INVESTIGATION MICROSTRUCTURE AND MECHANICAL PROPERTIES OF WHITE CAST IRON USING SAND CASTING

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ABSTRACT

This project is to investigate mechanical properties and microstructure of white cast iron using sand casting. There are three objectives for this project which are firstly to study the processing method of gray cast iron to produce white cast iron. Secondly, to investigate the microstructure and hardness of white cast iron compared to gray cast iron and lastly, to study the microstructure and hardness of white cast iron in differential type of quenching medium. The first part for this project is foundry laboratory which is involving the process of sand casting was performed by using furnace to melt the raw material. Then, the melted raw material produced is then poured into the desired mould and let it solidify by itself. After the casting process, the material will be through second part which involves heat treatment. The material is heated at 1020^{o}C for two hours. Then, the material is quenched into the medium of water and oil before inspection parameter was performed to investigate the mechanical properties (hardness) and microstructure of material before and after heat treatment process. To validate the prediction result, experimental values compared. Result showed that the hardness of material after heat treatment is higher than hardness before heat treatment. The grain size formed on material after heat treatment is finer grain size and there are no flakes. Different with material before heat treatment, it shows that there are flakes and the grain size is thin inside it. The predicted result showed that heat treatment exerted on material is influencing the change of mechanical properties and microstructure.

ABSTRAK

Projek ini menerangkan kajian sifat-sifat mekanik dan perubahan mikrostruktur besi tuang putih menggunakan proses tuangan logam. Projek ini mempunyai tiga objektif pertama, mengkaji kaedah memproses besi tuang kelabu kepada besi tuang putih. Kedua, mengkaji mirostruktur dan kekerasan besi tuang putih berbanding dengan besi tuang kelabu dan ketiga, mengkaji mikrostruktur dan kekerasan besi tuang putih pada medium lindap kejut yang berbeza. Bahagian pertama bagi projek ini melibatkan proses tuangan logam dilakukan dengan menggunakan relau untuk mencairkan bahan mentah. Kemudian, bahan mentah cair yang dihasilkan tadi dituangkan ke dalam acuan yang dikehendaki dan ia dibiarkan sejuk dengan sendirinya. Selepas proses tuangan logam, bahan tersebut akan melalui bahagian kedua yang melibatkan rawatan haba. Bahan dipanaskan pada suhu 1020°C selama 2 jam. Kemudian, bahan direndamkan ke dalam air dan minyak sebelum pemeriksaan parameter dilakukan untuk mengkaji sifat-sifat mekanikal (kekerasan) dan mikrostruktur bahan sebelum dan selepas proses rawatan haba. Untuk mengesahkan hasil ramalan, keputusan daripada eksperimen dibandingkan. Keputusan menunjukkan bahawa kekerasan bahan selepas rawatan haba adalah lebih tinggi daripada kekerasan sebelum rawatan haba. Saiz butiran yang terbentuk pada bahan selepas rawatan haba adalah lebih halus dan tidak terdapat kepingan-kepingan padanya. Berbeza dengan bahan sebelum rawatan haba, ia menunjukkan bahawa terdapat kepingan dan saiz butiran nipis di dalamnya. Hasil ramalan menunjukkan bahawa rawatan haba yang dikenakan ke atas bahan mempengaruhi perubahan sifat-sifat mekanikal dan mikrostruktur.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Basically there are four different kinds of cast irons whereby can be differentiated from each other by the distribution of carbon in their microstructure; gray cast iron, white cast iron, ductile cast iron and malleable cast iron. White cast iron is unique since it is the only member of the cast iron family in which carbon is present only as carbide. Due to the absence of graphite, it has a light appearance. The presence of different carbides, depending on the alloy content, makes white cast irons extremely hard and abrasion resistant but very brittle. An improved form of white cast iron is the chilled cast iron. The raw material required to carry out this project is pig iron. Pig iron is a metal material that results when iron ore, charcoal from coal, and limestone are melted together under intense air pressure. Pig iron formed when the combined material cools to form a high-carbon. The cooled material is rarely used by itself, as the large amount of carbon makes the material brittle and unstable. Usually, this type of iron is further refined through additional melting and blending processes to create wrought iron, cast iron, or steel. This project will through the metal casting and heat treatment process to achieve and gain the objective agreed. In order to obtain the absolute result, there are several method and tests that must be done to investigate the microstructure and mechanical properties of white cast iron such as using the microscope and hardness test.

