AN INVESTIGATION OF MICROSTRUCTURE AND MECHANICAL PROPERTIES OF MALLEABLE CAST IRON USING METAL CASTING PROCESS

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

This study is about the investigation of malleable iron microstructure and mechanical properties using metal casting process. Malleable iron, like wrought iron, is not often seen today. Malleable iron starts as a white iron casting that is then heated at about 900°C. It is white iron that has been converted by a two-stage heat treatment to a condition having most of its carbon content in the form of irregularly shaped nodules of graphite, called temper carbon. As stated previously, malleable iron is essentially white cast iron which has been modified by heat treatment. This annealing process is carefully controlled and can last for several days. The resulting crystalline structure makes the iron more ductile than it would normally be. It has greater ductility than gray cast iron because of its carbon content (2.5wt %), silicon content (1.0wt %), and manganese content (0.55wt %). The microstructure of malleable iron is irregularly shaped nodules of graphite in more compact or sphere form that gives malleable iron ductility and strength almost equal to cast. In this study, sand casting process is choose, where CO_2 sand will be used as a mould. The raw material that will be used is pig iron for the experiment. While the microstructure and mechanical investigation consist of hardness of the material, carbon content, and the composition of the material before and after metal casting process.

1.2 PROBLEM STATEMENT

Malleable cast irons may often be used in place of steel at considerable cost savings. The design and production advantages of malleable cast iron include low tooling, and production cost, good machinability without burring and also ability to cast into complex shapes. But the microstructure and mechanical properties of malleable cast iron is affected by following factors, such as chemical composition of the iron, rate of annealing and also the type of graphite formed (if any). From these studies, different annealing rate was used in order to develop the mechanical properties and microstructure of malleable iron.

1.3 OBJECTIVES

The objectives of this project are:

(i) To determine the processing method of malleable cast iron using metal casting process that is sand casting.

(ii) To study the effect of different annealing rate to the mechanical properties of malleable cast iron.

(iii) To investigate the difference in microstructure and mechanical properties of the malleable cast iron using different annealing rate process.

1.4 SCOPE OF PROJECT

The scopes of the project are:

(i) The CO_2 sand was used as a mould in this project.

(ii) The raw material that was used is pig iron to produce malleable cast iron.

(iii) The effect on microstructure and mechanical properties composition of malleable cast iron using different annealing rate process which consist of hardness, tensile strength, and carbon content.

1.5 OVERVIEW OF REPORT

Chapter 1 mainly briefs about the background of the project which involves the introduction, problem statements, objectives and scopes of the report. Chapter 2 basically describes more about the studies on microstructure and mechanical properties of malleable cast iron which has been done earlier by other scientists and engineers. Whereas Chapter 3 introduces the experimental procedure utilized to characterize the malleable cast iron studies the step by step process that will be done during this project. Chapter 4 mainly discuss about the results obtained during the experiment. Last but not least, Chapter 5 discuss about the conclusions that can be derived from this report and suggest few future recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, it basically describes more about the studies on microstructure and mechanical properties of malleable cast iron which has been done earlier by other scientists and engineers. Therefore, it also discussed about the heat treatment process and sand casting process which has been used in this experiment.

2.2 MALLEABLE CAST IRON

Malleable cast iron or malleable iron, as it is normally called, is made from pig iron low in silicon, sulphur and phosphorus, and from which the carbon has subsequently been largely removed by annealing a heat-treated iron-carbon alloy, which solidifies in the as-cast condition with a graphite-free structure, i.e. the total carbon content is present in the cementite form (Fe_3C). Two groups of malleable cast iron are specified (whiteheart and blackheart malleable cast iron), differentiated by chemical composition, temperature and time cycles of the annealing process, the annealing atmosphere and the properties and microstructure resulting there from. Malleable iron is made from white cast iron by annealing it at temperatures from 816°C to 1010°C over several days. When annealed, the iron carbide breaks up, producing rosettes of graphite. The iron is known for its shock resistance, strength, machinability, and ductility. Products such as engine blocks, iron ornaments, and valves can be made from malleable iron castings. The automotive, railroad, construction, agricultural implement, and hardware industries have wide uses for malleable iron castings (Fatahalla and Bahi, 1996).

2.2.1 Types of malleable cast iron

There are two types of malleable cast iron available. They are whiteheart malleable cast iron and blackheart malleable cast iron. The microstructure of whiteheart malleable cast iron depends on section size. Small sections contain pearlite and temper carbon in ferritic substrate. In the large sections exists three different zones: surface zone which contains pure ferrite, intermediate zone which has pearlite, ferrite and temper carbon, and core zone containing pearlite, temper carbon and ferritic inclusions. The microstructure shall not contain flake graphite as shown in Figure 2.1(Chao et al., 1989).

