated and the best alternative is adopted. Engineering design is about a methodical approach to solving a particular class of large and complex problems (Hyman, 1998).

2.2.1 Gating System and Mould Design

When selecting to manufacture a part by casting one must consider the material properties and possible defects that this manufacturing process produces. The primary way to control casting defects is through good mould design considerations in the creation of the casting's mould and gating system. The key is to design a system that promotes directional solidification. Directional solidification, in casting manufacture, means that the material will solidify in a manner that we plan, usually as uniformly as possible with the areas farthest away from the supply of molten metal solidifying first and then progressing towards the risers. The solidification of the casting must be such that there is never any solid areas that will cut off the flow of liquid material to unsolidified areas creating isolated regions that result in vacancies within the casting's material (Karsay, 2000).

In the development of an effective manufacturing process, gating system design is crucial in controlling the rate and turbulence in the molten metal being poured, the flow of liquid metal through the casting's system, and the temperature gradient within the metal casting. Hence a good gating system will create directional solidification throughout the casting, since the flow of molten material and temperature gradient will determine how the casting solidifies (Karsay, 2000).

When designing a mould for a casting or trying to fix or improve upon and existing design may want to consider the following area:

2.2.2 Insure that have Adequate Material

This may seem very obvious, but in the manufacturing of parts many incomplete castings have been a result of insufficient material. Make sure that calculation for the volume of all the areas of casting accounting for shrinkage (Karsay, 2000).

2.2.3 Consider the Superheat

Increasing the superheat, (temperature difference between the metal at pouring and freezing), as mentioned previously can increase fluidity of the material for the casting, which can assist with its flow into the mould. There is a compromise involved to the manufacturing process. Increasing the superheat has problems associated with it, such as increased gas porosity, increased oxide formation, and mould penetration (Karsay, 2000).

2.2.4 Insulate Risers

Since the riser is the reservoir of molten material for the casting it should be last to solidify. Insulating the top as mentioned earlier, will greatly reduce cooling in the risers from the steep temperature gradient between the liquid metal of the casting, and the room temperature air (Karsay, 2000).

2.2.5 Consider V/A Ratios

In casting manufacture, V/A ratio stands for volume to surface area or mathematically (volume/surface area). When solidification of a casting begins a thin skin of solid metal is first formed on the surface between the casting and the mould wall. As solidification continues the thickness of this skin increases towards the center of the liquid mass. Sections in the casting with low volume to surface area will solidify faster than sections with higher volume to surface area. When manufacturing a part by metal casting consideration of the V/A ratios is critical in avoiding premature solidification of the casting and the formation of vacancies (Karsay, 2000).

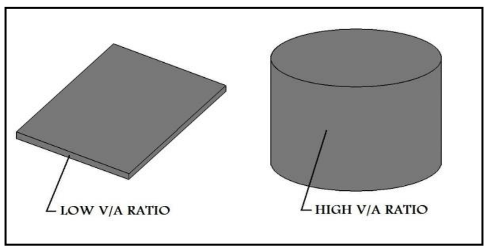


Figure 2.3: V/A ratio

2.2.6 Heat Masses

Avoid large heat masses in locations distant to risers. Instead locating sections of the casting with low V/A ratios further away from the risers will insure a smooth solidification of the casting (Karsay, 2000).

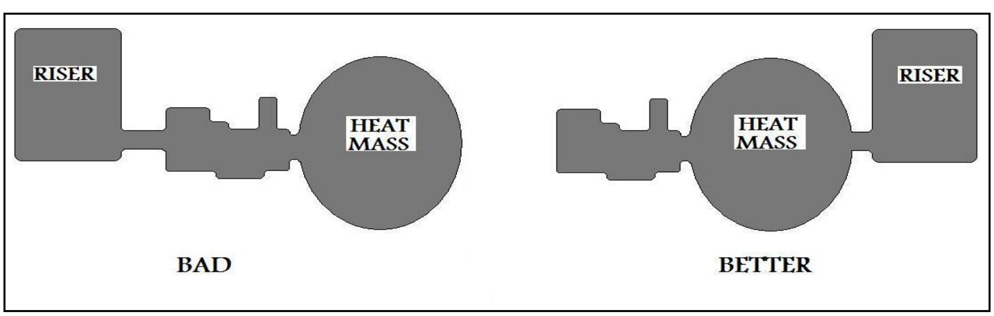


Figure 2.4: Heat mass and riser

2.2.7 Sections of the Casting

The flow of material is very important to the manufacturing process. Do not feed a heavy section through a lighter one (Karsay, 2000).

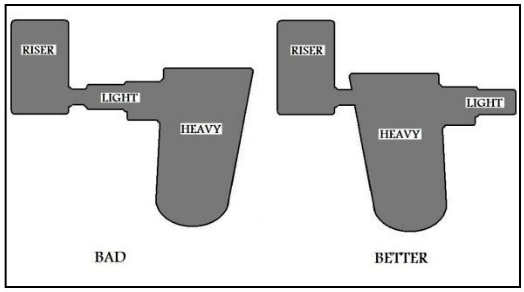


Figure 2.5: Sections of the casting

2.2.8 Consideration to L, T, V, Y and Junctions

Due to the nature of the geometry of these sections it is likely that they will contain an area where the casting's solidification is slower than the rest of the junction. These hot spots are circled in Figure 2.6. They are located such that the material around them, which will undergo solidification first, will cut of the hot spots from the flow of molten material. The flow of casting material must be carefully considered when manufacturing such junctions. If there is some flexibility in the design of the casting and it is possible you may want to think about redesigning the junction. Some possible design alternatives are shown in Figure 2.6. These should reduce the likelihood of the formation of hot spots (Karsay, 2000).

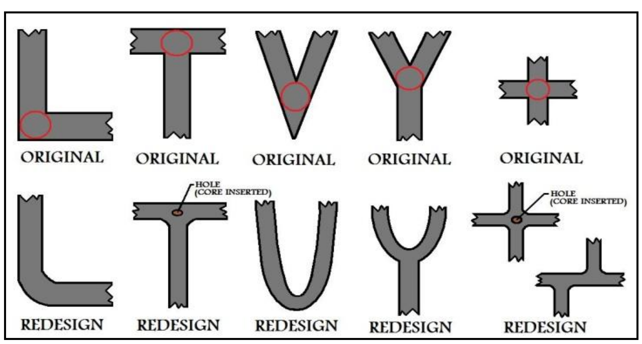


Figure 2.6: Consideration to L, T, V, Y and junctions

2.2.9 Prevent Planes of Weakness

When castings solidify, columnar grain structures tend to develop, in the material, pointing towards the center. Due to this nature, sharp corners in the casting may develop a plane of weakness. By rounding the edges of sharp corners this can be prevented (Karsay, 2000).

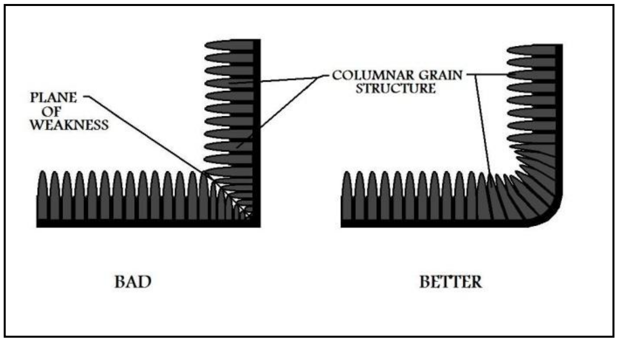


Figure 2.7: Prevent planes of weakness

2.2.10 Reduce Turbulence

When manufacturing a casting, turbulence is always a factor in our flow of molten metal. Turbulence, as covered earlier in the pouring section, is bad because it can trap gases in the casting material and cause mould erosion. Although not altogether preventable in the manufacturing process, turbulence can be reduced by the design of a gating system that promotes a more laminar flow of the liquid metal. Sharp corners and abrupt changes in sections within the casting can be a leading cause of turbulence. Their affect can be mitigated by the employment of radii (Karsay, 2000).

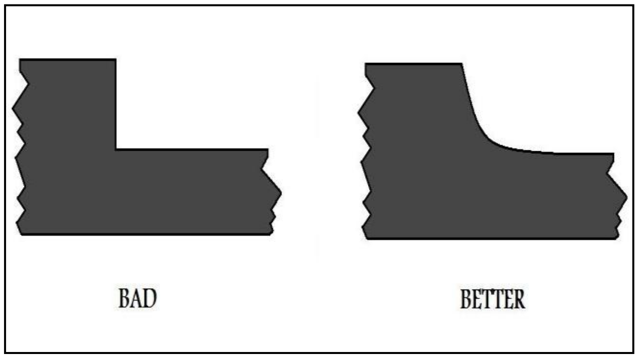


Figure 2.8: Reduce turbulence

2.2.11 Connection between Riser and Casting

Riser design is very important in metal casting manufacture. If the passage linking the riser to the casting solidifies before the casting, the flow of molten metal to the casting will be blocked and the riser will cease to serve its function. If the connection has a larger cross sectional area it will decrease its time to freeze. Good manufacturing design, however, dictates that we minimize this cross section as much as possible to reduce the waste of material in the casting process. By making the passageway short we can keep the metal in its liquid state longer since it will be receiving more heat transfer from both the riser and the casting (Karsay, 2000).

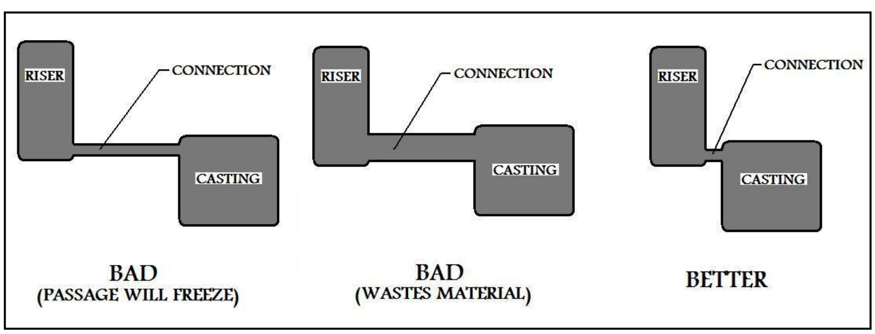


Figure 2.9: Connection between riser and casting

2.2.12 Tapered Down Sprue

Flow considerations for our casting manufacture begin as soon as the molten metal enters the mould. The liquid metal for the casting travels from the pouring basin through the down sprue. As it goes downward it will pick up speed, and thus it will have a tendency to separate from the walls of the mould. The down sprue must be tapered such that continuity of the fluid flow is maintained. Remember the fluid mechanics equation for continuity $A_1V_1 = A_2V_2$ .Where V is the velocity of the liquid and A is the cross sectional area that it is traveling through. If you are casting for a hobby and/or just cannot make these measurements, just remember it would be better to err on the side of making A_2 smaller, provided your pouring rate does not become too slow (Karsay, 2000).

2.2.13 Runner Geometry of Conventional Mould

Runner systems convey the molten material from the sprue to the gate. The section of the runner should have maximal cross sectional area and minimal perimeter. Runners should have a high volume-to surface area ratio. Such a section will minimize heat loss, premature solidification of the molten resin in the runner system, and pressure drop. The ideal cross-sectional profile for a runner is circular. While the full-round runner is the most efficient type, it also is more expensive to provide, because the runner must be cut into both halves of the mould. A less expensive yet adequately efficient section is the trapezoid. The trapezoidal runner should be designed with a taper of 2 to 5° per side, with the depth of the trapezoid equal to its base width. This configuration ensures a good volume-to-surface area ratio. Half-round runners are not recommended because of their low volume-to-surface area ratio. If the inscribed circles are imagined to be the flow channels of the polymer through the runners, the poor perimeter-to-area ratio of the half-round runner design is apparent in comparison to the trapezoidal design (Karsay, 2000).

2.2.14 Gates

The gate serves as a transition zone between the runner and the part, and should be designed to permit easy filling of the mould. Gates should be small enough to ensure easy separation of the runner and the part. However, they should be large enough to prevent premature freezing-off of the flow, which can affect the consistency of part dimensions. When specifying ate size, it is best to be "steel safe." Start with a gate size smaller than you think will do the job, and increase the size until proper filling of the mould is achieved consistently. The minimum size we suggest for gate diameters 0.75 mm, and, as a rule, it should not exceed the runner or sprue diameter. Gates are often designed to be half the nominal wall thickness of the part. Correct location of gates has a critical effect on finished part performance. You should consider the following guidelines when determining gate location (Karsay, 2000).

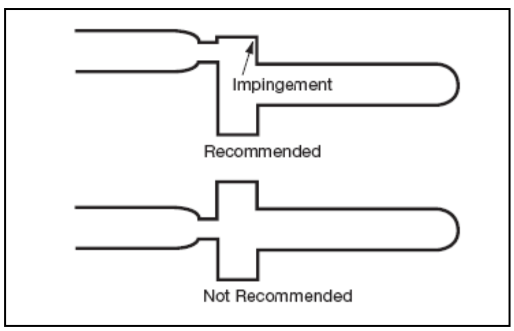


Figure 2.10: Positioning gates to improve flow

2.3 CAD/CAM

CAD/CAM is an acronym for Computer Aided Design / Computer Aided Manufacturing. In essence CAD is simply a drafting board in a computer and facilitates engineering and design with a monitor and a keyboard instead of a paper and pencil. The drawing is saved in an electronic data file for editing (Seames, 2003).

CAM is what can be done with the electronic data to help manufacture the engineered part represented in the electronic file. Although there can be hundreds of different manufacturing processes (stamping, forging, moulding, etc) “CAM” when teamed with “CAD” as in “CAD/CAM” has come to refer almost exclusively as the process of machining the CAD geometry on CNC machinery. Of course the computer file alone cannot machine a part nor can the computer. But with a CAD/CAM system the electronic CAD file can be used to create another file of tool paths that can be fed into the controls of the CNC machinery (Seames, 2003).

A direct link between product design and manufacturing can be established using CAD/CAM software. Product engineers use a CAD system to establish the part geometry, dimensions, and tolerances. This design data can be transferred to the CAM system where the part programmers develop the CNC program to machine the part (Seames, 2003).

A CAD/CAM system can consist of separate or integrated CAD and CAM software. For a system using separate CAD and CAM packages, transfer of drawing geometry using either direct or indirect translation is required. In this case, part geometry is first created on the CAD system and then transferred to the corresponding CAM system. After the geometry has been recreated in the CAM system, the programmer specifies the tools that will be used. Detail information for each tool, such as material, diameter, number of flutes, and length, will be specified (above right). Next the order of the machining process will be established (right). And finally a tool path with proper feed rate information is provided below right (Seames, 2003).

An integrated CAD/CAM system is a dedicated system that will allow the user to create product geometry and generate CNC programs all in one package. Data transfer from CAD to CAM is not required, and there is no data compatibility problem. This feature is important since it ensures the accuracy and reliability of the data (Seames, 2003).

2.3.1 G-codes and M-codes

G-code is a common name for the programming language that controls Numerical Control (NC) and CNC machine tools. Developed by the Electronic Industries Alliance in the early 1960s, a final revision was approved in February 1980 as RS274D (Pusztai, 2003).

Due to the lack of further development, the immense variety of machine tool configurations, and little demand for interoperability, few machine tool controllers (CNCs) adhere to this standard. Extensions and variations have been added independently by manufacturers, and operators of a specific controller must be aware of differences of each manufacturer’s product. When initially introduced, CAM systems were limited in the configurations of tools supported (Pusztai, 2003).

Manufacturers attempted to overcome compatibility difficulties by standardizing on a machine tool controller built by Fanuc. Unfortunately, Fanuc does not remain consistent with RS-274 or its own previous standard, and has been slow at adding new features and exploiting the increase in computing power. For example, they changed G70/G71 to G20/G21; they used parentheses for comments which caused difficulty when they introduced mathematical calculations so the use square parentheses for macro calculations; they now have nano technology recently in 32bit mode but in the Fanuc 15MB control they introduced HPCC (high precision contour control) which uses a 64-bit RISC (reduced instruction set computer) processor and this now has a 500 block buffer for look ahead for correct shape contouring and surfacing of small block programs and 5 axis continuous machining (Pusztai, 2003).

This is also used for NURBS to be able to work closely with industrial designers and the systems that are used to design flowing surfaces. The NURB has its origins from the ship building industry and is described by using a knot and a weight as for bending steamed wooden planks and beams (Pusztai, 2003).

2.4 CNC MILLING MACHINE

Computer Numerical Control (CNC) Milling is the most common form of CNC. CNC mills can perform the functions of drilling and often turning. CNC Mills are classified according to the number of axes that they possess. Axes are labeled as x and y for horizontal movement, and z for vertical movement, as shown in this view of a manual mill table. A standard manual light-duty mill (such as a Bridgeport™) is typically assumed to have four axes:

i. Table x
ii. Table y
iii. Table z
iv. Milling Head z

The number of axes of a milling machine is a common subject of casual "shop talk" and is often interpreted in varying ways. We present here what we have seen typically presented by manufacturers. A five-axis CNC milling machine has an extra axis in the form of a horizontal pivot for the milling head, as shown below. This allows extra flexibility for machining with the end mill at an angle with respect to the table. A six-axis CNC milling machine would have another horizontal pivot for the milling head, this time perpendicular to the fifth axis. CNC milling machines are traditionally programmed using a set of commands known as G-codes. G-codes represent specific CNC functions in alphanumeric format (Kalpakjian, 2000).