1.2 PROBLEM STATEMENT

Since there are limitation of the mechanical properties of gray cast iron such as hardness, tensile strength and others so, the white cast iron is needed. The mechanical properties of white cast iron is better than grey cast iron in order to produce something that need strength and ability to against the large force exerted on it. The white cast irons are used primarily for applications requiring wear and abrasion resistance such as mill liners and shot-blasting nozzles. Besides that**,** other uses include railroad brake shoes, rolling-mill rolls, clay-mixing and brickmaking equipment, and crushers and pulverizers.

1.3 PROJECT OBJECTIVES

a) To study the processing method of the gray cast iron to produce white cast iron.
b) To investigate the microstructure and the hardness of white cast iron compared to gray cast iron.
c) To study the microstructure and hardness of white cast iron in differential type of quenching medium (oil and water).

1.4 PROJECT SCOPES

The scope of study for this project includes the using of CO_2 sand as a mould in carry out the sand casting process. Other than that, the raw material used in sand casting process is pig iron which is as a basic thing in producing gray cast iron. In order to generate the white cast iron, the heat treatment (quenching) need to be held by reheating the gray cast iron then followed by rapid cooling. Then, an inspection parameter is performed to investigate the microstructure and mechanical properties (hardness) before and after heat treatment and all of them will be studied by suitable test and method.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, it basically describes more about the investigation of white cast iron microstructure and mechanical properties using green sand molding process done by other scientists and engineers. Therefore, in this part will discuss on white cast iron and its microstructure. Then, it is followed by mechanical properties and sand casting process.

2.2 METAL CASTING PROCESS

Casting is a 6000 year young process which is mentioned in several Sanskrit works such as Shilpashastra derived from Sthapatyaveda containing the principles of realizing all kinds of man-made structures (Ravi, 2005). Earliest castings include the 11 cm high bronze dancing girl found at Mohenjo-do in between the range dated 3000-3500 BC (Ravi, 2005). Besides that, there was remain of Harappan civilization contain kilns for smelting copper ingots, casting tools, stone moulds, cast ornaments, figurines and others items of copper, gold, silver and lead (Ravi, 2005).

Metal casting enables the production of simple and complex parts that meet a wide variety of needs and all manufactured goods contain one or more cast components. The basic metal casting process involved pouring or injecting molten metal into a mold or die containing a cavity of the desired shape. Most commonly used method for small and medium-sized castings is green sand casting and it is a traditional method of casting metals and has been used for millennia. Basically, sand casting consists of (a) placing a pattern (having the shape of desired casting) in sand to make an imprint, (b) incorporating a gating system, removing the pattern and filling the mold cavity with molten metal, (d) allowing the metal to cool until it solidifies, (e) breaking away the sand mold, and (f) removing the casting. Other methods include die casting, shell molding, investment casting, lost foam casting, and squeeze casting. So, in this project, the green sand or CO_2 will be used as a mould. This method is the most common metal casting technique, using silica sand (SiO_2) as a medium for the mould. The sand is coated with a mixture of clay and water and pressed manually or mechanically around the pattern to be cast. The advantages of this project are most ferrous and nonferrous metals can be used and low pattern and material costs. Green sand molding is frequently the most economical method of producing castings.

Figure 2.1: Metal Casting Process

2.2.1 Pattern

Patterns are the foundry man's mould forming tool. Pattern is used to form mould cavity in which molten metal is poured. A pattern is a replica of the part or component to be made by casting process. Pattern replicates the mould cavity and allows the molten metal to solidify inside the mould.

Wood is the most common used of pattern material because it is easy availability, low weight and low cost (Parashar and Mittal, 2006). It is easily to shape, join, work and relatively cheap compare to others pattern material like metal. 90% of the castings are produced by using wood pattern (Parashar and Mittal, 2006). The limitation for the wood pattern is lower life and economical for small quantity production.

Shrinkage allowance is the amount that a pattern is made over size to compensate for the contraction of the casting metal (Parashar and Mittal, 2006). It is the contraction during cooling to room temperature. All metal shrink when cooling except perhaps bismuth because of inter-atomic vibrations which are amplified by an increase in temperature.

2.2.2 CO_2 Sand Mould

The CO_2 sand process used rammed moist sand that is bound together with sodium silicate which is hardened on the pattern by blowing CO_2 gas through the mould (Lindberg, 1990). This method gives a good surface finish and high accuracy which reduce the machine allowance and versatile easier for small, medium and large foundries for light and heavy casting for ferrous and non-ferrous foundries alike (Jain, 1995).