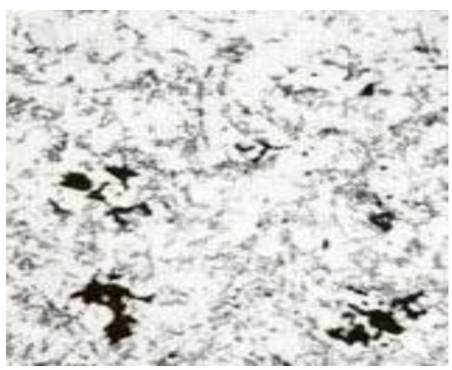


Figure 2.1: Whiteheart malleable iron

Source: Chao et al., 1989

The microstructure of blackheart malleable cast iron has a matrix essentially of ferrite. The microstructure of pearlitic malleable cast iron has a matrix, according to the grade specified, of pearlite or other transformation products of austenite. Graphite is present in the form of temper carbon nodules as shown in Figure 2.2. The microstructure shall not contain flake graphite (Chao, 1989).

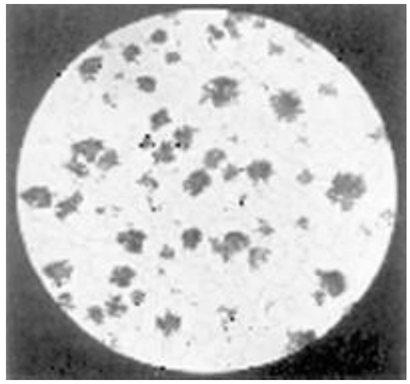


Figure2.2: Blackheart malleable iron

Source: Chao et al., 1989

2.2.1 Chemical Composition of Malleable Iron

The chemical composition of malleable iron generally conforms to the ranges given in the Table 2.1. Small amounts of chromium (0.01 to 0.03%), boron (0.0020%), copper (≤ 1.0%), nickel (0.5 to 0.8%), and molybdenum (0.35 to 0.5%) are also sometimes present (Forrest, 2003).

Table 2.1: Chemical composition of malleable iron

Element	Composition (%)
Carbon	2.16-2.90
Silicon	0.90-1.90
Manganese	0.15-1.25
Sulfur	0.02-0.20
Phosphorus	0.02-0.15

2.2.2 Microstructure of Malleable Iron

Figure 2.3 shows the equilibrium diagram for combinations of carbon in a solid solution of iron. The diagram shows iron and carbons combined to form $Fe-Fe_3C$ at the 6.67%C end of the diagram. The left side of the diagram is pure iron combined with carbon, resulting in steel alloys. Three significant regions can be made relative to the steel portion of the diagram. They are the eutectoid E, the hypoeutectoid A, and the hypereutectoid B. The right side of the pure iron line is carbon in combination with various forms of iron called alpha iron (ferrite), gamma iron (austenite), and delta iron. The black dots mark clickable sections of the diagram.

Allotropic changes take place when there is a change in crystal lattice structure. From 2802º-2552ºF the delta iron has a body-centered cubic lattice structure. At 2552ºF, the lattice changes from a body-centered cubic to a face-centered cubic lattice type. At 1400ºF, the curve shows a plateau but this does not signify an allotropic change. It is called the Curie temperature, where the metal changes its magnetic properties.

Two very important phase changes take place at 0.83%C and at 4.3% C. At 0.83%C, the transformation is eutectoid, called pearlite. At 4.3% C and 2066ºF, the transformation is eutectic, called ledeburite (Davis, 1996).