Figure 2.11: CNC milling machine (HAAS)

Source: Woodbury & Robert, 2000

2.5 INTRODUCTION OF METAL CASTING

Metal casting is a process in which a solid is melted by heating to a proper temperature, and the molten metal is then poured into a mould or cavity, which helps it to get a proper shape during its solidification. In this process, simple or complex shapes can be formed using any metal that can be melted. The finished components can have virtually any shape and configuration depending on the design. Moreover, in metal casting process one can improve the resistance to working stresses of the components. Size of cast parts varies from a fraction of an inch and a fraction of an ounce to over 30 feet (10 meters) and many tons, depending on its application. Metal casting has its advantages over other processes in the production components, where parts are having hollow sections or internal cavities, contain irregular curved surfaces and parts made from metals that are difficult to machine (Kalpakjian, 2000).

2.6 TYPES OF CASTING PROCESS

2.6.1 Permanent Pattern

This type of casting uses a model, or pattern, of the final product to make an impression which forms the mould cavity. Each mould is destroyed after use but the same pattern is used over and over again. Sand casting is a typical example of a permanent pattern process, where a pattern is placed into a special casting sand to form the right shape of cavity. Permanent pattern processes are usually cheaper than other methods, especially for small quantity production or ‘one-offs’, and are suitable for a wide range of sizes of product (Kohser, 2001).

2.6.2 Permanent Mould

In this method the same mould is used for large numbers of castings. Each casting is released by opening the mould rather than by destroying it. Permanent moulds need to be made of a material which can withstand the temperature fluctuations and wear associated with repeated casting. A good example of a product made with methods such of this is the ubiquitous ‘die-cast’ child’s toy ‘die’ is another word for ‘mould’(Kohser, 2001).

2.6.3 Expandable Mould and Pattern

With this type of casting, a pattern is made from a low melting point material and the mould is built around it. The pattern is then melted or burnt out as the metal is poured in. The mould has to be destroyed to retrieve the casting. This method is used to make moulds for casting high melting-point alloys like those used for jet engine turbine blades. A model (the pattern) of the blade is made in wax. The pattern is then coated in thick slurry containing ceramic particles. The slurry dries, and is then fired in an oven: this hardens the ceramic (like firing a pot) and melts out the wax, leaving a hollow ceramic mould. The metal is then poured in to the mould, which is broken away after the metal has solidified and cooled (Kohser, 2001).

2.7 DIE CASTING MATERIALS

The main die casting alloys are: zinc, aluminum, magnesium, copper, lead, and tin. Specific dies casting alloys include: ZAMAK, zinc aluminum, AA 380, AA 384, AA 386, AA 390, and AZ91D magnesium. The following is a summary of the advantages of each alloy:

- Zinc: the easiest alloy to cast; high ductility; high impact strength; easily plated; economical for small parts; promotes long die life.
- Aluminum: lightweight; high dimensional stability for complex shapes and thin walls; good corrosion resistance; good mechanical properties; high thermal and electrical conductivity; retains strength at high temperatures.
- Magnesium: the easiest alloy to machine; excellent strength-to-weight ratio; lightest alloy commonly die cast.
- Copper: high hardness; high corrosion resistance; highest mechanical properties of alloys die cast; excellent wear resistance; excellent dimensional stability; strength approaching that of steel parts.
- Lead and Tin: high density; extremely close dimensional accuracy; used for special forms of corrosion resistance.

The material used defines the minimum section thickness and minimum draft required for a casting as outlined in the table below:

Table 2.2: The Minimum Section Thickness and Minimum Draft

Material	**Min. thickness mm (in)**	**Min Draft Angle (◦)**
Aluminum Alloys	0.9mm (0.035 in)	0.5
Zinc Alloy	0.6mm (0.025 in)	0.25
Copper Alloys (Brass)	1.25mm (0.050 in)	0.7

Source: Technology Publications, 2006

2.7.1 Common Alloys in Die Casting

Aluminum, Zinc and Copper alloys are the materials predominantly used in die-casting. On the other hand, pure Aluminum is rarely cast due to high shrinkage, and susceptibility to hot cracking. It is alloyed with Silicon, which increases melt fluidity, reduces machinability. Copper is another alloying element, which increases hardness, reduces ductility, and reduces corrosion resistance (Jillek, 2005).

Aluminum is cast at a temperature of 650 ºC (1200 ºF). It is alloyed with Silicon 9% and Copper about 3.5% to form the Aluminum Association 380 alloy (UNS A03800). Silicon increases the melt fluidity, reduces machinability, Copper increases hardness and reduces the ductility. By greatly reducing the amount of Copper (less than 0.6%) the chemical resistance is improved; thus, AA 360 (UNS A03600) is formulated for use in marine environments. A high silicon alloy is used in automotive engines for cylinder castings, AA 390 (UNS A03900) with 17% Silicon for high wear resistance. (Jillek, 2005).

Zinc can be made to close tolerances and with thinner walls than Aluminum, due to its high melt fluidity. Zinc is alloyed with Aluminum (4%), which adds strength and hardness. The casting is done at a fairly low temperature of 425 ºC (800 ºF) so the part does not have to cool much before it can be ejected from the die. This, in combination with the fact that Zinc can be run using a hot chamber process allows for a fast fill, fast cooling (and ejection) and a short cycle time. Zinc alloys are used in making precision parts such as sprockets, gears and connector housings (Jillek, 2005).

2.7.2 Material Selection

The selection of proper materials is important to assist in the design of the casting process. Here are a few things to remember when selecting manufacturing materials. Certain materials react, (particularly in a molten state), a certain way with other materials they may encounter during the casting process. This should always be a consideration. For example liquid aluminum will react readily with iron. Iron ladles and surfaces contacting the molten aluminum can be covered with a spray-on ceramic coating to prevent this (Jillek, 2005).

When selecting a specific type of manufacturing process, remember that certain materials are more applicable to different types of casting techniques than others. The casting material's specific heat will as well as that of the mould material will be influential in controlling the thermal gradients in the system. Different materials will factor heavily on the melt's fluidity. A material high heat of fusion will take longer to solidify and may improve flow characteristics within the casting. When manufacturing a casting an alloy that freezes over a temperature range problems may occur due to the solid phase interfering with the liquid phase -both of which will be present within the temperature range. To help reduce this problem an alloy with a shorter solidification temperature range may be selected to manufacture the casting with. Or select a mould material with a high thermal conductivity, which could reduce the time spent in this range by increasing the cooling rate (Jillek, 2005).

2.8 BASIC FACTORS IN CASTING PROCESS

2.8.1 Mould Cavity

While making a mould cavity with desired shape and size, one must keep in mind the shrinkage factor of the solidifying metal. The cavity must contain with in itself all complexity of shapes of the desired finished component. Selecting the right mould material is also very important as it must be capable of reproducing the desired detail. The mould material should not be affected significantly by the molten metal that it must contain. In case of expandable moulds, a new mould must be prepared for each casting. Where, reusable or permanent moulds can be used more than once. The latter types are made from such materials that can withstand repeated castings. The permanent moulds are very costly as these are made of metal or graphite and are used for large production runs. For smaller quantities production, the expandable moulds are generally preferred, simply because of their economical aspect (Kohser, 2001).

2.8.2 Melting Process

Heating furnaces are used to heat the metal to molten temperature sufficient for casting. The heat required is to raise temperature to melting point and convert from solid to liquid. Also heat is used to raise molten metal to desired temperature for pouring. The objectives of melting process are providing molten material at the proper temperature and desired quantity. Melting process also required to avoid poor quality of the casting products (Kohser, 2001).

2.8.3 Pouring of the Metal

When manufacturing by metal casting, pouring refers to the process by which the molten metal is delivered into the mould. It involves its flow through the gating system and into the main cavity.

a) Pouring Temperature

The initial temperature of the molten metal used for the casting as it is poured into the mould. This temperature will obviously be higher than the solidification temperature of the metal. The difference between the solidification temperature and the pouring temperature of the metal is called the superheat (Kohser, 2001).

b) Pouring Rate

Volumetric rate in which the liquid metal is introduced into the mould. Pouring rate needs to be carefully controlled during the metal casting operation, since it has certain effects on the manufacture of the part. If the pouring rates it too fast then turbulence can result. If it is too slow the metal may begin to solidify before filling the mould (Kohser, 2001).

c) Turbulence

Turbulences are inconsistent and irregular variations in the speed and direction of flow throughout the liquid metal as it travels though the casting. The random impacts caused by turbulence, amplified by the high density of liquid metal can cause mould erosion. An undesirable effect in the manufacturing process of casting, mould erosion is the wearing away of the internal surface of the mould. It is particularly detrimental if it occurs in the main cavity, since this will change the shape of the casting itself. Turbulence is also bad because it can increase the formation of metal oxides which may become entrapped creating porosity in the solid casting (Kohser, 2001).

d) Fluidity

When pouring is a key element in the manufacturing process of metal casting, and the main goal of pouring is to get metal to flow into all regions of the mould before solidifying. The properties of the melt in a casting process are very important. The ability of a particular casting melt to flow into a mould before freezing is crucial in the consideration of metal casting techniques. This ability is termed the liquid metals fluidity (Kohser, 2001).

e) Pouring Techniques

It is a technique by which the moulds are filled in with molten metal. There must be provisions for air or gases inside the mould to come out when the molten metal is poured in. When the hot metal enters the mould cavity, it may generate various gases due to chemical reactions. The mould design should allow these gases to escape, so that the molten metal can spread and fill the mould cavity completely. It helps in producing defect free, fully dense and quality casting components (Kohser, 2001).

2.8.4 Solidification Process

After molten metal is poured into a mould, a series of events takes places during the solidification of the metal and its cooling to ambient temperature. These events greatly influence the size, shape; uniformity and chemical composition of the grain formed throughout the casting, which in influence its overall properties. The significant of both metal and the mould, the geometric relationship between volume and surface area of the casting, and the shape of the mould. Better design and control at this stage helps in getting quality output. The mould design should be such that it put less restraint to the shrinkage that occurs during the cooling of metals. It helps in preventing any kind of crack on the casting when it is still hot and its strength is low. Moreover, the designers should also be careful about the fact that porosity or voids may occur during solidification and solidification shrinkage. A quality casting product should be free from these defects (Kohser, 2001).

2.8.5 Mould Removal

After proper solidification, the casting should be removed from the mould. Generally, expandable moulds are broken apart and destroyed after each casting is produced without any difficulty. But, using re-usable moulds may cause major challenges from designers' point of view on the removal of casting from permanent moulds (Kohser, 2001).

2.8.6 Finishing Operations

Various cleaning, finishing and inspection operations are performed after the casting is removed from the mould. Extraneous material that is attached where the metal entered the cavity, excesses at mould parting lines, and mould material that is attached to the casting surface must all be removed (Kohser, 2001).

2.9 ROCKWELL HARDNESS TEST

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F_0 (Figure 2.12 A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Figure 2.12 B). When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Figure 2.12 C). The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number (Steven, 2000).

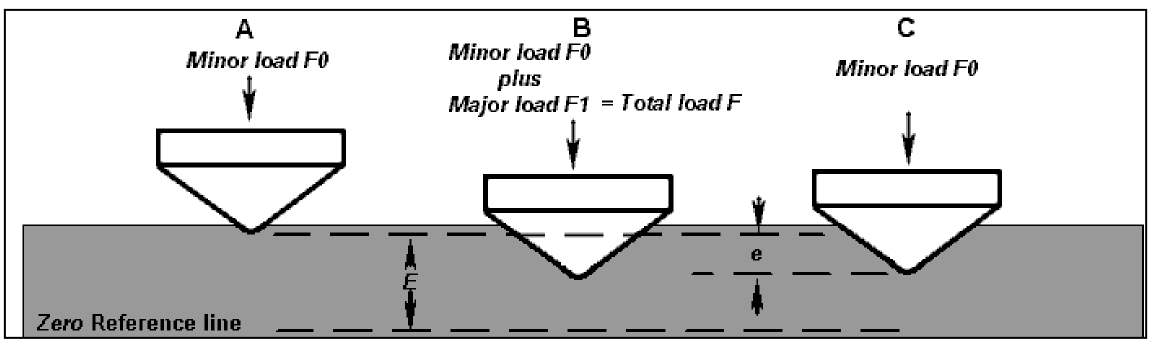


Figure 2.12: Rockwell Principle

(Source: Surface engineering forum, 2000)

F_0 = preliminary minor load in kgf

F_1 = additional major load in kgf

F = total load in kgf

e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm

E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number

D = diameter of steel ball

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the overall methodology of the project. In order to complete a project, methodology is one of the most important things to be considered to ensure that the project run smoothly and get the expected results which the one that needed the most. This chapter provides a discussion of the methodology used in conducting this project from starting until it is completed. To achieve the goals and objective of this project, a structure of overall methodology has been planned carefully and illustrated as a guideline. There are five main methods of conducting this project and they are, literature review, sketching and modeling, simulation and fabrication process. Each method is explained clearly under every subtitle.

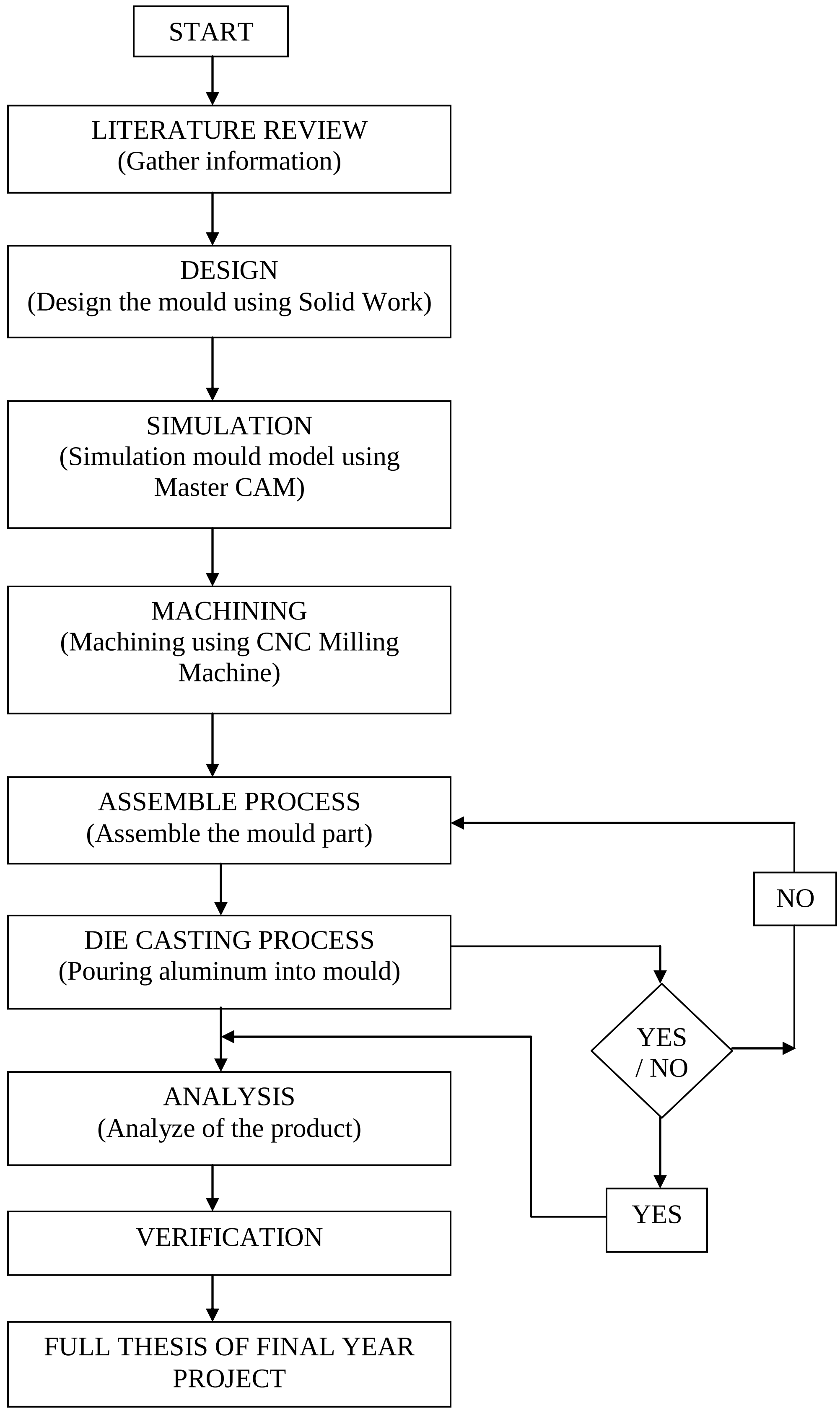


Figure 3.1: Project flow chart

3.2 LITERATURE REVIEW

Refers to the Figure 3.1, this project required to do preliminary study and research about the topic before the designing procedure begins. The title must be understood very well in order to get information which is related. Information are searched through reference books, journals, website in internet, discussion with supervisor and other relevant academic material that related to this project to find out the needs, objective and background of the project. The basic ideas can be generated from the sources above and the designing with own ideas. The literature is more about the tensile test specimen, mould and gating system design, material selection, machining process, CAD/CAM software and casting process. The detail literature review can be referred in chapter two.