Basically, this procedure is more accurate mould than either green sand and it avoids baking (Lindberg, 1990). It is better withstanding handling and metal head pressure such that a dry compressive strength of over 1.4 MPa is arrived. The carbon dioxide is expected to form a weak acid which hydrolyses the sodium silicate resulting in amorphous silica which forms the bond. The introduction of CO_2 gas starts the reaction by forming hydrated sodium carbonate ($Na_2CO_3 + H_2O$). This gelling reaction increases the viscosity of the binder till it becomes solid. The compressive strength of the bond increases with standing time due to dehydration. The gassing of carbon dioxide pressure should be maintained around 0.14 to 0.28 MPa depending largely on the section to be gassed (Rao, 1998).

2.2.3 The Formation of Gray Cast Iron

Gray cast iron is formed when the carbon in the alloy exceeds the amount that can dissolve in the austenite and precipitates as graphite flakes. When a piece of solidified gray iron is fractured, the fracture surface appears gray because of the exposed graphite. Gray iron is very easy and cost effective to make, making it a highly popular iron alloy. Its properties make it highly suitable for a wide range of uses, and examples of this iron alloy can be seen in many locations around the world, including museums which maintain products of historic interest. This iron alloy has properties which can vary slightly, depending on how quickly it cools and the concentration of various elements in the alloy. The key feature of grey iron is that it includes flakes of graphite which develop during the cooling process.

2.3 CAST IRON

The term cast iron refers to a family of ferrous alloys composed of iron, carbon (range from 2.11% to about 4.5%), and silicon (up to about 3.5%). Cast irons are usually classified according to their solidification morphology from the eutectic temperature. Cast iron are also classified by their structure; ferritic, pearlitic, quenched and tempered or austempered. Cast irons have relatively low melting temperatures and liquid-phase viscosities, do not form undesirable surface temperatures and undergo moderate shrinkage during solidification and cooling. The cast irons must balance good formability of complex shapes against inferior mechanical properties compared white those of wrought alloys. A cast iron is formed into a final shape by pouring molten metal into a mold. The shape of the mild is retained by the solidified metal.

2.3.1 Gray cast iron

In this structure, graphite exists largely in the form of flakes. It is called cast iron because when it is broken, the fracture path is along the graphite flakes and has, therefore a gray, sooty appearance. These flakes act as stress raisers. As a result, gray cast iron has negligible ductility and it is weak in tension, although strong in compression, as are other brittle materials

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On the other hand, the presence of graphite flakes gives this material the capacity to dampen vibrations caused by internal friction and consequently the ability to dissipate energy. This capacity makes gray cast iron a suitable and commonly used material for constructing machine-tool bases and structures.

2.3.2 White cast iron

White cast iron is formed when much of the carbon in a molten cast iron forms iron carbide instead of graphite upon solidification. The microstructure of as-cast unalloyed white cast iron contains large amounts of iron carbides in a pearlitic matrix. To retain the carbon in the form iron carbide in white cast irons, their carbon and silicon contents must kept relatively low (that is, 2.5 – 3.0 percent C and 0.5 – 1.5 percent Si) and the solidification rate must be high. White cast irons are most often used for their excellent resistance to wear and abrasion. The large amount of iron carbides in their structure is mainly responsible for their wear resistance. White cast iron also serves as the raw material for malleable cast irons.

The white cast iron structure is very hard , wear resistant, wear resistant and brittle because of the presence of large amounts of iron carbide(instead graphite). White cast iron is obtained cooling gray cast iron rapidly or by adjusting the composition by keeping the carbon and silicon content low. This type of cast iron is also called white iron because of the white crystalline appearance of the fracture surface.

2.3.3 Malleable Cast Iron

Malleable cast iron is obtained by annealing white cast iron in an atmosphere of carbon monoxide and carbon dioxide at between 800 ^{o}C and 900 ^{o}C for up to several hours, depending on the size of the part. During this process the cementite decompose into iron and graphite. The graphite exists as clusters or rosettes.in a ferrite or pearlite matrix; consequently, malleable cast iron has a structure similar to the nodular iron. This structure promotes ductility, strength and shock resistance.

2.3.4 Ductile Cast Iron

This structure is developed from the melt. The carbon forms into spheres when cerium, magnesium, sodium, or other elements are added to a melt of iron with a very low sulfur content that will inhibit carbon from forming. The control of the heat-treating process can yield pearlitic, ferritic, martensitic matrices into which the carbon spheres are embedded.