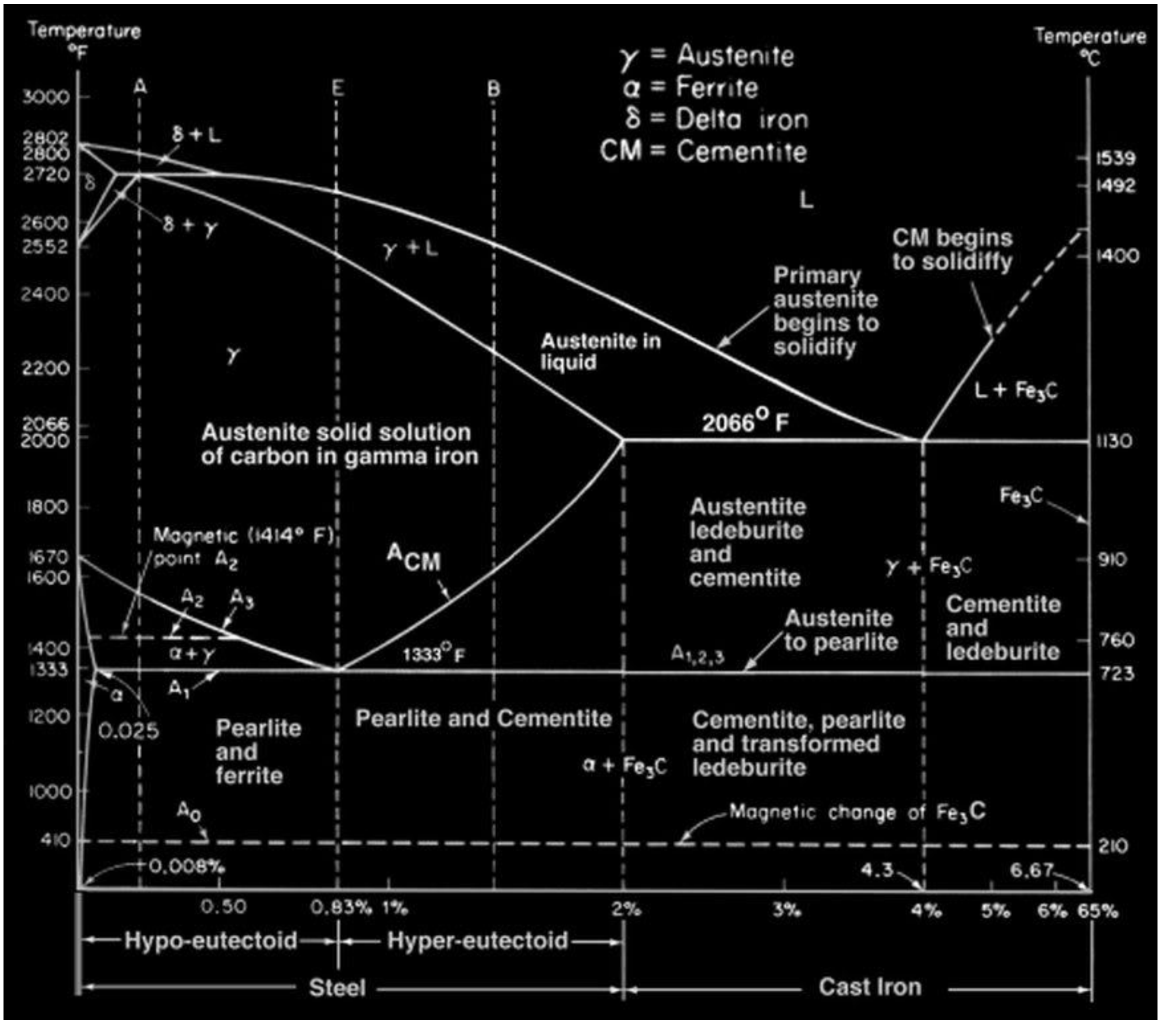


Figure 2.3: Fe-Fe_3C Phase Diagram.

Source: Davis, 1996

2.2.4 Mechanical Properties of Malleable Iron

Malleable iron, like ductile iron, possesses considerable ductility and toughness because of its combination of nodular graphite and low-carbon metallic matrix. Because of the way in which graphite is formed in malleable iron, however, the nodules are not truly spherical as they are in ductile iron but are irregularly shaped aggregates. It can be specified either by its tensile properties or by hardness of the casting. Unless the relationship between the test bar properties and the specific casting hardness is established, both strength and hardness should not be specified together. ASTM Specification A220 defines eight grades of pearlitic malleable iron with increasing strength and decreasing ductility. Specification A47 is for ferritic malleable iron, which has the lowest strength and highest ductility. The tensile properties of malleable iron are determined with a 0.625-in. (16-mm) diameter cast-to-size test bar. Machining these test bars before testing has only a slight effect on the properties (Kumari R.U. and Rao P.P.,2009).

Malleable iron and ductile iron are used for some of the applications in which ductility and toughness are important. In many cases, the choice between malleable and ductile iron is based on economy or availability rather than on properties. In certain applications, however, malleable iron has a distinct advantage. It is preferred for thin-section castings are for parts that are to be pierced, coined, or cold formed, for parts requiring maximum machinability, for parts that must retain good impact resistance at low temperatures, and for parts requiring wear resistance(martensitic malleable iron only).

Malleable iron is ideal for thin-sectioned components that require ductility. Ferritic malleable iron is produced to a lower strength range than pearlitic malleable iron but with higher ductility. It is the most machinable of cast irons, and it can be die-strengthened or coined to bring key dimensions to close tolerance limits. However, ductile iron is replacing malleable iron in many different applications because the engineering properties of ductile iron are almost identical to that of malleable iron, and ductile iron does not require extensive heat treatment to precipitate graphite.The mechanical properties of test pieces of malleable cast iron shall be in accordance with the values listed in Table 2.2 and Table 2.3. (Putatunda et al., 2006).

Table 2.2: Mechanical properties of whiteheart malleable cast iron

Designation	Diameter of test piece mm	Tensile strength N/mm²	0,2% proof stress N/mm²	Elongation (L_0 = 3d) % min	Hardness HB
W 35-04	9 - 15	340 - 360	-	5 - 3	230
W 38-12	9 - 15	320 - 380	170 - 210	15 - 8	200
W 40-05	9 - 15	360 - 420	200 - 230	8 - 4	220
W 45-07	9 - 15	400 - 480	230 - 280	10 - 4	220

Table 2.3: Mechanical properties of blackheart malleable cast iron

Designation	Diameter of test piece mm	Tensile strength N/mm²	0,2% proof stress N/mm²	Elongation (L_0 = 3d) % min	Hardness HB
B 30-06	12 - 15	300	-	6	150 max
B 32-12	12 - 15	320	190	12	150 max
B 35-10	12 - 15	350	200	10	150 max
P 45-06	12 - 15	450	270	6	150-200
P 50-05	12 - 15	500	300	5	160-220
P 55-04	12 - 15	550	340	4	180-230
P 60-03	12 - 15	600	390	3	200-250
P 65-02	12 - 15	650	430	2	210-260
P 70-02	12 - 15	700	530	2	240-290

Source: Putatunda et al., (2006).