3.3 DESIGN THE MOULD

After completing the literature review, the designing process began. The design concept must be clarified so that the shape and the dimension can be estimated roughly. All the ideas for the mould design are sketched on the drawing paper first to ensure that idea selection can be made after the selected design was chosen. Sketching of design is the most important things before transferring to the CAD software. All parameters in design process are determined to avoid problems in the future especially in designing the mould in Solid Work.

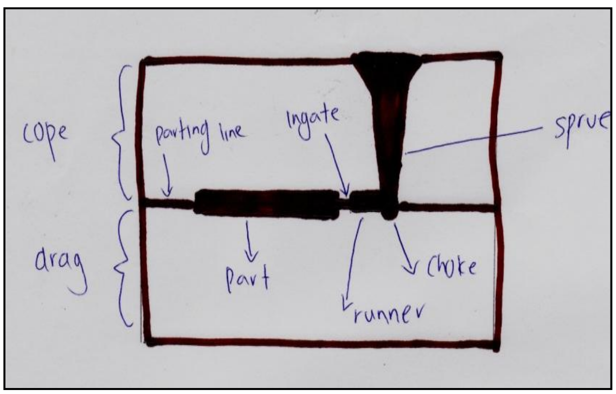


Figure 3.2: Cope and drag sketching

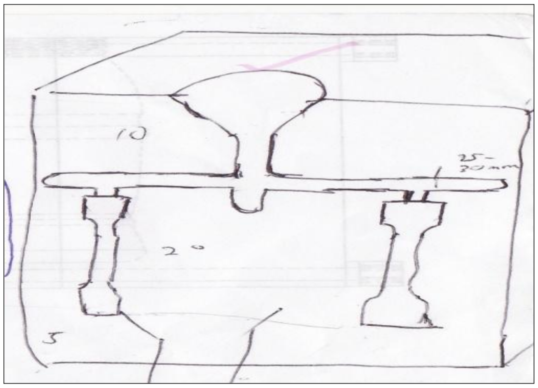


Figure 3.3: Gating system sketching

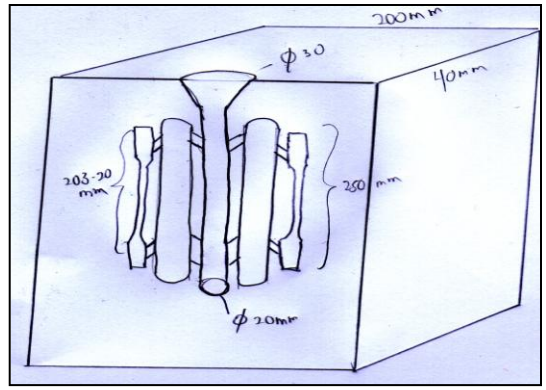


Figure 3.4: Gating system sketching

3.3.1 Introduction to Solid Works

Solid work is the global standard in 3D mechanical design software. It helps organization to reduce time to market, design better quality product faster, maintain a competitive advantage, and increase the sales. Solid work delivers powerful 3D design capabilities, unmatched ease of use, and an affordable cost. Solid work software allows AutoCAD user to become rapidly productive using 3D mechanical design and 2D detailing capabilities of Solid works as well as leveraging 2D legacy data.

Solid Works uses a feature-based "parametric" approach to modeling and assembling. In the Solid Works 3D modeling environment the creation of a solid or surface typically begins with the definition of topology in either a 2D or 3D sketch. The topology defines the connectivity and certain geometric relationships between vertices and curves both in the sketch and external to the sketch. To this topology are added dimensions which determine the lengths and sizes for the curves and locations for the vertices in conjunction with topological constraints. The dimensions which are added are termed "parameters" because they can be changed either independently or by "parameters" created prior to their creation.

3.3.2 Mould Design

There are several steps that need to be followed in designing the bottle shape using Solid Works. Usually the designing starts with frame drawing extrude the 2-D drawing, and refining the shape:

1. Choose and decide the plane to start the drawing. The choice of plane that will be used is depends on the shape of the drawing should be.
2. The drawing of the frame design would be in 2-D form and here again, decide a plane which should be used to extrude the 2-D drawing into 3-D drawing. The dimension of the drawing should be precisely calculated so that the designs are suitable and follows the standards.
3. The 3-D shape design have better option in doing the modification and good looking shape by applying chamfer option and “Extrude Boss” or “Extrude Cut”.
4. Use Fillet and Chamfer to make the edge of design. A sharp edge will causes the machining not perfectly completed and may lead to unapproachable dimension in final product outlet.
5. Use Mass Properties function to view the volume of the designed mould and the exact dimension.

3.3.3 Drawing in Solid Works

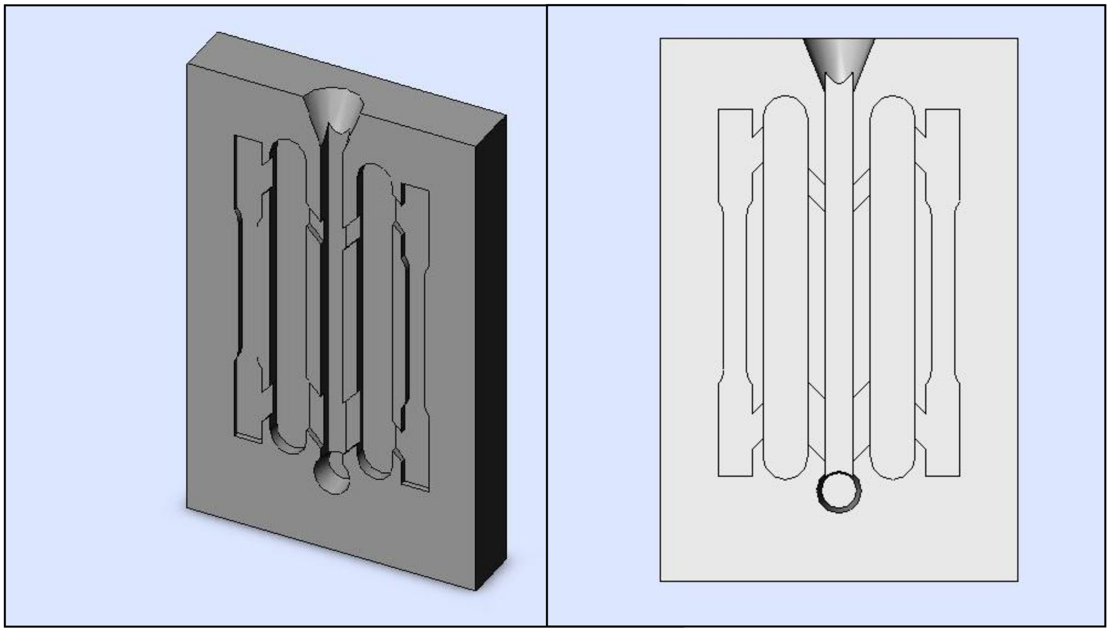


Figure 3.5: 3D drawing of right side vertical mould

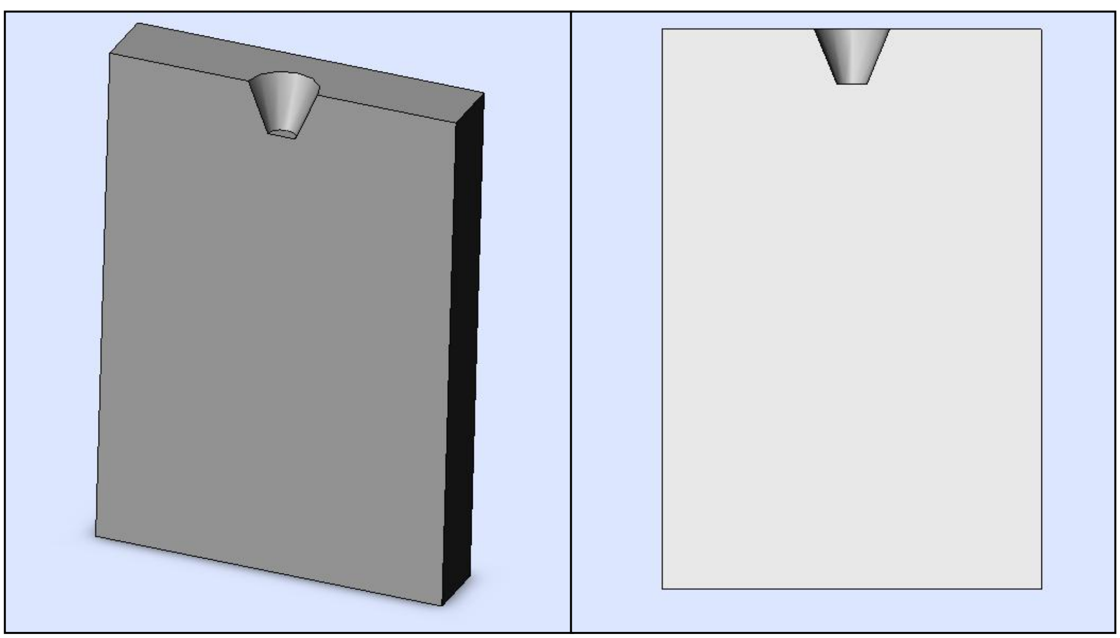


Figure 3.6: 3D drawing of left side vertical mould

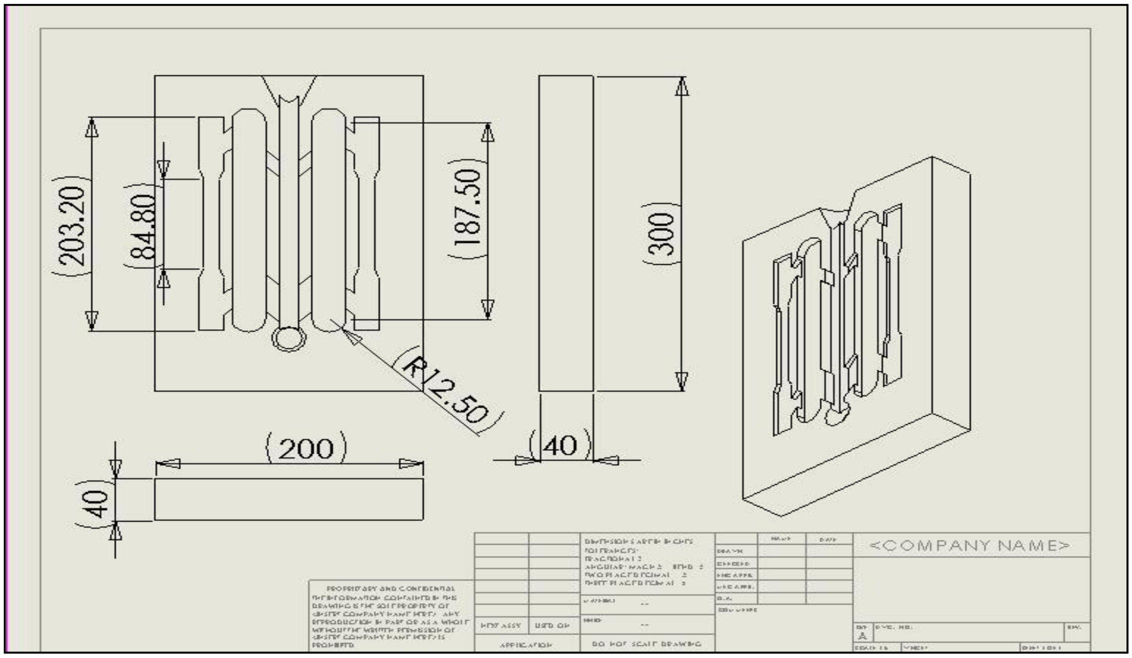


Figure 3.7: 2D drawing of right side vertical mould

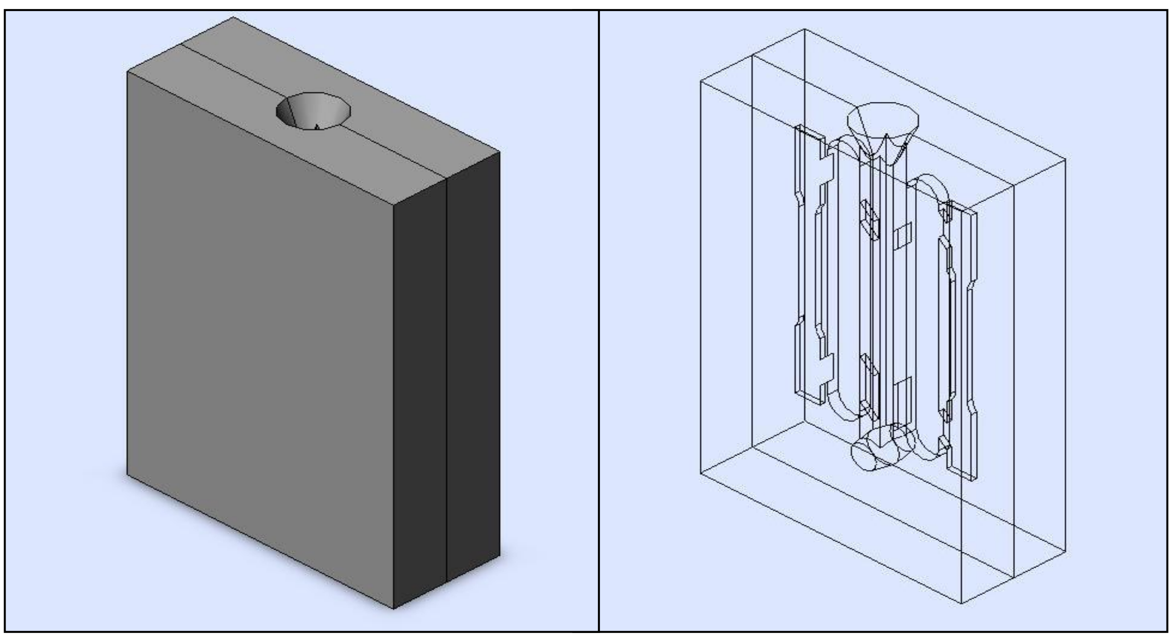


Figure 3.8: Isometric view

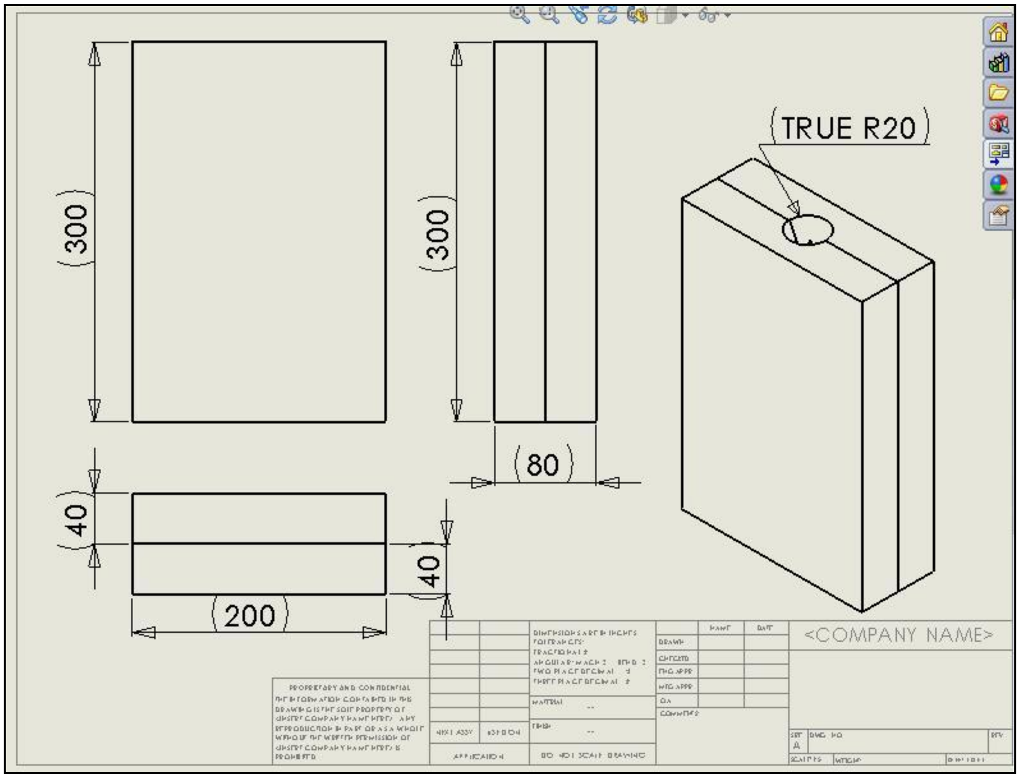


Figure 3.9: 2D drawing

3.4 GATING SYSTEM CALCULATIONS

In casting design, the quality of the final component and the yield of the casting are two major considerations. Both of these considerations depend upon the gating system used to cast the component. The term gating system refers to all passageways through which the molten metal enters a mould cavity. Then metal will solidify to form the desired casting shape. It mainly includes pouring basin, sprue, runners and gates. Design of gating system must consider following points (Zurani, 2009):

- The molten metal enters quickly, quietly and in a continuos manner to prevent miss run or cold shut.
- Prevent the sand or slug inclusion from reaching casting.
- The air inside the mould and generated gasses are smoothly discharged.