2.4 MICROSTRUCTURE OF WHITE CAST IRON

A very small amount of the carbon is dissolved in the pure iron matrix. This component of the microstructure is known as Ferrite. Further amounts of carbon can either form Iron Carbide, [Fe3C], which is hard and brittle, or Graphite, which is almost pure carbon and is soft and has little strength. The form the carbon takes is determined by the rate of cooling during solidification, by the influence of other alloying elements and by subsequentthermaltreatment.

In white cast iron, there is little or no graphite in the structure and this is causing the material is very hard and brittle; in contrast to the grey fracture where graphite is present. Where larger proportions of graphite are formed, the shape and size of the graphite has a significant effect on the properties of the cast iron. Other elements which are present in the alloy affect the form of the graphite and the structure and properties of the material matrix. The chemical composition of white cast iron generally conforms to the ranges given in the Table 2.1.

Table 2.1: Chemical composition of white cast iron (Source: Janina M. Radzikowska, 2001)

Element	**Composition (%)**
Carbon	1.8 - 3.6
Silicon	0.5 - 1.9
Manganese	0.25 - 0.80
Sulfur	0.06 - 0.20
Phosphorus	0.06 - 0.20

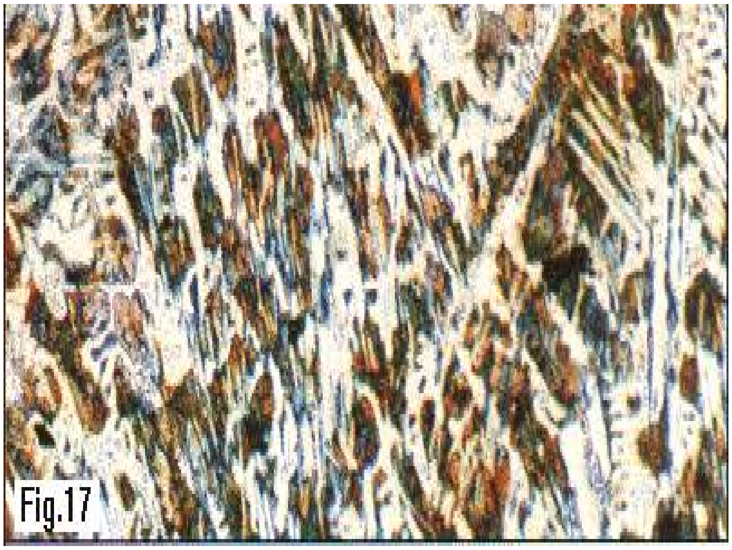

Figure 2.2: Microstructure of white cast iron containing massive cementite (white) and pearlite etched with 4% nital, 100x.

(Source: http://www.metallography.com)

Figure 2.3: High magnification view (400x) of the white cast iron specimen, etched with 4% natal.

(Source: http://www.metallography.com)

2.5 MECHANICAL PROPERTIES

The mechanical properties of a material describe how it will react to physical forces. The mechanical properties of a material are those properties that involve a reaction to an applied load. The mechanical properties of metals determine the range of usefulness of a material and establish the service life that can be expected. Mechanical properties are also used to help classify and identify material. The most common properties considered are strength, ductility, hardness, impact resistance, and fracture toughness. Mechanical properties occur as a result of the physical properties inherent to each material, and are determined through a series of standardized mechanical tests. These are the several mechanical properties for white cast iron.

Table 2.2: Mechanical properties of white cast iron (Source: http://www.matweb.com)

Mechanical Properties	Metric
Hardness, Rockwell	47.1 - 54.4 HRC
Tensile Strength Ultimate	345 – 689 MPa
Modulus of Elasticity	165 – 179 GPa
Izod Impact Unnotched	40.7 – 244 J

2.6 HEAT TREATMENT

Heat treatment involves the improvement of properties of metals and alloys by changing their microstructure. Heat Treating is controlled heating and cooling of a solid metal or alloy by methods designed to obtain specific properties by changing the microstructure. Heat Treating takes place below the melting point of the metal and changes in microstructure take place within the solid metal. Changes in microstructure are due to the movement of atoms within crystal lattices in response to heating or cooling over a period of time. The ability to tailor properties by heat treating has contributed greatly to the usefulness of metals and their alloys in an assortment of applications such as sheet metal for cars and aircraft.