Ductile iron has a clear advantage where low solidification shrinkage is needed to avoid hot tears or where the section is too thick to permit solidification as white iron (Solidification as white iron throughout a section is essential to the production of malleable iron).Malleable iron castings are produced in section thicknesses ranging from about 1.5 to 100 mm and in weights from less than 0.03 to 180 kg or more (Putatunda et al., 2006).

2.3 HEAT TREATMENT PROCESS

Heat treatment is a process where the metal is heated and then cooled at a controlled temperature to alter their physical and mechanical properties without changing its original shape. The objective of heat treatment is to improve machining, improve formability, and also restore ductility after a cold working operation.

Through heat treating, we can make a metal harder, stronger, and more resistant to impact. Also, heat treating can make a metal softer and more ductile. Successful heat treatment requires close control over all factors affecting the heating and cooling of a metal. This control is possible only when the proper equipment is available. The furnace must be of the proper size and type and controlled, so the temperatures are kept within the prescribed limits for each operation. Even the furnace atmosphere affects the condition of the metal being heat-treated (Hafiz, 2001).

2.3.1 Types of heat treatment

The various types of heat-treating processes are similar because they all involve the heating and cooling of metals; they differ in the heating temperatures and the cooling rates used and the final results. Four basic types of heat treatment are used today. They are annealing, normalizing, hardening, and tempering.

Annealing is a process done to relieve internal stresses, soften, make them more ductile, and refine their grain structures. Annealing consists of heating a metal to a specific temperature, holding it at that temperature for a set length of time, and then cool the metal to room temperature. The cooling method depends on the metal and the properties desired.

Normalizing is a type of heat treatment applicable to ferrous metals only. It differs from annealing in that the metal is heated to a higher temperature and then removed from the furnace for air cooling. The purpose of normalizing is to remove the internal stresses induced by heat treating, welding, casting, forging, forming, or machining. In normalizing, the mass of metal has an influence on the cooling rate and on the resulting structure.

The hardening treatment for most steels consists of heating the steel to a set temperature and then cooling it rapidly by plunging it into oil, water, or brine. Most steels require rapid cooling (quenching) for hardening but a few can be air-cooled with the same results. Hardening increases the hardness and strength of the steel, but makes it less ductile. Generally, the harder the steel, the more brittle it becomes. To remove some of the brittleness, you should temper the steel after hardening.

Pure iron, wrought iron, and extremely low-carbon steels have very little hardening properties and are difficult to harden by heat treatment. Cast iron has limited capabilities for hardening. When you cool cast iron rapidly, it forms white iron, which is hard and brittle. And when you cool it slowly, it forms gray iron, which is soft but brittle under impact.

As the carbon content increases, the hardening ability of the steel increases; however, this capability of hardening with an increase in carbon content continues only to a certain point. In practice, 0.80 percent carbon is required for maximum hardness. When you increase the carbon content beyond 0.80 percent, there is no increase in hardness, but there is an increase in wear resistance.

Tempering consists of heating the steel to a specific temperature (below its hardening temperature), holding it at that temperature for the required length of time, and then cooling it, usually instill air. The resultant strength, hardness, and ductility depend on the temperature to which the steel is heated during the tempering process.The purpose of tempering is to reduce the brittleness imparted by hardening and to produce definite physical properties within the steel. Besides reducing brittleness, tempering softens the steel. Tempering relieves quenching stresses and reduces hardness and brittleness. Actually, the tensile strength of a hardened steel may increase as the steel is tempered up to a temperature of about 450°F.Above this temperature it starts to decrease. Tempering increases softness, ductility, malleability, and impact resistance. (Stokes, B.et al., 2006).

2.3.2 Heat Furnace

Laboratory furnaces as shown in Figure 2.4 provide continuous heating to process samples and materials. They are generally built from high temperature (refractory) materials so that they can maintain high temperatures without breaking down. Often, laboratory furnaces are set to function for months at a time to complete a processing set (Chao et al., 1989).

Figure 2.4: Laboratory Heat Furnace

2.3.3 Sand Casting

Sand casting is an economical process for creating rough metal parts. Raw castings are then machined into finished products or components. Sand casting is the least expensive of all the casting processes, including die and investment casting. In the sand casting process, a pattern is made in the shape of the desired part. The pattern is typically made of wood, plastic, or metal. A single piece or solid pattern is used for simple designs.

Patterns that are more complex are made in two parts, called split patterns. The upper part of a split pattern is called a cope, while the bottom section is called a drag where the cope and drag separate is known as the parting line. Both solid and split patterns can have cores inserted to complete the final part shape. When making a pattern, it is necessary to taper the edges so the pattern can be removed without breaking the mold (Davis, 1996).