- Prevent to molten metal running against the core or mould at the outlet of the ingate and eroding them.
- Allow easy removal of the runner and riser.

3.4.1 Weight of Product

Weight = 118.89 gram (1 cavity)

= 0.11889 kg

= 0.11889 x 2

= 0.23778 kg (2 cavity)

After calculate the weight the product , the allowance of reserving weight for pouring weight also must be calculate. If the product has less machining surface, the weight of casting product should be considered 1.1 times the finished product. The weight of gating system must also be included. The molten metal prepared must be 10% more than the above weight (weight of casting and weight of gating system).

Weight x molten metal allowance

0.23778 kg x 1.1 = 0.26156 kg

Density of aluminum, (ρ)

ρ = 0.0028 kg/cm^3

Flask height, H = 5cm

Product height, h = 1.905cm

3.4.2 Gating Ratio

In order to fill quickly and quietly a mould with molten metal, the cross sectional areas of the sprue, runner and ingate need to be adequately balanced. Ratios between these cross sectional areas are called gating ratio. When runner is branched into multiple ingates, the flow of molten metal and temperature distribution must be properly arranged to minimize the casting stress and strain. Figure 3.12 presents a symmetrical arrangement of the gating system that aims at even distribution of molten metal among the ingate (Zurani, 2009).

Table 3.1: Gating Ratios

Material	Sectional area of sprue	Sectional area of runners	Sectional area of ingates
Steel	1	1.2 ~ 2	1.5 ~ 2.5
Cast Iron	1	0.75	0.5
Cast steel	1	1	1
Aluminum alloy	1	4	4
Magnesium alloy	1	2	2

For this project, the casting material is aluminum alloy. The gating ratio system can be calculated as the formula below:

Gating ratio = 1 : 4 : 4
(Sprue) : (runner) : (ingate)

3.4.3 Pouring Time

A casting that fills too slow can have discontinuities such as cold shuts and misruns. Too fast filling can lead to solid and gaseous inclusions. The higher limit of filling time (slowest filling) is governed by the need to avoid premature freezing in thin sections before complete filling. The lower limit of the filling time (fastest filling) is governed by the onset of surface turbulence. The correct filling time lies somewhere in between, and is a function of cast metal, weight, minimum section thickness and pouring temperature. Several empirical equations for determining the correct filling time for major metals have been developed by casting researchers, based on experimental investigations (Zurani, 2009). For this project, the part is small, so the time pouring can estimate is 2.5 second.

Pouring time = 2.5 sec

3.4.4 Metal Velocity

The optimal filling time is determined such that gating channels can be designed to avoid surface turbulence and minimize bulk turbulence within the gating channels as well as the mould cavity. This mainly depends on the velocity of the molten metal, which varies widely within the gating channels as well as inside the mould cavity. For a given location in the casting, the velocity also changes with time, from the start to end of filling. The most important event is that of molten metal emerging from the ingate, just after the filling of gating channels and before the filling of mould cavity. The metal is both hot and fast at this location and instant, and can lead to considerable damage if not controlled properly. The velocity of molten metal at the ingate depends on mainly two parameters: (1) the metallostatic head and (2) the ratio of cross-sections of sprue exit, runners and ingates, referred to as the gating ratio. In general, the velocity of molten metal must be kept lower than 1 m/s for ferrous metals and 0.5 m/s for aluminum alloys (Zurani, 2009).

Velocity

v = c$\sqrt{2\ x\ g\ x\ (H - 0.5h)}$

v = $0.35\sqrt{2x\ 981x\ (5 - 0.5(1.905))}$

v = 31.189 cm/sec

3.4.5 Ingate Sectional

Gates should be small enough to ensure easy separation of the runner and the part. However, they should be large enough to prevent premature freezing-off of the polymer flow, which can affect the consistency of part dimensions. The minimum size suggest for gate diameter is 0.75 mm, and, as a rule, it should not exceed the runner or sprue diameter. Gates are often designed to be half the nominal wall thickness of the part.

$= \dfrac{w}{v\ x\ t\ x\ \rho}$

$= \dfrac{0.261558\ kg}{(31.189\ cm/sec)(2.5\ sec)(0.0028\ kg/cm^3)}$

= 1.198 cm^2

2 ingate = 1.198 cm^2 / 2

= 0.599 cm^2

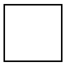
≈ 0.60 cm^2

Gating ratio = 1 : 4 : 4

(sprue) : (runner) : (ingate)

0.30cm^2 : 1.20cm^2 : 1.20cm^2

Ingate = 0.60 cm^2



a *a* $a^2 = 0.60\ cm^2$

$a = \sqrt{0.60}$

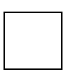
$a = 0.775cm$

$a = 7.75mm$

3.4.6 Runner Sectional

The main function of the runner is to slow down the molten metal, which speeds up during its free fall through the sprue, and take it to all the ingates. This implies that the total cross-sectional area of runner must be greater than the sprue exit. In general, a ratio of 1:4:4 is recommended. The second implication is that the runner must fill completely before letting the molten metal enter the ingates. Finally, in casting where more than one ingate is present, the runner cross-section area must be reduced after each ingate connection (by an amount equal to the area of that ingate), to ensure uniform flow.

Runner = 1.20cm^2



b *b* $b^2 = 1.2cm^2$

$b = \sqrt{1.20}$

$b = 1.095cm$

$b = 10.95mm$

3.4.7 Sectional Sprue

It arrests the free fall of molten metal through the sprue and turns it by a right angle towards the runner. It must be designed to minimize turbulence and air aspiration.

The recommended shape of a sprue well is cylindrical, with diameter twice that of sprue exit and depth twice that of runner. A fillet between the well and runner will facilitate smooth transfer of molten metal.

Sprue = 0.30cm^2

πr^2= 0.30cm^2

r = 0.309 *cm*

Ø = 0.618 *cm*

Ø = 6.18 *mm*

3.5 MATERIAL SELECTION

In this project, the material selection is very important part to consider during machining and casting process. The material selection should not be solely based on cost. The proper material selection technique involves carefully defining the application requirement in terms of mechanical, thermal, environmental, electrical and chemical properties. Based on this project, the material required to use during the process are aluminum and mild steel. However the cost for each material to use is too high. Therefore, the best solution is to use the existing material in laboratory especially Mechanical Laboratory.

All the existing material from our lab will be used as a machining process and casting process. The selecting materials are:

i. Mild Steels
ii. Aluminum alloys

The reason why mild steel (machining process) has been chosen to produce and fabrication of die is because mild steel has low carbon percentage which contains 0.16–0.29% carbon and the melting temperatures of mild steel is higher than aluminum alloy melting temperature and so that it is suitable to acts as die in the die casting. Furthermore, Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. The density of mild steel is approximately 7.85 g/cm^3(0.284 lb/in^3) and the Young's modulus is 210,000 MPa (30,000,000 psi).

The second material selection is aluminum alloy. Aluminum alloy is one of the few metals that can be casted by all of the processes used in casting metals. There are many factors that affect selection of a casting process for producing a specific aluminum alloy part. Many aluminum alloy castings can be produced by any of the available methods. For a considerable number of castings, however, dimensions or design features automatically determine the best casting method. Small castings usually are made with metal moulds to ensure dimensional accuracy.

- MILD STEEL :300mm x 200mm x 40mm

Figure 3.10: Raw material for mould (Mild Steel)

3.6 SIMULATION IN MASTER CAM

After design in Solid work complete and suitable with dimensions and specification, the drawing should be converted to the Master CAM format. In this process machining simulation of mould is shown by the Master CAM. G codes and M codes will be generated from Master CAM as well where these codes are required to be transferred to CNC Milling Machine. By running the simulation in Master CAM, errors can be detected so that it can be fixed before the real machining in CNC Milling Machine.