Heat treating processes include annealing, normalizing, tempering, stress relieving, solution treating, age hardening, and bright hardening. Quenching, or cooling from a higher temperature, is an integral part of many heat treating processes when hardening is involved.

2.6.1 Quenching

Quenching is an accelerated method of bringing a metal back to room temperature, preventing the lower temperatures through which the material is cooled from having a chance to cause significant alterations in the microstructure through diffusion. Quenching can be performed with forced air convection, oil, fresh water, salt water and special purpose polymers.

The slower the quench rate, the longer thermodynamic forces have a chance to alter the microstructure, which is in some cases desirable, hence the use of different media. When quenching in a liquid medium, it is important to stir the liquid around the piece to clear away steam from the surface; steam pockets locally defeat the quench by air cooling until they are cleared away.

2.6.2 Quenching Medium

Quenching media is very important to hardening because it is a very effective of hardness of the material.

2.6.2.1 Water

Water is fairly good quenching medium.it is cheap,readily available, easily stored nontoxic nonflammable smokeless and easy to filer and pump but with water quench the formation of bubbles may cause soft spots in the metal.Agitation is recommended with use of water quench.Still other problems with waterquench inclued its oxidizing nature,its corrosivity and the tendency to excessive distortion and cracking although this bad properties for plain carbon steels.

2.6.2.2 Oil

When slower cooling rate is desired oil quenches can be employed.The slower cooling throug the ms to mf temperature range leads to a milder temperature gradient and a reduced likelyhood of cracking.Problems associated with quenchants include water contamination,smoke and fire hazards.in addition quench oils tend to be somewhat expensive.

2.7 MECHANICAL PROPERTIES TESTING

The mechanical properties of a material are those properties that involve a reaction to an applied load. The mechanical properties of metals determine the range of usefulness of a material and establish the service life that can be expected. Mechanical properties are also used to help classify and identify material. The most common properties considered are strength, ductility, hardness, impact resistance, and fracture toughness.

2.7.1 Hardness Testing

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting. Hardness is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value is the result of a defined measurement procedure.

The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry.

Figure 2.4: Hardness Testing Machine

(Source: www.shuennyueh.com)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology can properly refer to the theoretical analysis of the methods appropriate to conduct a project or study which is of most importance to ensure a smooth development of the study.

This chapter provides a discussion of the methodology used in conducting this project from starting until it is completed. The microstructure and hardness of gray cast iron and white cast iron will be investigated.

3.2 DESIGN OF EXPERIMENT

This foundry laboratory was prepared to investigate the effect mechanical properties and change in microstructure of white cast iron using sand casting and heat treatment process. In this process, it consisted of process pattern making, mould making, melting procedure, pouring the molten metal into the mould, felting and then followed by heat treatment process (in order to produce white cast iron). Before run the experiment, a methodology flow chart of experiment flow was shown in Figure 3.2.