2.3.4 Process Cycle

The process cycle for sand casting consists of six main stages. The first step in the sand casting process is to create the mold for the casting. A sand mold is formed by packing sand into each half of the mold. The sand is packed around the pattern, which is a replica of the external shape of the casting. When the pattern is removed, the cavity that will form the casting remains. The second step is clamping process. Once the mold has been made, it must be prepared for the molten metal to be poured. The surface of the mold cavity is first lubricated to facilitate the removal of the casting. Then, the cores are positioned and the mold halves are closed and securely clamped together. It is essential that the mold halves remain securely closed to prevent the loss of any material. The third step is pouring the molten metal. The molten metal is maintained at a set temperature in a furnace. After the mold has been clamped, the molten metal can be ladled from its holding container in the furnace and poured into the mold as shown in Figure 2.5.

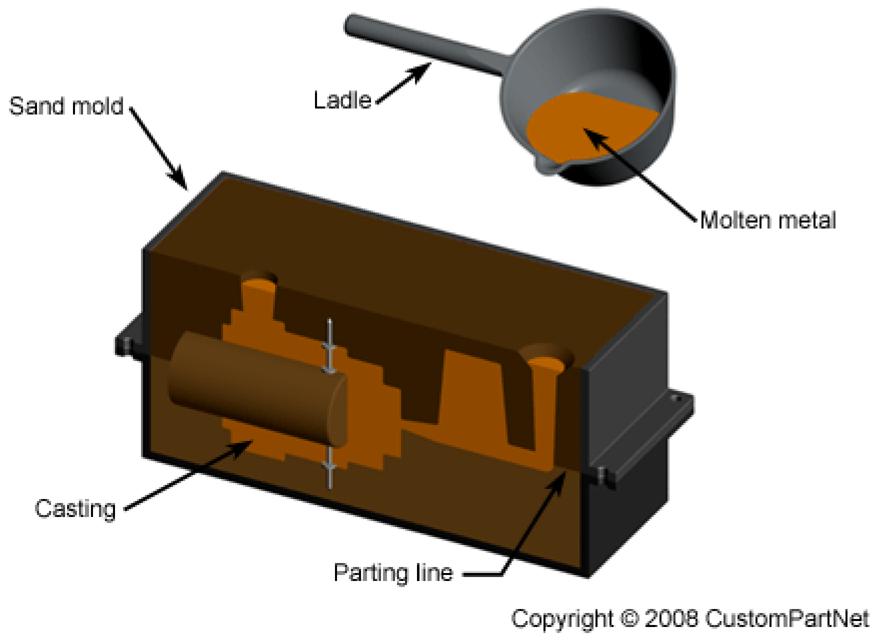


Figure 2.5: Pouring process

Source: Kumari R.U. and Rao P.P.,(2009).

The fourth step is cooling stage. The molten metal that is poured into the mold 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 mold can not 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. The fifth step is removal process where the sand mold can simply be broken, and the casting removed. Once removed, the casting will likely have some sand and oxide layers stick onto the surface. The last step is trimming process. During cooling, the material from the channels in the mold solidifies attached to the part. This excess material must be trimmed from the casting manually via cutting or sawing (Davis, 1996).

2.3.5 Sand

The sand that is used to create the molds is typically silica sand (SiO_2) that is mixed with a type of binder to help maintain the shape of the mold cavity. Using sand as the mold material offers several benefits to the casting process. Sand is very inexpensive and is resistant to high temperatures, allowing many metals to be cast that have high melting temperatures (Davis, 1996).

2.4 MECHANICAL TESTING

There are two mechanical testing that will be done on the malleable cast iron. They are Rockwell Hardness Testing and Ultimate Tensile Strength.

2.4.1 Rockwell Hardness Testing

The Rockwell Hardness test uses a machine to apply a specific load and then measure the depth of the resulting impression. The indenter may either be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120° angle and 0.2 mm tip radius, called a brale. A minor load of 10 kg is first applied, which causes a small initial penetration to seat the indenter and remove the effects of any surface irregularities. Then, the dial is set to zero and the major load is applied. Upon removal of the major load, the depth reading is taken while the minor load is still on. The hardness number may then be read directly from the scale. The indenter and the test load used determine the hardness scale that is used (A, B, C).

In testing harder materials, hard cast iron and many steel alloys, a 120 degrees diamond cone is used with up to a 150 kilogram load and the hardness is read on the "C" scale. There are several Rockwell scales other than the "B" & "C" scales, (which are called the common scales). Below are the common scales used in laboratory (Hafiz, 2001):

Scale	Materials
A	Cemented carbides, thin steel and shallow case hardened steel
B	Copper alloys, soft steels, aluminum alloys, malleable iron, etc.
C	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel and other materials harder than B 100
D	Thin steel and medium case hardened steel and pearlitic malleable iron
E	Cast iron, aluminum and magnesium alloys, bearing metals
F	Annealed copper alloys, thin soft sheet metals
G	Phosphor bronze, beryllium copper, malleable irons
H	Aluminum, zinc, lead
K,L,M,P,R,S,V	Bearing metals and other very soft or thin materials,including plastics.