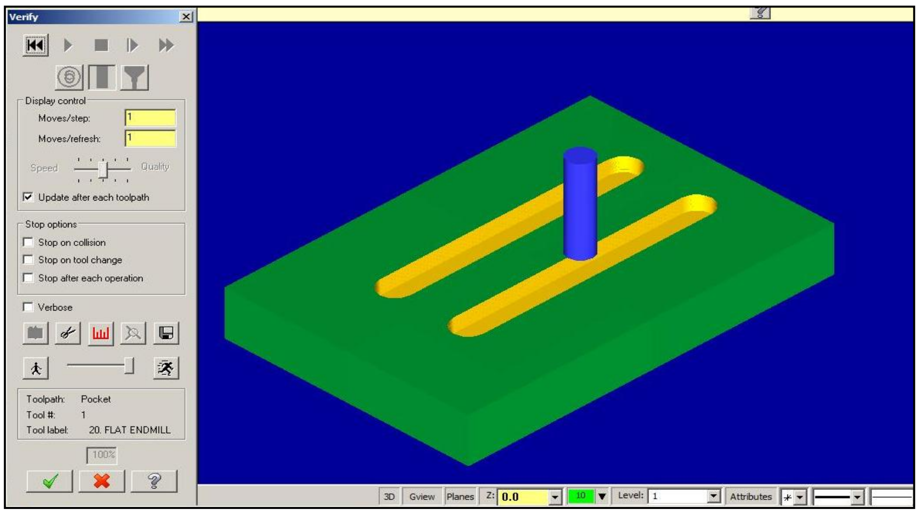


Figure 3.11: Pocket process for riser

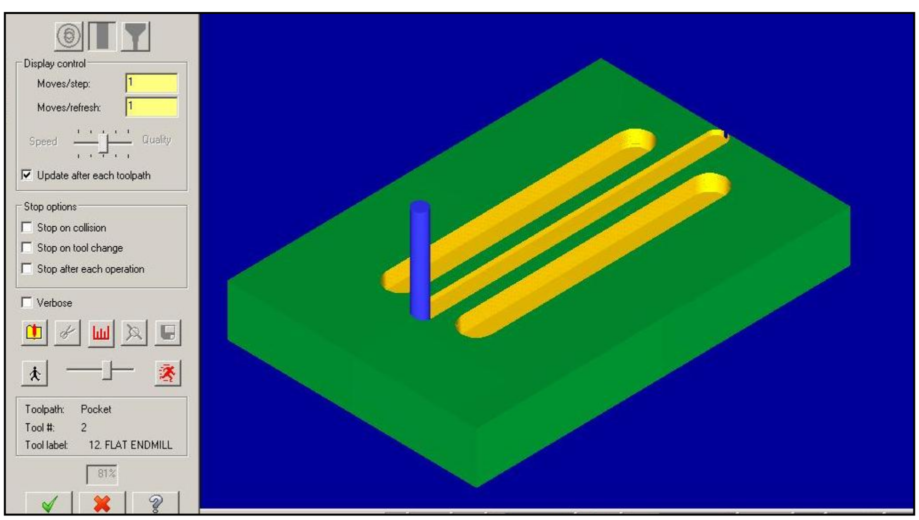


Figure 3.12: Pocket process for runner

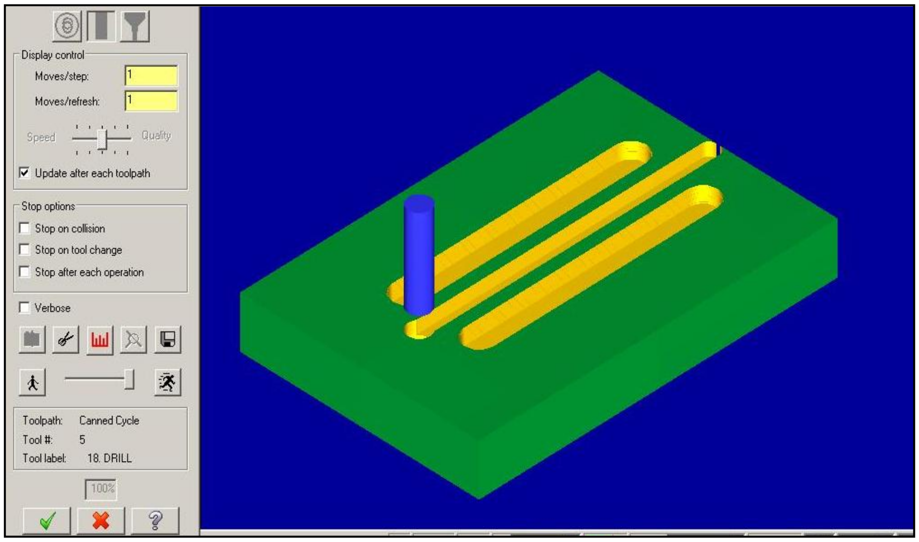


Figure 3.13: Center drill and drilling process for well

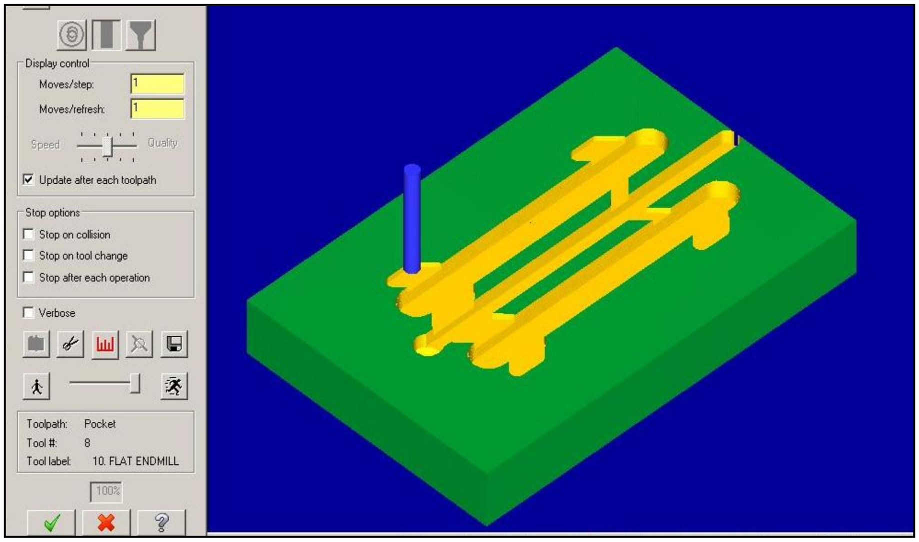


Figure 3.14: Pocket process for ingate

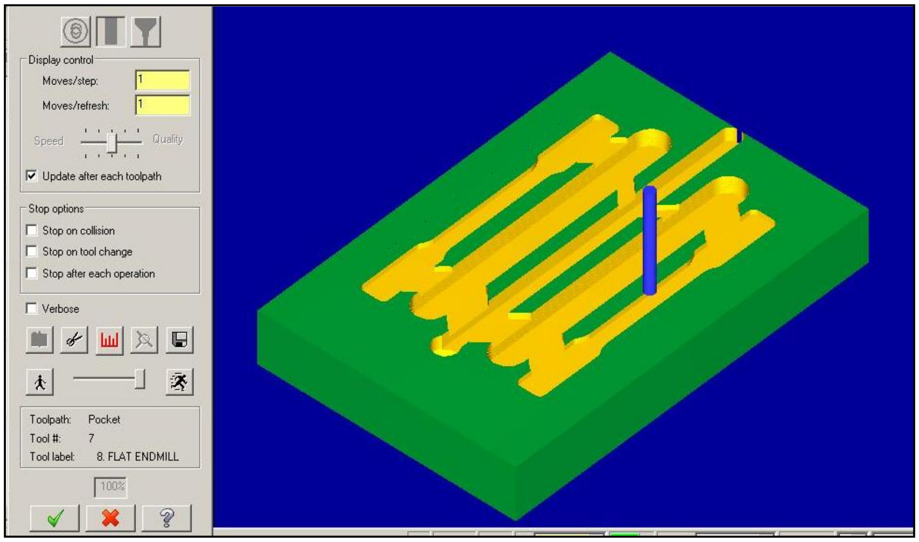


Figure 3.15: Pocket process for part

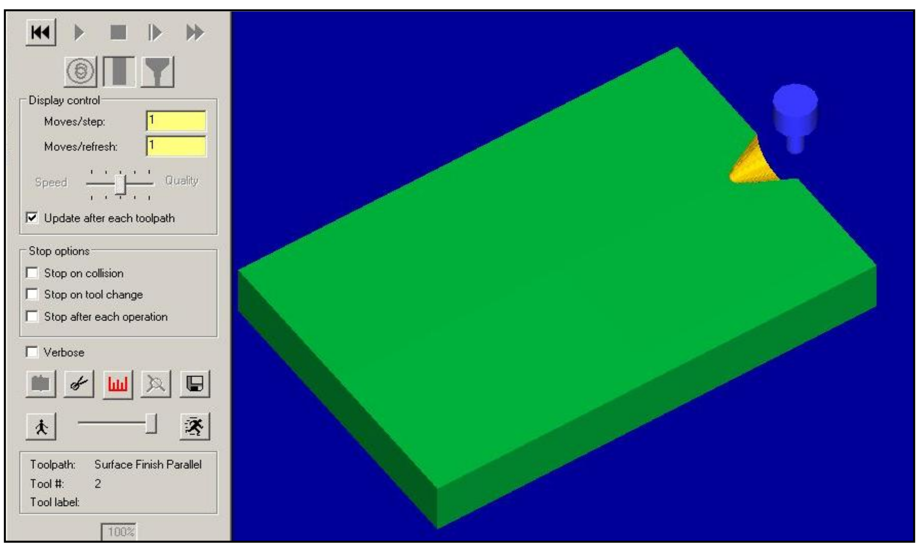


Figure 3.16: Surface finish parallel process for sprue

3.6.1 G Codes and M Codes

The G codes and M codes are codes which CNC Milling Machine needed to run the machining to fabricate the mould. These codes will be generated in Master CAM program during simulation process. The codes will be transferred from the Master CAM program to CNC Milling Machine using USB devices. The codes are used to command specific actions for the machine, for example to make the hole and finishing the surfaces of mould.

```
%
O0000(DRAG1)
(DATE=DD-MM-YY - 08-04-10 TIME=HH:MM - 00:54)
(MCX FILE - \AZUAN SOLID\DRAG1.MCX)
(NC FILE - \DRAG1.NC)
(MATERIAL - MILD STEEL MM - )
( T1 |     8. BALL ENDMILL | H1 )
( T240 |     6. BALL ENDMILL | H240 )
N100 G21
N102 G0 G17 G40 G49 G80 G90
N104 T1 M6
N106 G0 G90 G54 X-30.504 Y-75.391 S1800 M3
N108 G43 H1 Z24.876
N110 Z4.876
N112 G1 Z-.224 F4.5
N114 X-19.454 F1000.
N116 G0 Z4.776
N118 Z24.776
N120 Z24.969
N122 X19.496
N124 Z24.876
N126 Z4.876
N128 G1 Z-.224 F4.5
N130 X30.546 F1000.
N132 Y-75.191
N134 X19.496
N136 G0 Z4.776
N138 Z24.776
N140 Z24.969
N142 X-19.454
N144 Z24.876
N146 Z4.876
N148 G1 Z-.224 F4.5
```

Figure 3.17: G and M codes of CNC milling process

3.7 MACHINING PROCESS

3.7.1 Introduction of CNC Machining

CNC milling is a process that can create complex 3D shapes in metal and other materials such as hard plastics. A CNC milling machine is controlled by a computer program generated by a CAM application from a 3D model of the part. Since CNC milling does not require hard tooling such as moulds or dies, it is useful for small runs of parts and for prototyping. It is also used for post-machining cast or extruded parts to add features that cannot be moulded in or that require higher tolerances.

3.7.2 General Procedure to CNC Machining Operation

This is the main process in mould fabrication. This operation will be fully conducted by the machine. The operations are:

1. The material which will be used as the mould material is placed at the platform of the machine. The exact dimension of the material must follow the design mould from the designed product.
2. The cutting tools which needed are setup to the machine. This is to make the machining more appropriate. The tools must be attached according to the settings number so it would not mistakenly choose tools while machining. Double checking need to be done to avoid any mistakes.
3. The surface of the material is first machine by using slab milling. This is to create a flat and clear surface. Besides, the machining will be smooth.
4. The machining of the full shape of mould starts after that. This process will take long hours of time.
5. The fully machined moulds taken out for further finishing operation.

Figure 3.18: CNC milling machine

3.7.3 Machining Operation

After switch ON the Machine, the process of fabrication will continue with facing the workpiece. The surface of the material is first machine by using face milling. This is to create a flat and clear surface. Besides, the machining will be smooth. In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the workpiece surface. After finish the facing process, the fabrication process will continue with setting the workpiece. The process will started with setting origin workpiece. This process is to get center point of workpiece. The machining operations to be performed will dictate which tools to be used. The required tools need to be mounted at the correct tool holders. The Tool Room Mill uses CT40 tooling. It consists of three parts which are pull studs, tool holders and cutting tools. After finish setup the machine, the process fabrication will continue with simulation program by using simulator. The Graphics screen will display the programmed tool path and generate an alarm if there are any errors/problems. After finish the setup machine and simulate the program by using simulator, the process fabrication will continue with machining the part. The machining time was 8 hours, 0 minutes, 57 seconds.

Table 3.2: Type of tooling

No of process	Type of tool	Diameter	RPM	Feed rate
1.	End mill	20mm	500	50
2.	End mill	12mm	800	80
3.	Center drill	5mm	1300	65
4.	Drill	18mm	360	18
5.	End mill	8mm	1200	60
6.	End mill	10mm	1000	50

Figure 3.19: Facing process

Figure 3.20: Pocket process

Figure 3.21: Pocket process

Figure 3.22: Center drilling process

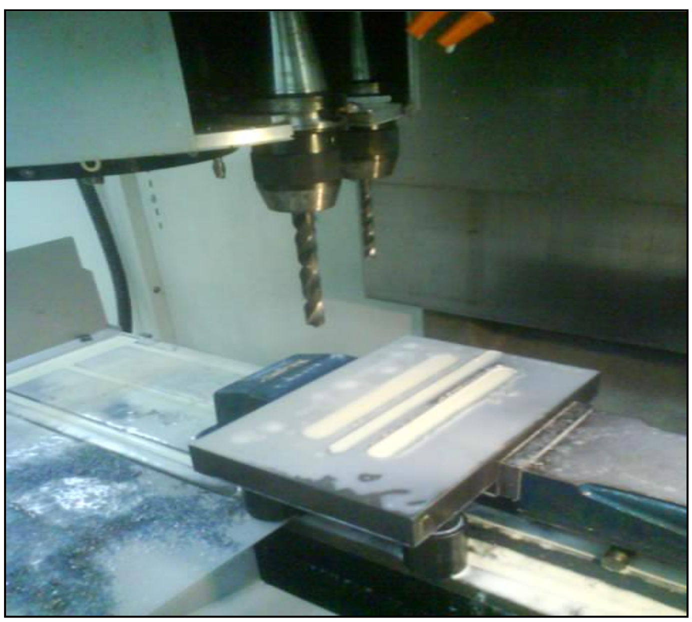


Figure 3.23: Drilling process

Figure 3.24: 3D pocket process

Figure 3.25: Surface grinding process

3.8 CASTING PROCESS

After finish the machining process, the next process is casting process. The process cycle for metal casting consists of six main stages. There are:

- Mould making - The first step in the casting process is to create the mould for the casting. These steps already explain in design, simulation and machining process.
- Clamping - Once the mould has been made, it must be prepared for the molten metal to be poured. The surface of the mould cavity is first lubricated to facilitate the removal of the casting. Then, the cores are positioned and the mould halves are closed and securely clamped together. It is essential that the mould halves remain securely closed to prevent the loss of any material.
- Mould Preheating - Preheating process is very important to ensure casted material (aluminum alloy) not frozen too quickly during pouring process. Infrared Thermometer is a handy temperature measuring instrument for various measures. Temperature of mould would be half from temperature of casted material.
- Pouring - The molten metal is maintained at a set temperature in a furnace. After the mould has been clamped, the molten metal can be ladled from its holding container in the furnace and poured into the mould. The pouring can be performed manually or by an automated machine. Enough molten metal must be poured to fill the entire cavity and all channels in the mould. The filling time is very short in order to prevent early solidification of any one part of the metal.
- Cooling - The molten metal that is poured into the mould will begin to cool and solidify once it enters the cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed. The mould cannot be opened until the cooling time has elapsed. The desired cooling time can be estimated based upon the wall thickness of the casting and the temperature of the metal. Most of the possible defects that can occur are a result of the solidification

process. If some of the molten metal cools too quickly, the part may exhibit shrinkage, cracks, or incomplete sections. Preventative measures can be taken in designing both the part and the mould and will be explored in later sections.

- Removal - After the predetermined solidification time has passed, the mould can be open, and the casting removed. This step, sometimes called shakeout.

- Trimming - During cooling, material from the channels in the mould solidifies attached to the part. This excess material must be trimmed from the casting either manually via cutting or sawing, or using a trimming press. The time required to trim the excess material can be estimated from the size of the casting's envelope. A larger casting will require a longer trimming time. The scrap material that results from this trimming is either discarded or reused in the casting process.

Figure 3.26: Mould clamping

Figure 3.27: Temperature measure using Infrared Thermometer

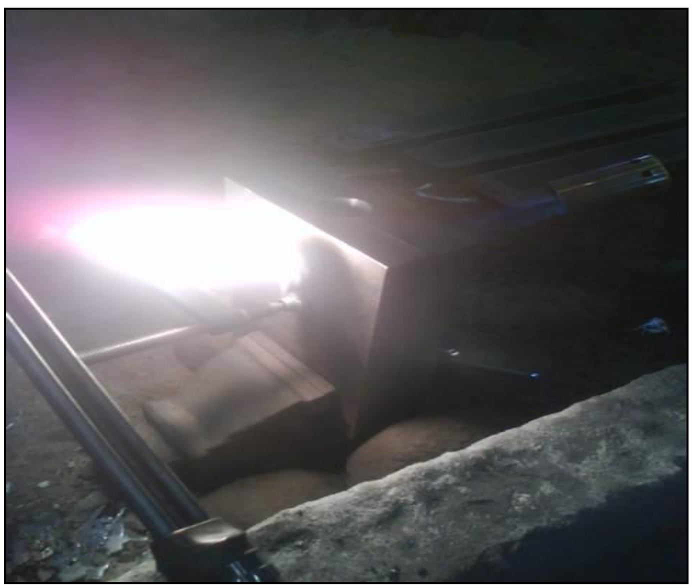


Figure 3.28: Preheating process

Figure 3.27 and Figure 3.28 showed the preheating process for the mould. Pre heating process is very important to ensure casted material (aluminum) not frozen too quickly during pouring process. Temperature of mould that suggested would be half from temperature aluminum. Temperature for aluminum alloy is 700◦c and temperature for mould is around 350◦c.

Figure 3.29: Pouring process

Figure 3.30: Pouring process

3.9 COOLING PROCESS

Cooling is the next process after the complete casting process. The cooling process of aluminum alloys are affected by material properties such as: strength, ductility, and thermal stresses. However, if the cooling rate is too slow, undesirable alloy segregation at the grain boundaries will be resulted. Conversely, if the cooling rate is too fast an increased tendency for distortion may result. Many methods for quenching exist, including: cooling in air, water, oil, and salt. The rate of cooling helps determine many of the important characteristics of the aluminum alloy. For this project, there are three types for cooling media used which are water, oil and air.

Figure 3.31: Cooling media using water

Figure 3.32: Cooling media using oil

Figure 3.33: Cooling media using air

3.10 HARDNESS TEST

Analysis of the products will be made to study the effects of cooling media to the casted material. There are a lot of analysis can be made such as appearance products inspection, microstructure examination, mechanical testing and other related analysis. For these projects, the analysis focuses on structure and shape of products and mechanical testing. The hardness is determined from the same specimen. A standard specimen of dimensions (3.0cm x 2.5cm x1.0cm) of aluminum is cutting from the dog bone specimen for the same purpose.

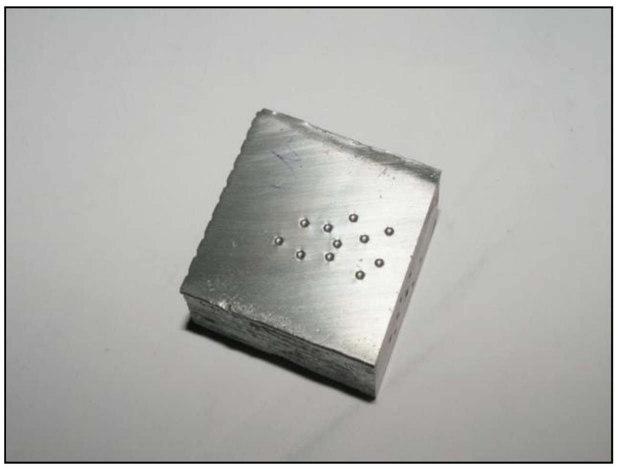


Figure 3.34: Specimen size

The hardness method is using Rockwell hardness test which choose base on the hardness of material. This hardness test uses a direct reading instrument based on the principle of differential depth measurement. The Rockwell hardness number is based on an inverse relationship to the measurement of the additional depth to which an indenter is forced by a heavy (major) load beyond the depth resulting from a previously applied (minor) load. Initially a minor load is applied, and a zero datum position is established. The major load is then applied for a specified period and removed, leaving the minor load applied.

The resulting Rockwell number represents the difference in depth from zero datum position as a result of the application of major load. The entire procedure requires only 5 to 10 s. Use of a minor load greatly increases the accuracy of this type of test, because it eliminates the effects of backlash in the measuring system and causes the indenter to break through slight surface roughness. The 1200 sphero-conical diamond indenter is used mainly for testing hard materials such as hardened steels and cemented carbides. Hardened steel ball indenters with diameters 1/16in. are used for testing in this project.

Figure 3.35: Outer surface hardness test

Figure 3.36: Inner surface hardness test

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will focus on the result and analysis of the mould and the final product. Comparison between the rate of the entire cooling medium which is air, water and oil are made in order to highlight the different hardness result. Besides, comparison between outer surface hardness and inner surface hardness of the material also been discussed. At the end of this chapter casted material's final shape and defect will be discussed in detail and a few improvements have been suggested.

4.2 RESULT OF MOULD FABRICATION PROCESS

Moulds have been produced as a result at all process starting from designing, simulation and machining. In order to make sure the flatness of the mould surface, surface grinder machine are used. Furthermore, air grinder is used to remove all burrs and define mould's taper and chamfer as shown in Figure 4.4.

Figure 4.1: Complete mould

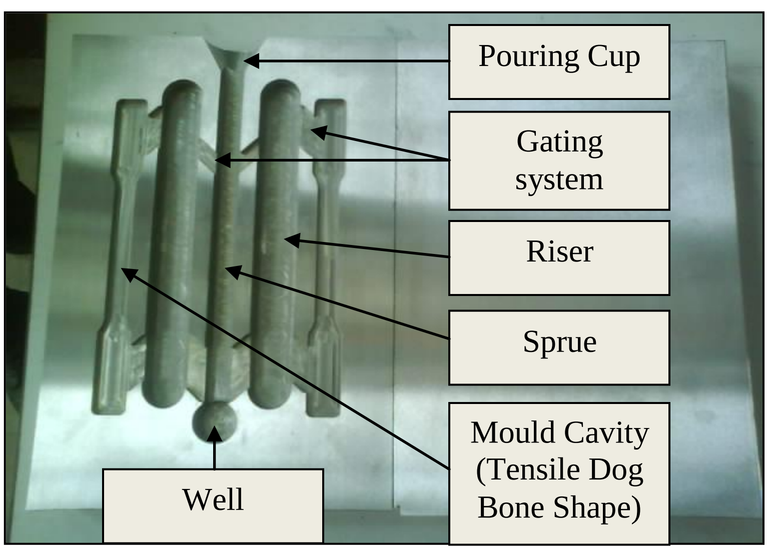


Figure 4.2: Top view

Figure 4.3: Finishing process using surface grinding machine

Figure 4.4: Finishing process using air grander

4.3 FINAL PRODUCT

After finishing all the machining process from previous steps; the process continued with casting process. Aluminum's temperature used is approximately $700^{\circ}C$ while mould temperature is approximately half of it which is around $350^{\circ}C$.Infrared

Thermometer is used to measure the mould temperature. The first step in measurement, is determining the desired target. The temperature measurement is taken when the trigger is activated. This is usually a button located either underneath the pyrometer (gun style). The final product is as shown as the entire figure below (Figure 4.5, 4.7, 4.8).

Figure 4.5: Mould and casting product

Figure 4.6: Infrared Thermometer

Figure 4.7: Casting product

Figure 4.8: Tensile test specimens

4.4 ANALYSIS FOR ROCKWELL HARDNESS TEST

Rockwell Hardness Test was used to measure the hardness of the casted material. This hardness test uses a direct reading instrument based on the principle of differential depth measurement. As what has been mentioned previously, here are two types of Rockwell test used which is Surface Hardness Test and Inner Surface Hardness Test. The result has been presented in the following table and graph as shown below. From the result, the hardness values of aluminum alloy are different for each cooling medium.