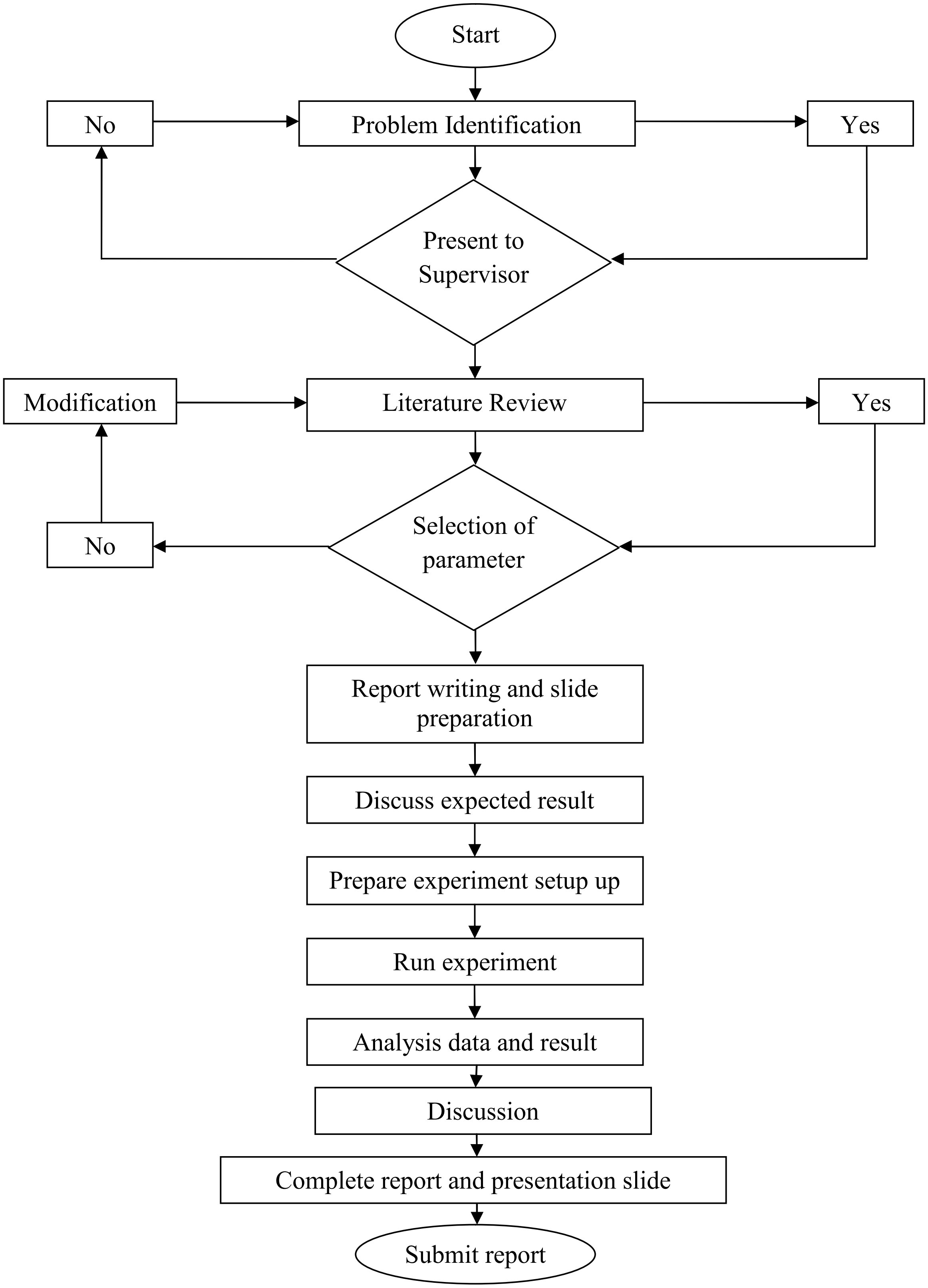

Figure 3.1: Flow chart PSM

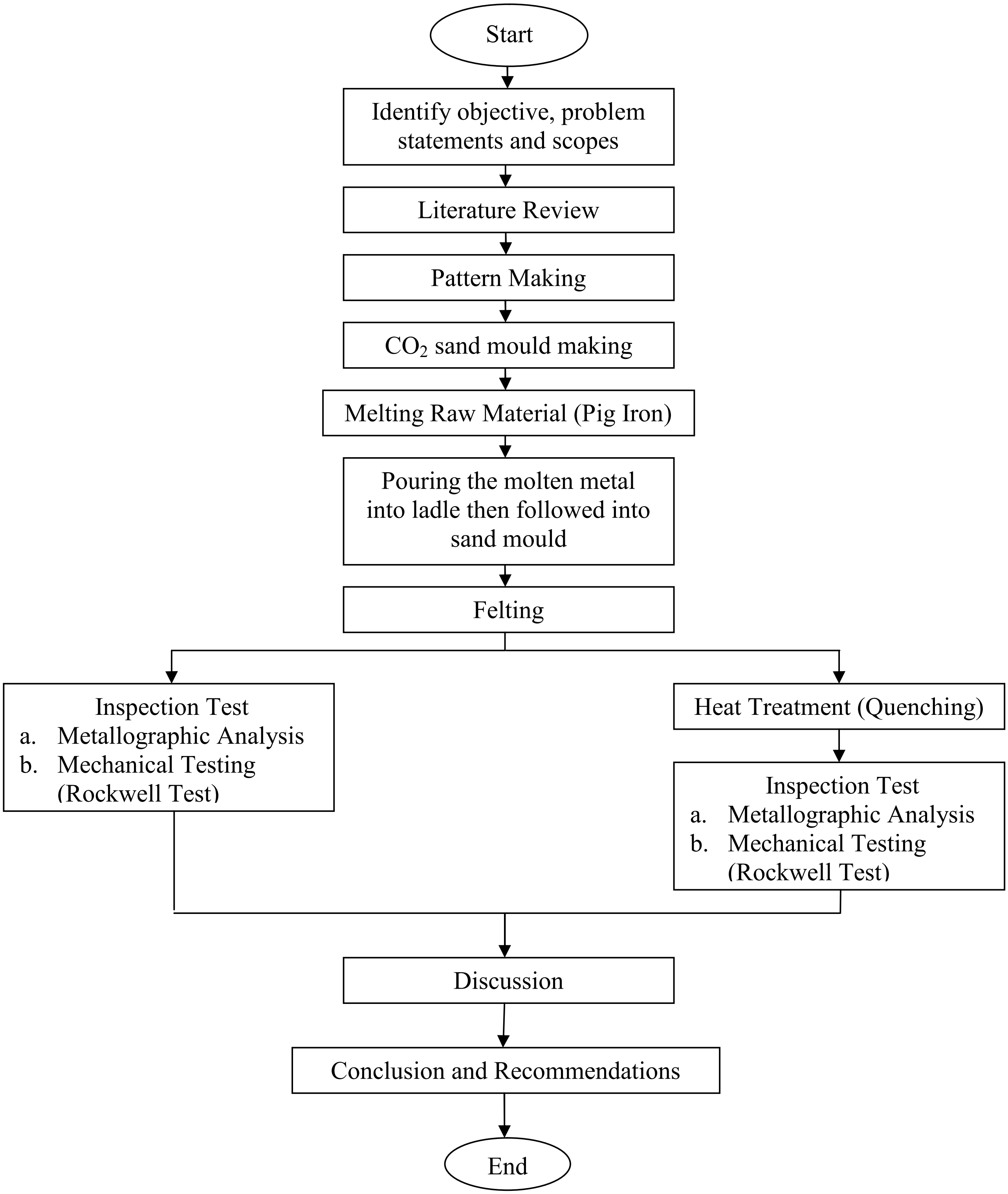

Figure 3.2: Experiment setup

3.3 SAND CASTING PROCESS

Gray cast iron is produced by metal casting. The raw material, pig iron has been used as a fuel and it melted in the furnace at temperatures range 1200^{o}C to 1400^{o}C. The molten metal is then poured into molds that have been made to get the desired form and substance. The material produced is gray cast iron after it has cooled for a while in the mold. Figure 3.3 shows the flow chart of sand casting process.