2.4.2 Ultimate Tensile Strength

The ultimate tensile strength (UTS) is the maximum resistance to fracture. It is equivalent to the maximum load that can be carried by one square inch of cross-sectional area when the load is applied as simple tension. It is expressed in pounds per square inch. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength and other tensile properties. The stress-strain curve as in Figure 2.6 relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. A typical engineering stress-strain curve is shown below. If the true stress, based on the actual cross-sectional area of the specimen, is used, it is found that the stress-strain curve increases continuously up to fracture (Hafiz , 2001).

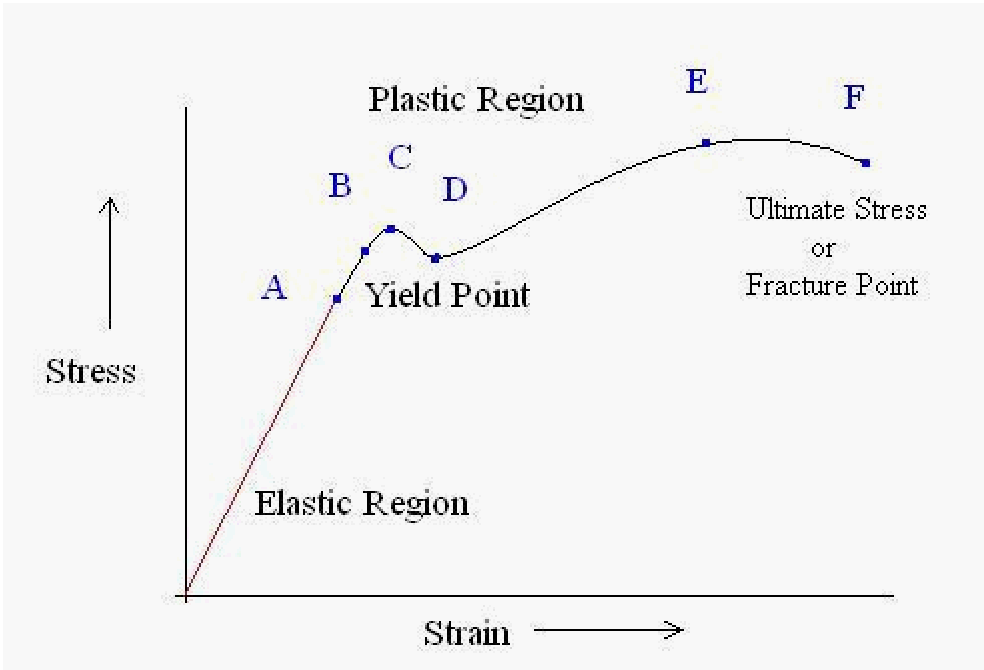


Figure 2.6: Stress-strain curve

2.5 CONCLUSIONS

From the available literature, it is quite evident that many attempts were made to understand and predict the behaviors of malleable iron that includes the study of graphite morphology and its evolution, the response of the microstructure upon heat treatment, and the mechanical properties correlation and also possible applications.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter introduces the experimental procedure utilized to characterize the malleable cast iron studies the step by step process that will be done during this project. This project is being done to find the various mechanical properties and microstructure of malleable cast iron before and after metal casting process and also using different annealing rate. During the experiment, we will be using three different types of specimen in order to observe the difference in microstructure and mechanical properties. With the use of different annealing rate of heat treatment, it might influence which will give different performance of mechanical properties and microstructure after through the post processing. The flow chart in Figure 3.1 shows the overall flow of project in step by step process.