4.4.1 Outer Surface Hardness Data

Table 4.1: Outer Surface Hardness Data

No	water	oil	air
1.	49.80	40.20	27.80
2.	48.60	39.90	28.90
3.	49.20	39.00	28.50
4.	49.00	40.60	27.40
5.	48.90	38.80	29.10

4.4. 2 Inner Surface Hardness Data

Table 4.2: Inner Surface Hardness Data

No	water	oil	air
1.	38.00	30.10	21.40
2.	37.50	29.50	21.80
3.	38.40	28.80	20.20
4.	36.90	29.90	20.90
5.	37.80	29.30	21.30

4.4.3 Graph of Outer Surface Hardness Test

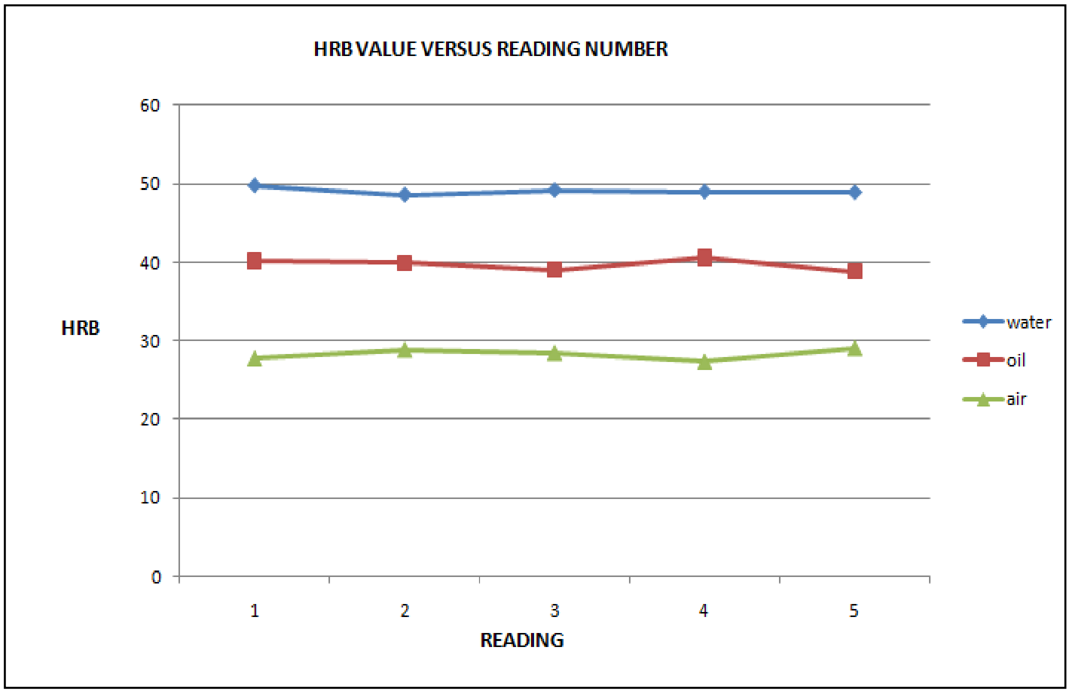


Figure 4.9: Graph of outer surface hardness test

The above graph has shown the result of outer surface hardness test. Based on the graph, the main different between cooling rate effect of the three medium which is water, air and oil have been proved. The average value for water medium is 49.10 HRB, for oil medium is 39.70 HRB and air medium is 28.34 HRB. From the analysis and table of the hardness test results, it is clearly shown that the best value gain for hardness's cooling rate are from water base medium, followed by oil and air. Basically, water has proved to be the best mediums for cooling rate compare the oil and air medium.

Callister et al. (2006) also say that the severity of quench is a term often used to indicate the rate of cooling; the more rapid the quench, the more severe the quench. Of the three most common quenching media- water, oil and air- water produces the most severe quench, followed by oil, which is more effective than air. The degree of agitation of each medium also influences the rate of heat removal. Increasing the velocity of the quenching medium across the specimen surface enhances the quenching effectiveness. During the cooling process of the aluminum specimen, heat energy must be transported to the surface before it can be dissipated into the cooling medium. As a consequence, the cooling rate within and throughout the interior of the aluminum structure varies with position and depends on the geometry and size.

4.4.4 Graph for Inner Surface Hardness Test

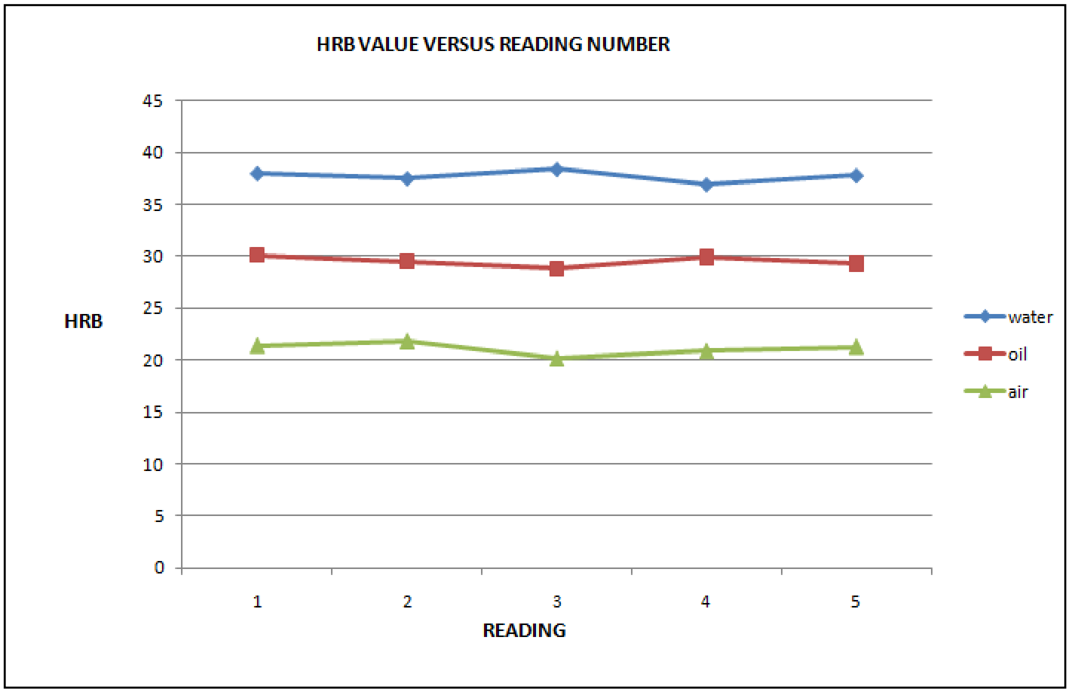


Figure 4.10: Graph of inner surface hardness test

The above graph is a result of different inner surface hardness test by three medium. The blue color show the graph of water medium, the red color show the oil medium and green color show the graph of air medium. The average value for water medium is 37.72 HRB, for oil medium is 29.52 HRB and air medium is 21.12 HRB From the graph, it is clearly proved that water is still the best cooling medium compared to oil and air. As what have stated above, water has proved to be the best medium for cooling rate compare the oil and air medium.

Sim et al. (2004) showed that the hardness of aluminum increases with the increasing of cooling rate. Additionally, the hardness increases with increasing pearlite percentage. The hardness of aluminum increases rapidly as the martensite percentage is increased. The hardness's of the water-quenched samples is increased by a factor close 3 and 3.5 compared to the hardness values obtained from oil and air. This is because martensite is one of the most common strengthening phases in aluminum. In general, the hardness increases because of the refinement of the primary phases after rapid cooling. It is well known that the water quenching creates a supersaturated solid solution, and vacancies increase with carbon content in water quenched samples. Thus, high hardness correlates with high resistance to slip and dislocation. We claim that the increase in the hardness is due to the delay in the formation of ferrite which promotes the formation of pearlite and martensite at a higher cooling rate. Thus, the increase of hardness with the water quenched aluminum can be explained by the increasing relative volume of pearlite and martensite after quenching.

4.4.5 Comparison between Outer and Inner Surface Hardness Test

Table 4.3: Data of hardness test with water as cooling media

No	Outer Surface	Inner Surface	Different Value
1.	49.80	38.00	11.80
2.	48.60	37.50	11.10
3.	49.20	38.40	10.80
4.	49.00	36.90	12.10
5.	48.90	37.80	11.10

Table 4.4: Data of hardness test with oil as cooling media

No	Outer Surface	Inner Surface	Different Value
1.	40.20	30.10	10.10
2.	39.90	29.50	10.40
3.	39.00	28.80	10.20
4.	40.60	29.90	10.70
5.	38.80	29.30	9.50

Table 4.5: Data of hardness test with air as cooling media

No	Outer Surface	Inner Surface	Different Value
1.	27.80	21.40	6.40
2.	28.90	21.80	7.10
3.	28.50	20.20	8.30
4.	27.40	20.90	6.50
5.	29.10	21.30	7.80

Table 4.6: Data of different value for each cooling media

No	Water	Oil	Air
1.	11.80	10.10	6.40
2.	11.10	10.40	7.10
3.	10.80	10.20	8.30
4.	12.10	10.70	6.50
5.	11.10	9.50	7.80

4.4.6 Graph of Comparison between Outer and Inner Surface Hardness Test

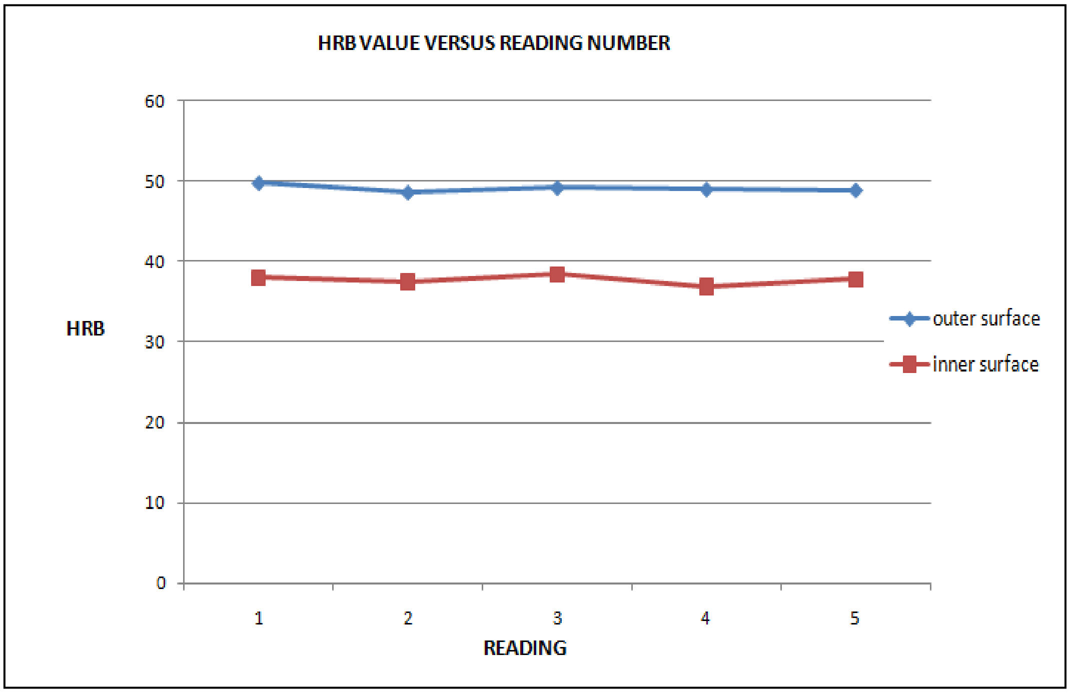


Figure 4.11: Graph of hardness test with water as cooling media

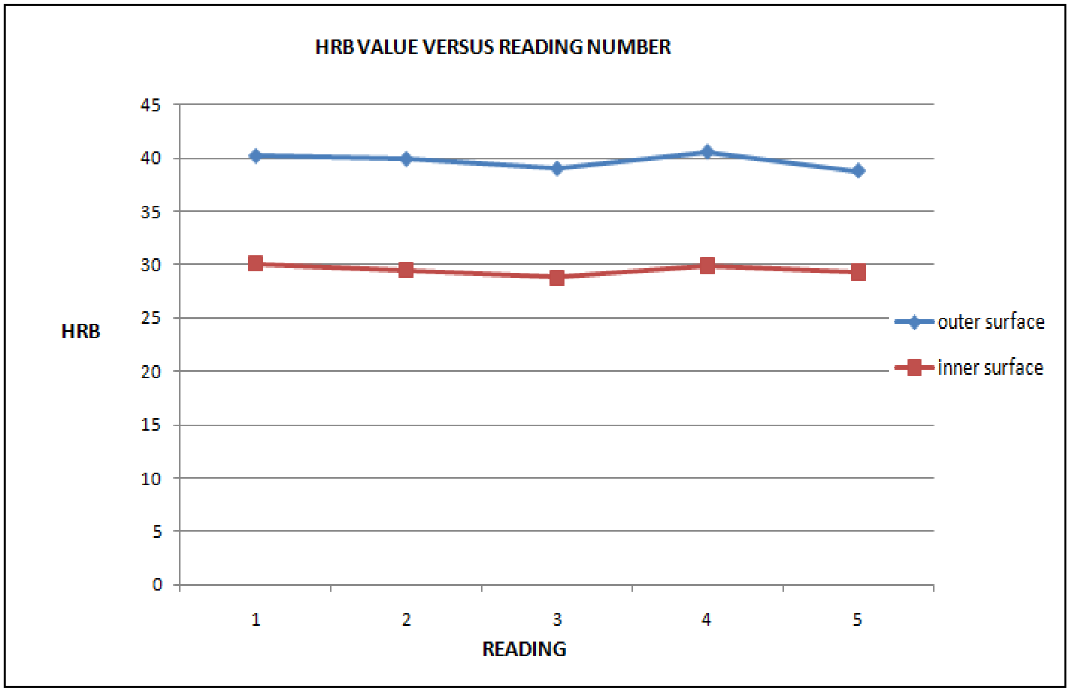


Figure 4.12: Graph of hardness test with oil as cooling media

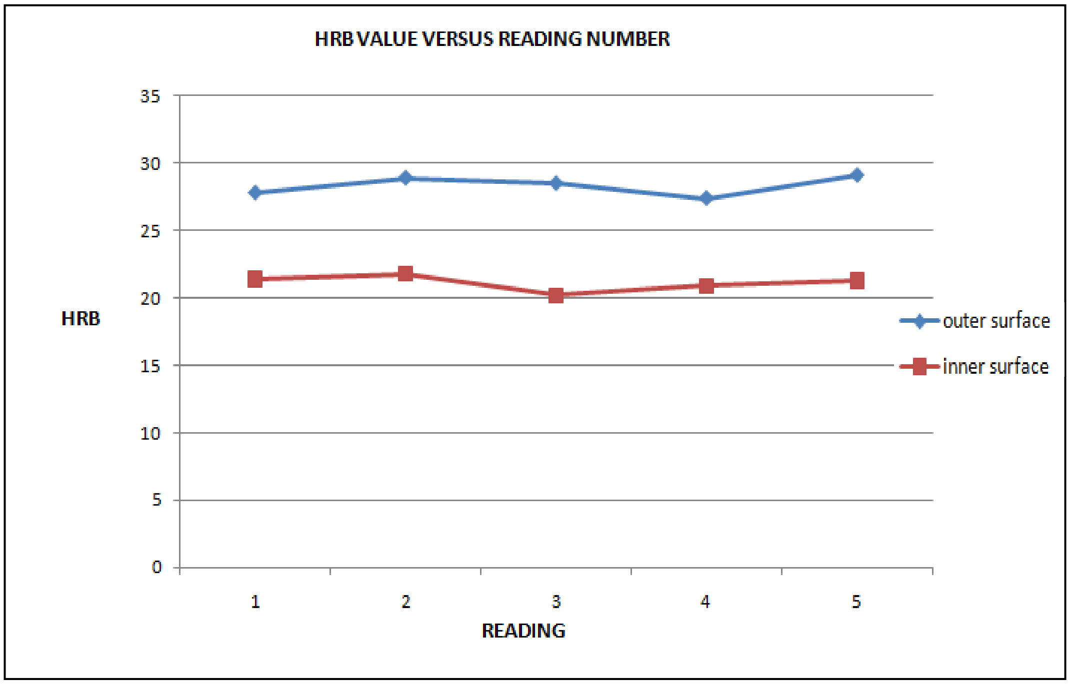


Figure 4.13: Graph of hardness test with air as cooling media

Basically, all three graphs (Figure 4.11, 4.12, 4.13) have shown the different effect between surface hardness test and inner surface hardness test. From the graphs, it is shown that surface hardness test values are higher compared to inner surface test. The comparison between inner surface and outer surface hardness test for water is 11.38 HRB, for oil is 10.18 HRB and for air is 7.22 HRB**.** The main reason of the above result is because material's surface will be the only area exposed to the cooling medium compared to the inner surface area which is exist only below the outer surface of the material. Thus, the strength of inner surface hardness will be less compared to outer surface hardness. Callister et al. (2006) also say that the cooling rate is a maximum at the surface diminishes with position from point along the depth of the specimen. The quenched end is cooled most rapidly and exhibits the maximum hardness; 100% martensite is the product at position for most aluminums. Cooling rate decreases with distance from the quenched end, and the hardness also decreases. With diminishing cooling rate, more time is allowed for carbon diffusion and the formation of a greater proportion of the softer pearlite, which may be mixed with martensite and bainite. Thus, the aluminum that is highly hardenable will retain large hardness values for relatively long distances; the aluminum with low hardenability will not.