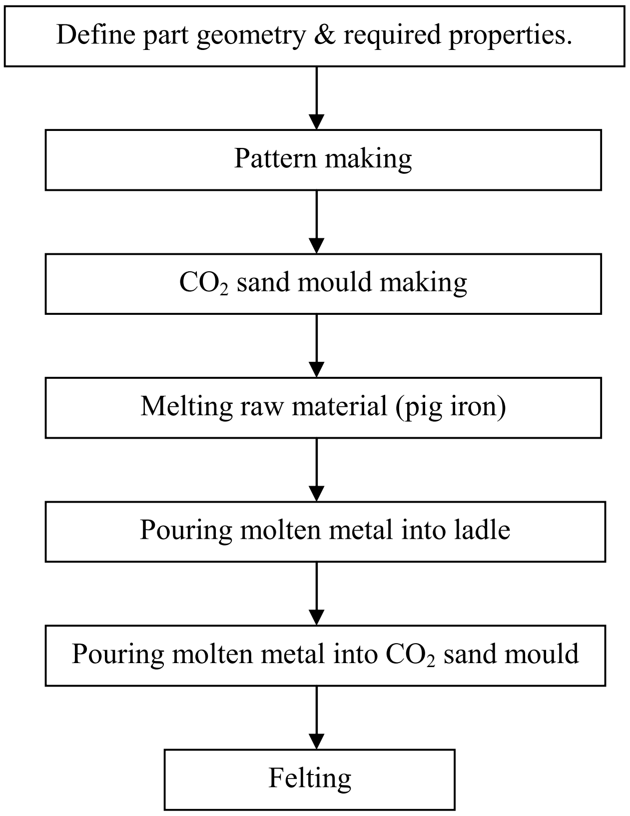

Figure 3.3: Flow chart for sand casting process.

3.3.1 Preparation of Pattern

The pattern should be made first before the metal casting process. The measurement used must be appropriate for the material that will be produced and fulfill the desired pattern. The pattern is made by using wood, and it involves several machining processes such as cutting wood, lathe and grinding processes.