3.2 FLOW CHART

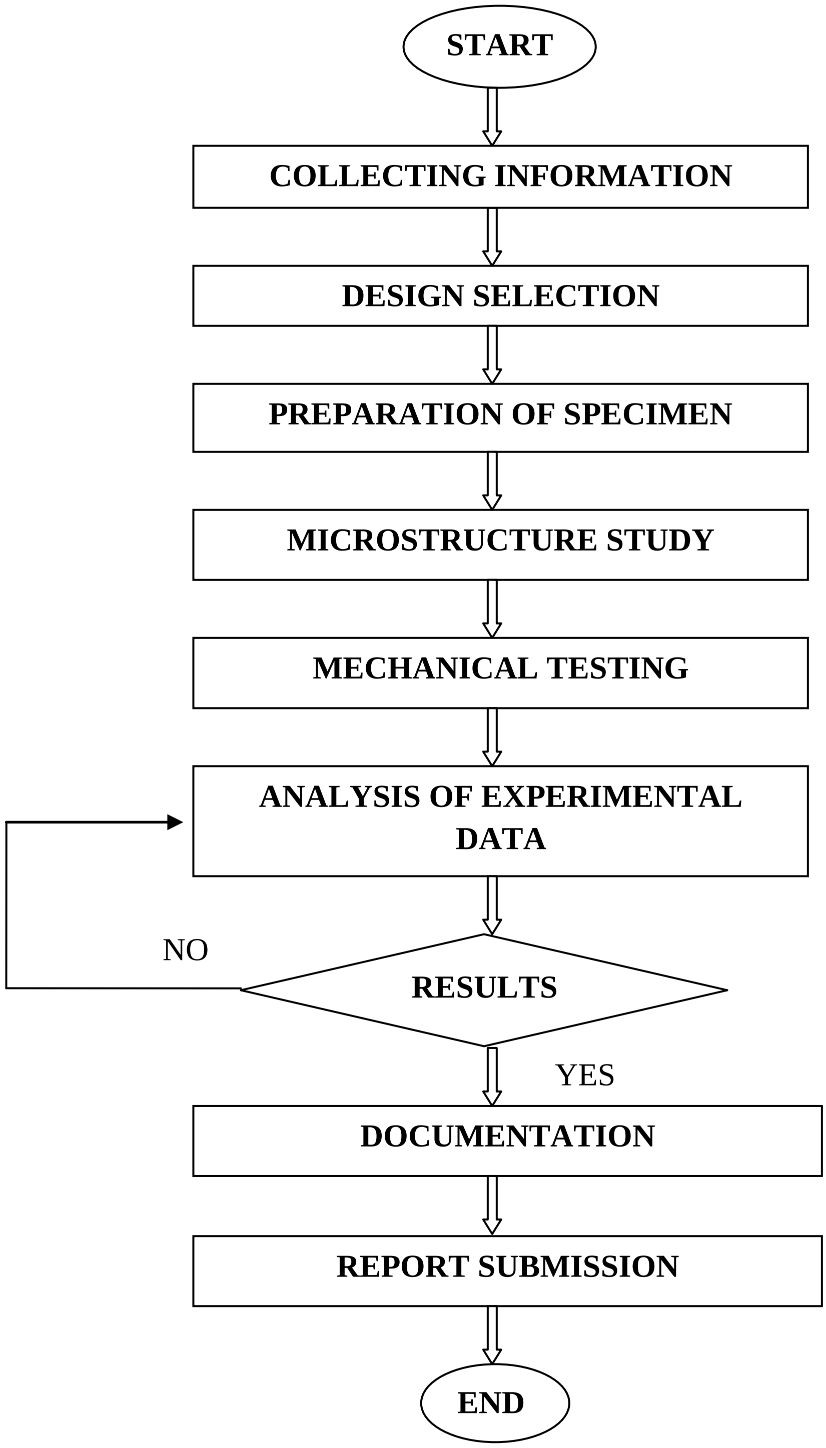


Figure 3.1: Process flow chart of study

3.3 FLOW CHART DESCRIPTIONS

3.3.1 Design Selection

The design that has been selected for this project is a rod shape (Figure 3.2). The shape is selected to be used for the ease of machinability. The specimen will be used for the Rockwell hardness testing, and to investigate the microstructure of the malleable cast iron.

Figure 3.2: Rod shape specimen

Source: Kumari R.U. and Rao P.P.,(2009).

3.3.2 Preparation of specimen

Pig iron or iron ore will be used as a raw material in this project (Figure 3.3). The iron ore which was made in the standardized composition grades of required dimensions will be purchased from the local market and the specimen for this project will be prepared from it. The composition study on pig iron will be done using spectrometer. The major composition of pig iron is iron (Fe) with (wt 88%). Table 3.1 shows the average composition for every element in (wt%) in the pig iron.

Figure 3.3: Pig iron

Source : Putatunda et al., (2006)

Table 3.1: Composition of pig iron base on spectrometer view.

Element	Wt %	Element	Wt %
Fe	88.8	Ni	0.101
C	>4.50	Al	0.0128
Si	2.09	Co	<0.010
Mn	0.571	Cu	0.401
P	0.0668	Nb	0.0153
S	0.0269	Ti	0.0485
Cr	0.0125	V	<0.005
Mo	<0.01	W	0.269
Pb	<0.05		

3.3.3 Preparation of Molds

In this section, a detailed explanation is given about the preparation of the molds into which the molten iron is poured. All molds are made from patterns which are made of wood. The molds are supported by and enclosed in a flask, which are also made of wood. The most common materials for molding are sand, either dry or green, loam, plaster of Paris or iron. In this project, CO_2 sand was used. The iron molds are permanent molds. Cavities in the castings are formed by the use of cores, which are made of CO_2 sand. In molding, the sand is rammed up around the pattern, and the pattern is removed. The impression left in the sand represents the shape of the casting to be made.

3.3.4 Casting Process

The pig iron is now heated at about 900^{o}C (1,650^{0}F) with a hematite substance in the furnace. When the iron is poured into the mold it fills the impression, and the result is a "hard iron" casting. The molds are poured by the use of clay lined hand ladles. After the molds have been poured they are allowed to cool, and the castings solidify. The castings are removed from the sand and the feeders and gates are knocked off. This is easily possible because the hard iron is extremely brittle (Putatunda et al., 2006).