4.5 SHAPE ANALYSIS OF THE CASTED MATERIAL

The last step is to analyze the defect of the casted material. Therefore, analysis of casting defect is important to obtain how defects can occur in casting process and reduce defect in casting. Quality of the casting product means free of defect or less defect. The casted product should have a desired surface quality, a proper dimension and internal reliability.

4.5.1 Short Casting or Misruns

A misrun occurs when the liquid metal does not completely fill the mould cavity, leaving an unfilled portion. The fluidity can be increased by changing the chemical composition of the metal or by increasing the pouring temperature. Misruns are closely related and both involve the material freezing before it completely fills the mould cavity. The other causes are the mould was too cold when cast. The prevention for the problem is pre heating the mould until the temperature approximately 350◦C half of the liquid metal temperature around 700◦C. From the Figure 4.14 and Figure 4.15 below, it shows the defect of the casted material because of different mould temperature during the pouring the molten metal in the mould.

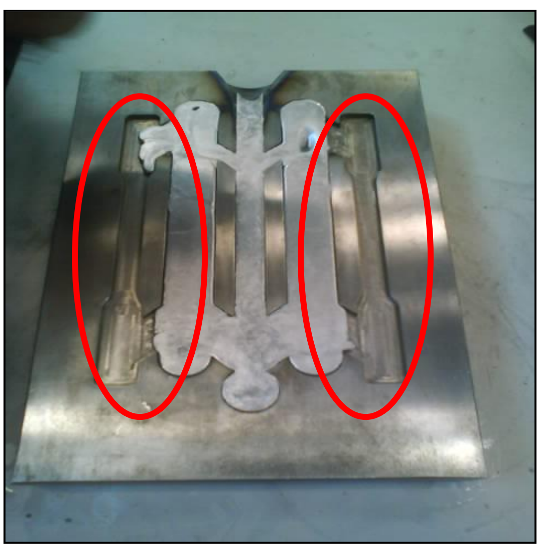


Figure 4.14: Temperature mould 200◦C

Figure 4.15: Temperature mould 350◦C

4.5.2 Shrinkage

Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies. As the molten metal cools and solidifies it will begin to contract. This means, although the molten metal completely filled up the mould, by the time the casting was cold, the casting is smaller than the mould. This means, a pattern must be made larger than the design drawing. The difference between the size or dimensions of the desired casting and the size of the pattern used to create the mould is called a shrinkage allowance. The sprue function to supply extra metal but if the sprue is too small, flows of molten metal through it may solidify before the mould cavity was fully filled up. Solidification of molten material in sprue before mould cavity fully covered may cause shrink cavity. The prevention for the problem is use the large sprue. The sprue should be thicker than the section of the mould it is connected to. Make sure the gates are cut as wide as possible. Large gates allow the metal in the sprue to stay warm from the heat of the main body of the casting. So the sprue will hopefully cool slower.

Figure 4.16: Shrinkage problem

Figure 4.17: Shrinkage problem

4.5.3 Crack

The next defect in casting product is cracking problem. The cracks mainly situated at the places where the thickness is non-uniform. The cracks are not severe but minor cracks only at the well. The cracks on the casting part mainly because castings unreasonable structural design, there are sharp corners, wall thickness changes over the poor, cast local overheating, pouring temperature is too high, removed from the mould casting early, heat hot or burning, and also excessive cooling rate (Campbell, 2004). The prevention for the problem is improved casting structural design, to avoid sharp corners, seek uniform thickness, smooth transition. Ensure that all parts of casting solidification or solidification at the same time, and also improving the design of gating system.

Figure 4.18: Cracking at the well

4.5.4 Cold Shut

Cold shuts occur when two fronts of liquid metal do not fuse properly in the mould cavity, leaving a weak spot. A casting defect caused by either a lack of fluidity in the molten metal or cross-sections that are too narrow and small thickness of the casting. The other causes for these defects are large surface area to volume ratio of the casting, high heat transfer rate of the mould material and back pressure of the gases entrapped in the mould cavity due to inadequate venting. The prevention for the problem is the fluidity can be increased by changing the chemical composition of the aluminum or by increasing the pouring temperature. Also check the gating system and make the venting to ensure the gases removed from mould (Campbell, 2004).

Figure 4.19: Cold shut at the tensile specimen

4.5.5 Flash

This casting shows a very common defect, flash. This is where the mould somehow separated enough to allow metal between the halves, along the parting line. In fact, it even filled some of the small gap between the two halves. From the Figure 4.20 and Figure 4.21, the outer of riser completely filled in with flash. Fixing flash is no problem as it's usually less than 0.5mm so can be broken off with a hammer or pliers. Another cause is clearance between two elements of the mould or between mould and core and poorly fit mould joint. The prevention for the problem is the improve mould fitting and assembly, care in pattern making, moulding and core making and also control of their dimensions (Campbell, 2004).

Figure 4.20: Flash defect

Figure 4.21: Flash defect

4.5.6 Porosity

Gas porosity is the formation of bubbles within the casting after it has cooled. This occurs because most liquid materials can hold a large amount of dissolved gas, but the solid form of the same material cannot, so the gas forms bubbles within the material as it cools. Gas porosity may present itself on the surface of the casting as porosity or the pore may be trapped inside the metal, leading to an increased risk of breaking or stress corrosion. To prevent gas porosity the material may be melted in a vacuum, in an environment of low-solubility gases, such as argon or carbon dioxide, or under a flux that prevents contact with the air. To minimize gas solubility the superheat temperatures can be kept low. Turbulence from pouring the liquid metal into the mould can introduce gases, so the moulds are often streamlined to minimize such turbulence (Campbell, 2004).

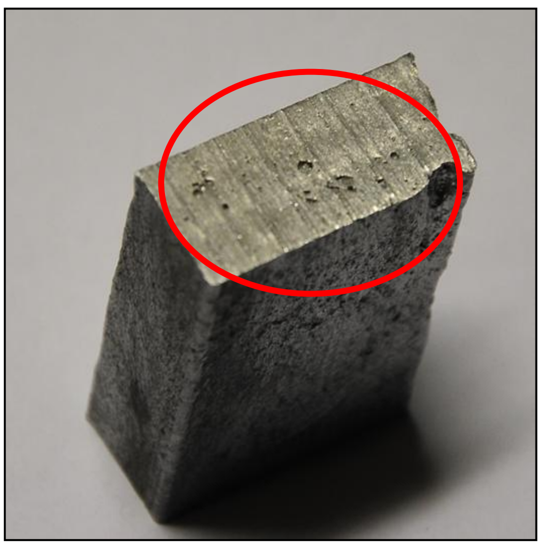


Figure 4.22: Gas porosity defect

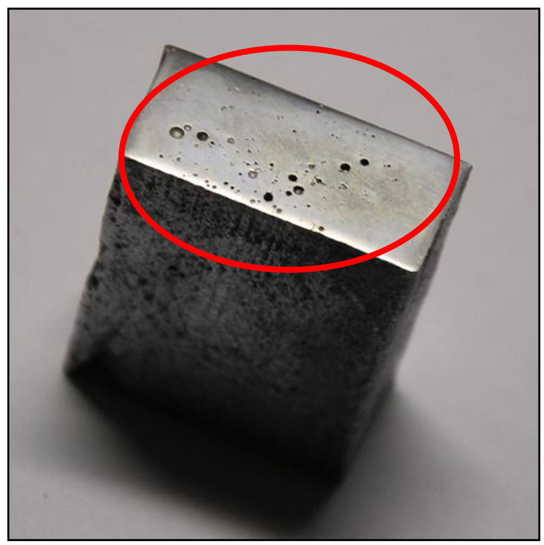
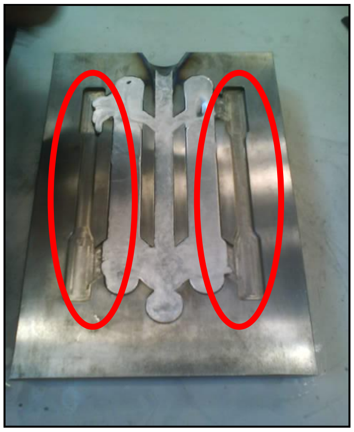
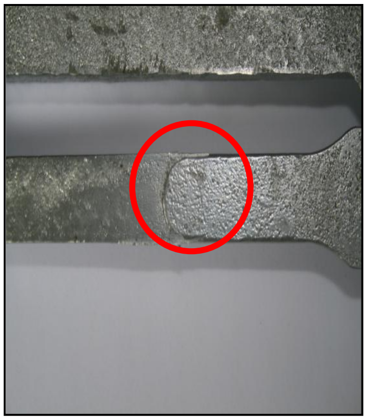
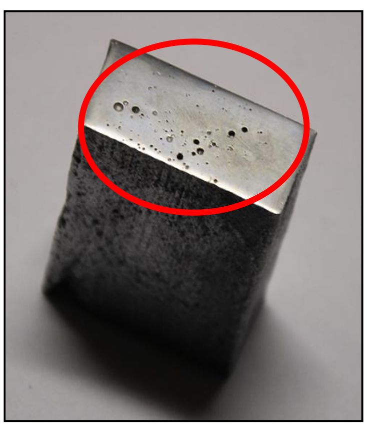


Figure 4.23: Gas porosity defect

4.6 Summary

No.	Casting Defects	Causes	Improvement Suggestion
1.	 **Short casting or misruns**	Material freezing before it completely fills the mould cavity. Metal was too cold when cast. Mould was too cold when cast.	Pre heating the mould until the temperature approximately 350◦C half of the liquid metal temperature around 700◦C.
2.	 **Shrinkage**	Sprue is too small it will cool before the casting. Castings in the mould poorly located. Pouring temperature is too high, pouring too fast.	Pouring molten metal from the riser to improve the riser design. Improve the position of the casting in the mould pouring temperature and casting speed reduced.
3.	 **Crack**	Castings unreasonable structural design. Pouring temperature is too high. Heat hot or burning, excessive cooling rate.	Improved casting structural design, to avoid sharp corners. Ensure that all parts of casting solidification or solidification at the same time, improving the design of gating system.

4.	 **Cold Shut**	Lack of fluidity in the molten metal or cross-sections that are too narrow and small thickness of the casting. High heat transfer rate of the mould material.	Increasing the pouring temperature. Check the gating system and make the venting to ensure the gases removed from mould.
5.	 **Flash**	Small gap between the two halves. Sprue is very tall and the casting covers a wide area of the mould face.	Improve mould fitting and assembly. Care in pattern making, moulding and core making and also control of their dimensions.
6.	 **Porosity**	Liquid materials can hold a large amount of dissolved gas. Not enough metal reservoirs to eliminate shrinkage porosity. Metal contains gas.	Material may be melted in a vacuum. Avoid improper gating systems. Reduce pouring height.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

The project was done successfully with achieving the project objective. This chapter will discuss about the overall conclusion of the project and the recommendation.

5.2 CONCLUSION

Overall, this project has been accomplished by five main process which is designing, simulation, fabrication, casting and analysis. All the process have highlighted a few important factor in metal casting which is defining the optimum mould design and structure beside the shape analysis of the casted material itself. In order to complete this study, details studies on mechanical properties of the aluminum hardness have been made by comparing the effect of the cooling rate between three medium which is water, oil and air.

The project also focused on improving the design and analysis process by using computer aided mechanism such as CAD and Master CAM as required for simulation machining. Although there are several problems occur during the process, it has been carefully studied and solved one by one and a few countermeasures have been suggested.

Conclusively, the main objective for this project which is to design and fabricate the mould for tensile test specimen, ASTM E8 and to study the mechanical properties of the casted materials and its comparison with effect of the cooling rate between water, oil and air have been achieved. Throughout all the process, studies on fabrication process of a casting material have fulfilled nearly every factor needed in understanding the concept of metal casting.

5.3 RECOMMENDATIONS

For the future work in order to design and fabricate the mould and study the mechanical properties based on casted material, the following aspect could be taken into consideration:

i. The design for mould should follow the design consideration. For example the taper at the riser must be increase from 3◦ to 5◦ in order that the part easy to breakout.
ii. Master CAM is a very useful tool in verifying and investigating the performance of a component being designed, for example from the results of this project, choosing the most suitable mould model and design.
iii. Make the analysis of the mould based on the parts that produce by using Pro CAST software.
iv. Study on other parameters that can be controlled and compare of casted material such as effect of pouring time and effect of mould temperature.
v. Compare the results between the casted tensile and tensile test specimen at the lab.
vi. Make the tensile test using tensile machine for compare the strength of the casted material.

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Shen Jun, Liu Yong-chang, Han Ya-ji, Gao Hou-xiu, 2006. Effects of cooling rates on microstructure and microhardness of lead-free Sn-3 S%Ag solders. *Trans. Nonferrous Met. Soc China* 16(2006) 59-64.

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APPENDIX A

PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 1

<table>
<tr><th rowspan="2">Work Progress</th><th colspan="15">Week</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th></tr>
<tr><td rowspan="2">Get the project title and arrange discussion time with supervisor.</td><td bgcolor="red"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="2">Find the problem statement and project objectives.</td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="2">Find scope of the project, hypothesis. Verify problem statement, project objectives, scope and hypothesis.</td><td></td><td></td><td bgcolor="red"></td><td bgcolor="red"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="2">Do research and collect the information
(mould design, casting process, hardness test)</td><td></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="2">Study and learning the theory of mould design and effect of cooling rate at the casted material</td><td></td><td></td><td></td><td></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="2">Do the design of the mould and design consideration, Do the simulation using master CAM</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="red"></td><td bgcolor="red"></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="2">Report Writing (Chapter 1, 2, 3)
(Introduction, Literature review, Methodology)</td><td></td><td></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td bgcolor="red"></td><td></td><td></td></tr>
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<tr><td rowspan="2">Submit draft thesis and slide presentation</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="red"></td><td></td></tr>
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<tr><td rowspan="2">Final year project 1 presentation</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td bgcolor="red"></td></tr>
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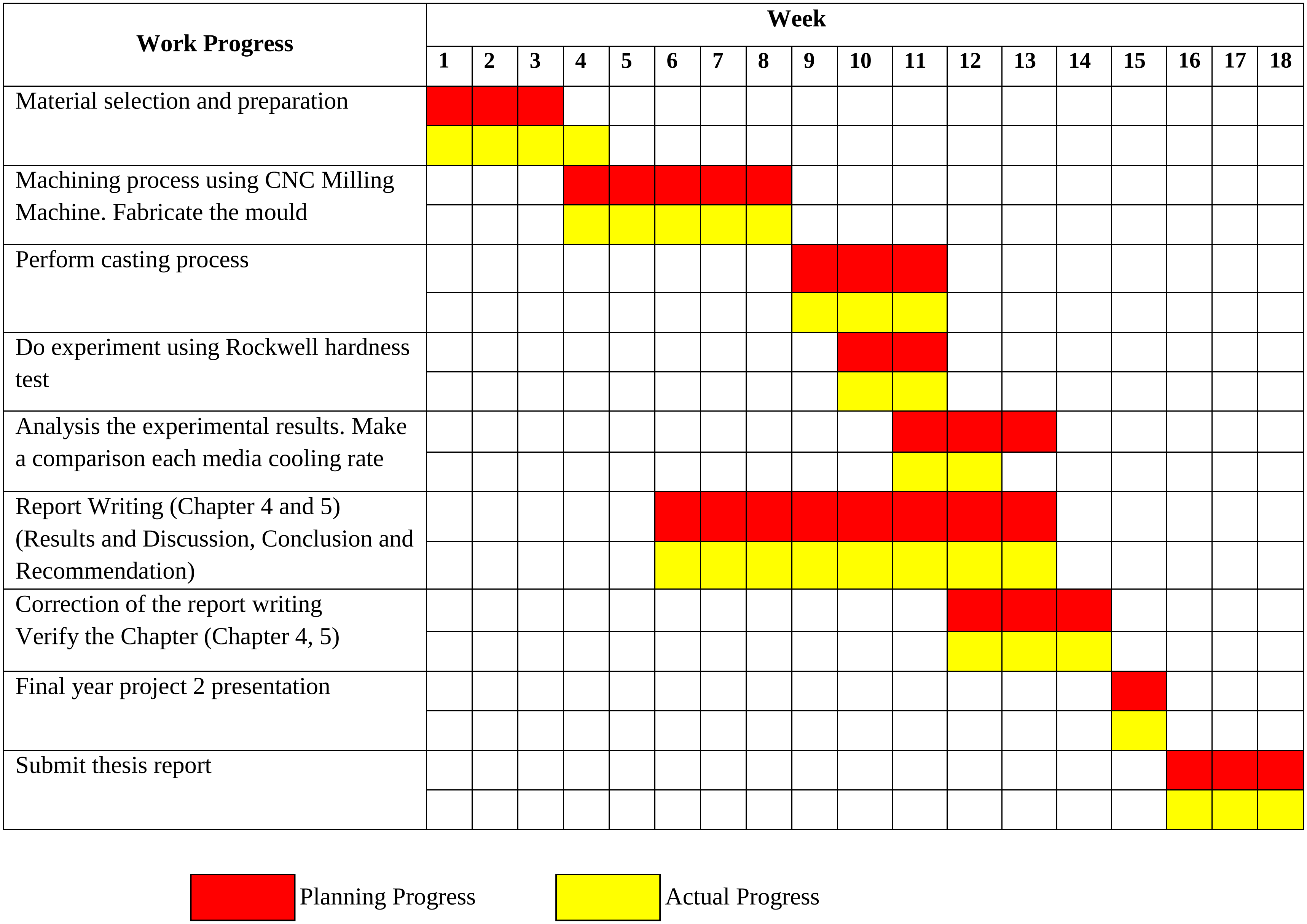
<table><tr><td bgcolor="red"></td><td>Planning Progress</td><td bgcolor="yellow"></td><td>Actual Progress</td></tr></table>

PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 2



APPENDIX B

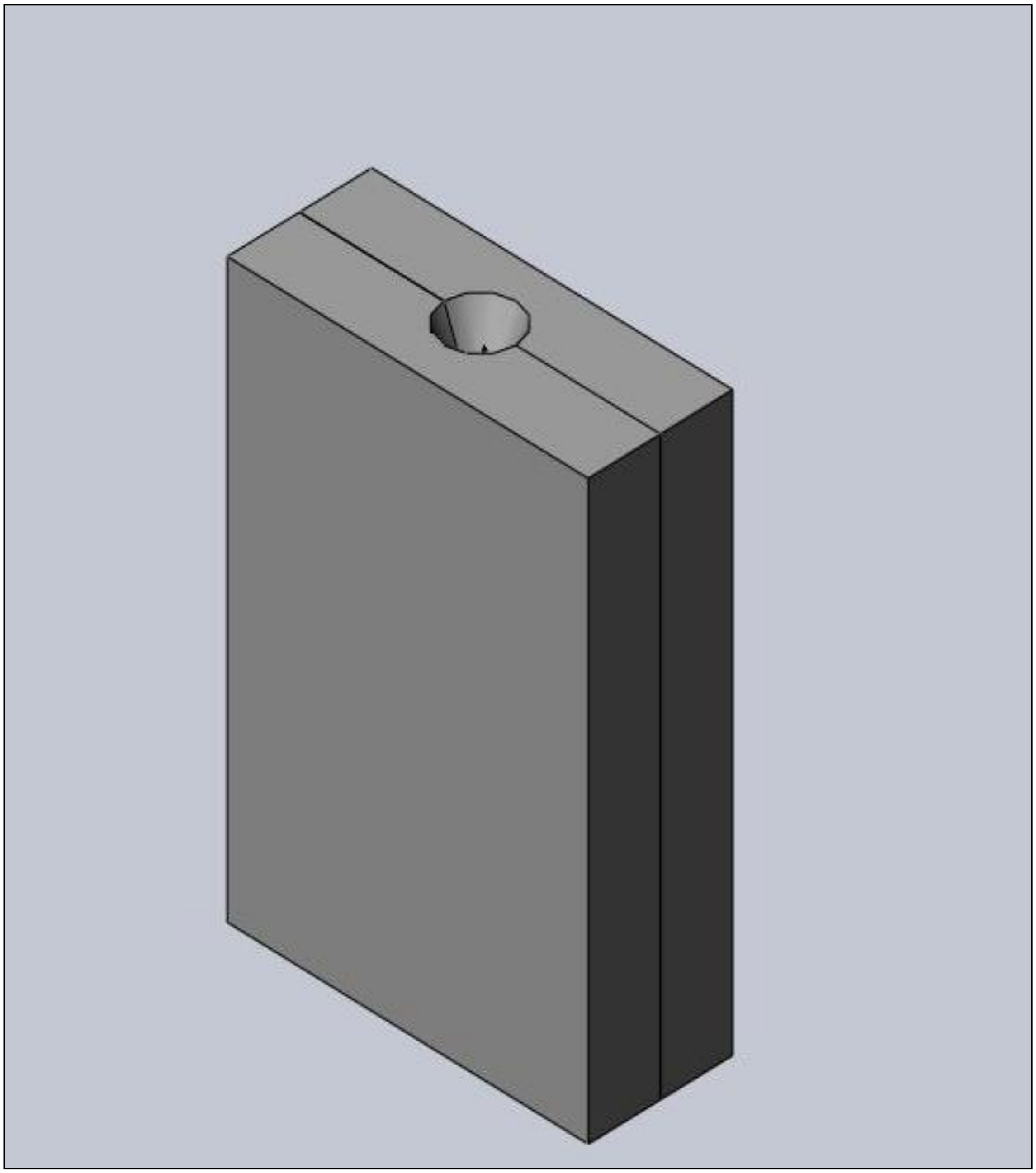


Figure 6.1: 3D drawing of complete mould

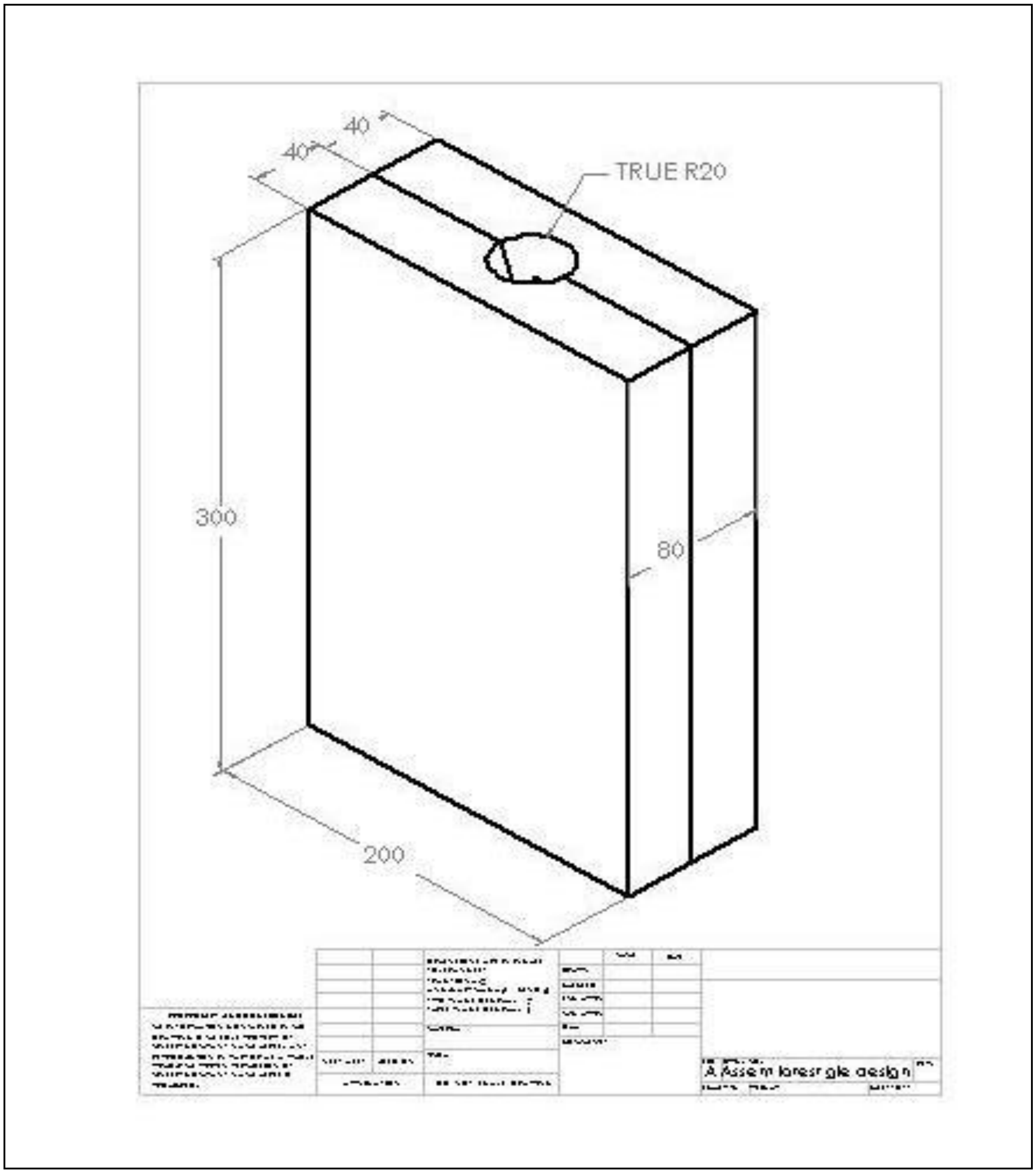


Figure 6.2: Sheet drawing of complete mould

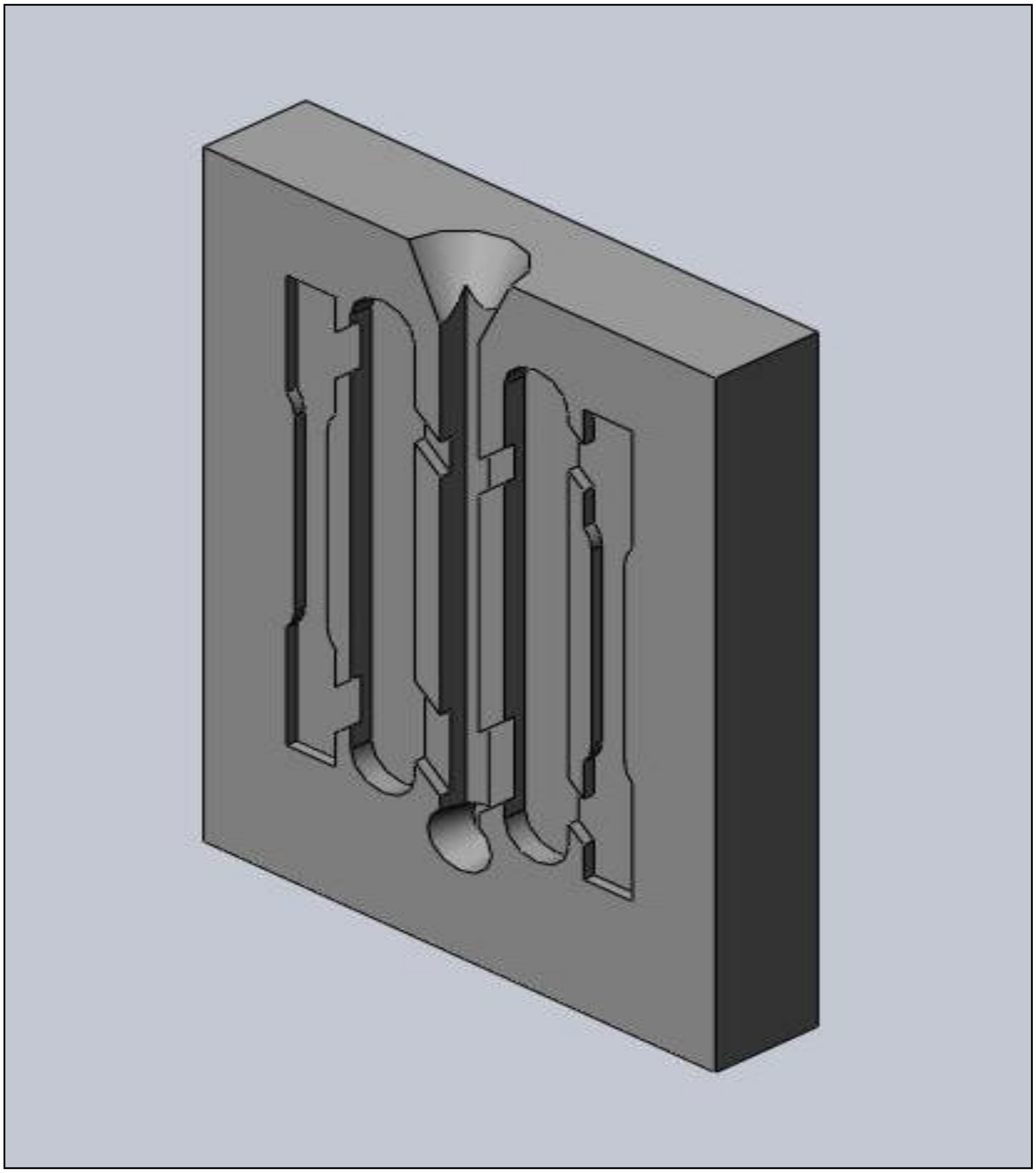


Figure 6.3: 3D drawing of left mould

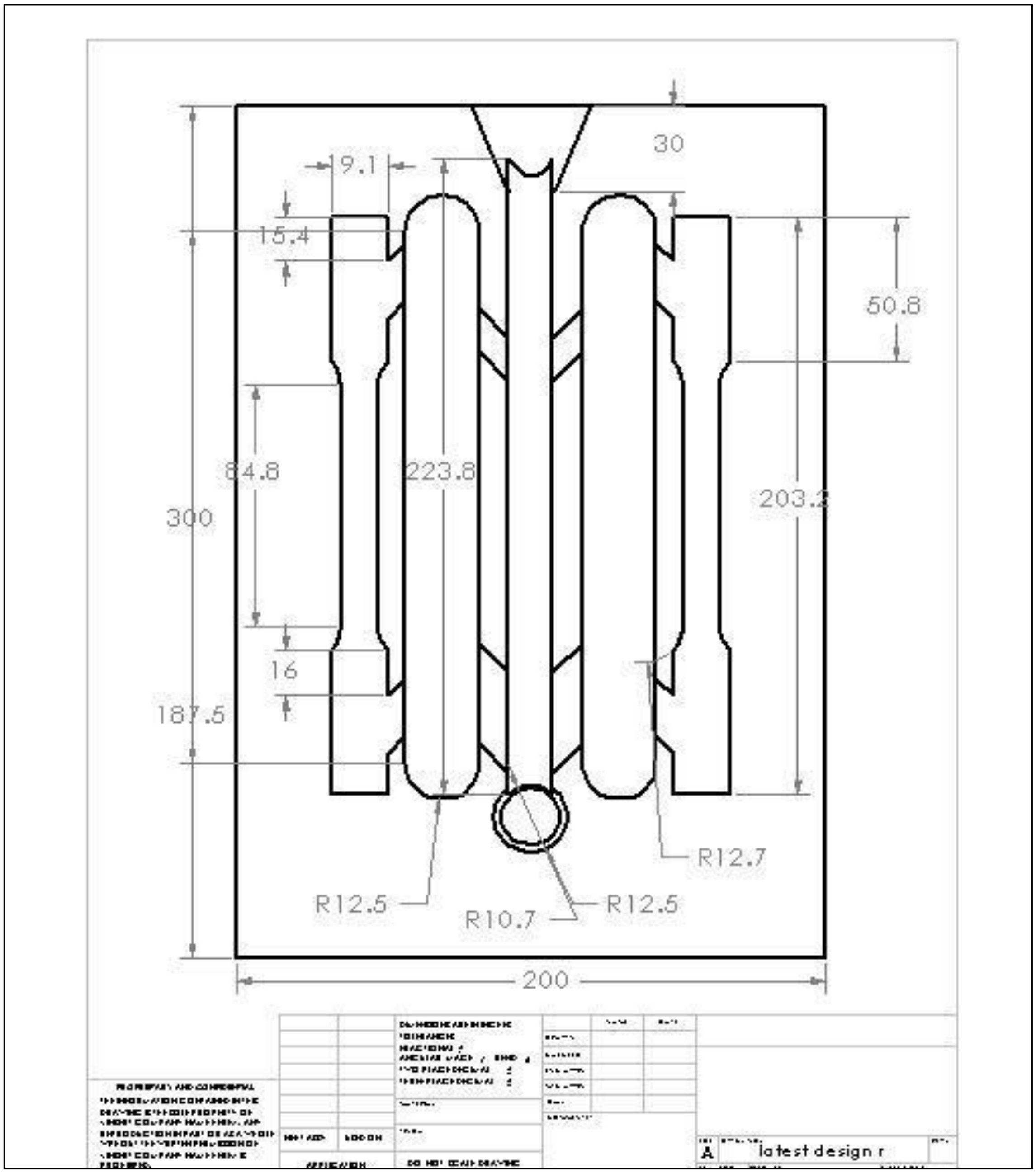


Figure 6.4: Sheet drawing of left mould