Wood is the pattern material that suitable to use because it is easily to join, work and low cost. In order make the pattern, there must be a draft allowance or tapered allowance to provide on the vertical faces of the removable pattern so that the pattern can withdrawn from the rammed sand without causing the damage to the vertical side without the need for excessive rapping.

Figure 3.4: Top view of pattern design

3.3.2 CO_2 Sand Mould Making

Basically, CO_2 sand mould had better withstanding handling and high metal head pressure. The bonding strength between obtained by the hardening action is sufficient to eliminate baking and drying of the mould. The metal can be poured immediately. For common used of sodium silicate used for CO_2 gas should have a mass ratio varying 2.1 to 2.3 (Jain, 1995).

Muller and mixer are required to ensure proper mixing and dispersion of sand bond with sodium silica. Then, let the Muller machine running for a period of time so that sodium silicate and silica. The sand is continuing rammed so that it is pack and possesses certain strength. After the silica sand is ready, it transferred into drag as shown in Figure 3.5. Before placed the silica sand same height as the drag, the pattern was applied parting powder to help easier remove sand mould. Make some holes on the sand mould before the CO_2 gas was applied on it.

Figure 3.5: A batch muller mixer

3.3.3 Melting Raw Material

The raw material used is pig iron which is put in the furnace and let it melt for a sudden time until the raw material of pig iron from solid form become molten metal. Usually the slag was discovering in the molten metal due to the stirring effect in the furnace. So, a slag catcher is used to filter the slag from the furnace and remove the slag from time to time in order to ensure level of purify molten metal was produced. The sufficient time must be provided before proceed to transport to the ladle for pouring process.

3.3.4 Pouring Molten Metal Into Mould

During the process of pouring, the ladle was use to transfer the molten metal from the furnace to the mould. For the fast pouring will minimize the temperature loss during mould cavity filling and this can reducing the rate of oxidation and metallurgical fade. For constant flow rate of molten metal can help to reduce the defects during the process of solidification.

Figure 3.6: Pouring the molten metal from furnace to ladle

Figure 3.7: Pouring the molten metal from ladle to mould

3.3.5 Felting

The complete process of the cleaning of casting is called felting which is involves the removal of the gate system. This process is separating out the casting product and cleaning the casting surface. First step hammer is used to knock out the casting from the sand mould. Follow by the abrasive cut off to remove the gating system. The last step before go for the inspection parameter is cleaning the sand particle sticking to the casting surface by sand blasting. The casting is kept in the closed box and a jet of compressed air with a blast if sand grains were directed against the casting surface.

3.4 SAMPLE PREPARATION

The specimen preparation process is important to be done for the next process. Small specimens should be obtained to facilitate the process of heat treatment and analysis that will be done next. Besides that, the specimen also necessary to be cleaned on it in order to facilitate the microstructure of the specimen can be seen clearly.

For this part, 3 samples of specimens are needed. The first one is for the gray cast iron analysis and others will be used for the heat treatment process in order to obtain the white cast iron and they also will be analyzed

3.4.1 Surface Grinding

The surface of gray cast iron is then cleaned using a hand grinder. The goal is to remove impurities resulting from the pouring of molten metal during the process of metal casting.

Figure 3.8: Hand Grinder

3.4.2 EDM-Wire Cut

EDM wire cut is a cutter that appropriate to cut the gray cast iron. Gray cast iron is cut into three small specimens to facilitate the process of heat treatment and analysis will be done in the next. The process of wire cut machine is the machine using the process of erosion resulting from the potential difference through a wire. The electrode is a wire coil that continuously rotates and turns over the engine going.

Figure 3.9: EDM-Wire Cut Machine

3.5 GRAY CAST IRON ANALYSIS

The gray cast iron produced by metal casting is investigated in term of its microstructure and mechanical properties. After the preparation process to get the shiny surface of experimental material is done, the experimental material can already test on microscope to view the microstructure. The microstructure's image will be adjusted by the viewer until the image of the structure appearance on screen of computer by using its own software. From that, the image can be seeing clearly. Then, the hardness of gray cast iron is obtained through the related test.

3.6 HEAT TREATMENT (QUENCHING)

This process is important in order to produce the white cast iron. The specimens are heated in heater furnace at 1020°C or 1293 K for 2 hours. (Zhongli Liu, Yanxiang Li, Xiang Chen and Kaihua Hu, 2008). Then the specimens are cooled in the two different medium, water and oil. The first specimen is soaked in the water for 2 seconds and the second specimen is soaked in the oil for 30 seconds.