3.3.5 Heat Treatment

Each different type of malleable iron has a different method of processing. Malleable iron is a white iron that has been converted by a two-stage heat treatment to a condition having most of carbon content in the form of irregularly shaped nodules of graphite, called temper carbon. It is obtained when white cast iron is heated to 760°C for 24 hours per each 25 mm of thickness and then cooled slowly. This heat treatment converts graphite from flake form to quasi-spheroidal shape. The graphite has a flake appearance, it possesses a quasi-spheroidal (temper carbon) appearance in malleable iron (Hafiz, 2001).

Quenching is generally done by cooling at a sufficiently high rate to avoid undesirable internal microstructure as well as to ensure uniform mechanical properties, minimize residual stresses, and avoid warpage. For the experiment, air quenching is used where just to let the specimens expose to the temperature room.

When ready for annealing, the castings should be brushed and packed in iron boxes, each casting being surrounded by a mixture of fresh hematite (red iron ore), hematite already used in the annealing process, and iron scale from the rolling-mills. The box is covered up, placed in an annealing oven, and fired at a bright red heat for from three to seven days. After withdrawing from the furnace, the boxes are allowed to cool, and the castings are cleansed from the adhering ore. The castings will now be tough, strong, flexible, and much softer, and may be forged. At end of the process, malleable cast iron will be produced. If the process has not been carried far enough, there will remain a core of unconverted iron. Cast-iron contains a high percentage of carbon, whilst the converting material is rich in oxygen. It is generally considered that the change which takes place is due to the oxidation of the carbon contained in the iron (Shaker M.A.,1992).

3.3.6 Grinding Process

The specimens for microstructure examination were prepared by grinding to obtain the smooth and flat surface of material. The grinding is prepared on hand grinding deck of abrasive papers of grades 240, 400 and 600. The grinding process must begin from smoothest abrasive paper to rough types. Every change of the abrasive paper, rotate the material on 90°. After this process, the materials are washed with acetone and dried. The process is shown in Figure 3.4.

Figure 3.4: Grinding process

3.3.7 Polishing Process

After the grinding process have done ,the experimental material need to polish by Polisher-Grinder Metaserv (PGM) with suitable abrasive materials to make a surface of material more shinning.6 micron,1 micron and 0.5 micron solution diamond of abbrasive materials is used for this polishing process. The thoroughly polished specimen was washed in warm water and swabbed with mentholated spirit and dried using warm air as shown in Figure 3.5(a),(b), and (c).

(a) 6 micron solution

(b) 1 micron solution

(c) 0.5 micron solution

Figure 3.5: Polisher-grinder Meserv for various size.

3.3.8 Optical Investigation

The study on microstructure of malleable iron before and after metal casting process is done. During the observation, microstructures, grain sizes, defects, textures, and also the compositions of carbon content are observed. The observation is done with the aid of optical microscope. The surface of the specimen to be examined is seen through "Progress Capture" software. The image seen, which may be photographed, represents the surface features of the specimen as in Figure 3.6.

Figure 3.6: Optical Microscope.

3.3.9 Mechanical testing

For the mechanical testing, tensile test and hardness test will be performed. The heat treated samples were polished in emery papers (or SiC papers) of different grades for hardness measurement. The hardness test measures the resistance of the material to a permanent indention of particular geometry over a specified length of time. Rockwell Hardness test was performed at room temperature to measure the macro hardness of the malleable cast iron specimens in A scale. The load was applied through the square shaped diamond indenter for few seconds during testing of all the samples. Four measurements for each sample were taken covering the whole surface of the specimen and averaged to get final hardness results. A load of 60 kg was applied to the specimen for 30 seconds. Then the depth of indentation was automatically recorded on a dial gauge in terms of arbitrary hardness numbers. Then these values were converted to in terms of required hardness numbers (as Brinell's or Vicker's hardness numbers. As for the tensile testing, the main objective of tensile test is to determine its ultimate tensile strength, where the maximum load sustains the specimen during the test.

3.3.11 Conclusions

The experimental procedures are utilized to characterize the malleable cast iron studies. The samples were taken in a group for each different annealing rate that being used. Rockwell Hardness test was performed at room temperature to measure the macro hardness of malleable cast iron specimens. Tensile test were also carried out to record the tensile strength of the heat treated specimens. The samples were also prepared for microstructural analysis. The data collected were presented in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter mainly discuss about the results obtained during the experiment. The tests that have been done during this experiment are tensile test, Rockwell hardness test and microstructure observations.

4.2 MECHANICAL PROPERTIES

The mechanical properties were measured by using Instron 1195 and dimensions of specimen was carried out according to ASTM A602-94(2009), are given in Table 4.1, lists the mechanical properties which are tensile strength, % elongation and hardness of malleable cast iron using three different annealing rates.

Table 4.1: Mechanical Properties of malleable cast iron

Annealed	**UTS(MPa)**	**%Elongation**	**Hardness(RA)**
Day 3	371.3	19.05	49
Day 4	368.2	18.60	48
Day 5	363.1	18.00	47

4.2.1 Hardness Measurement

Figure 4.1 shows that hardness decreases as the annealing rate was prolonged. This is due to decrease of tensile strength with increasing of annealing rate. This is due to the spheroidal graphite embedded in a ferrite matrix. The hardness of malleable cast iron specimens ranges from 45-50 RA.

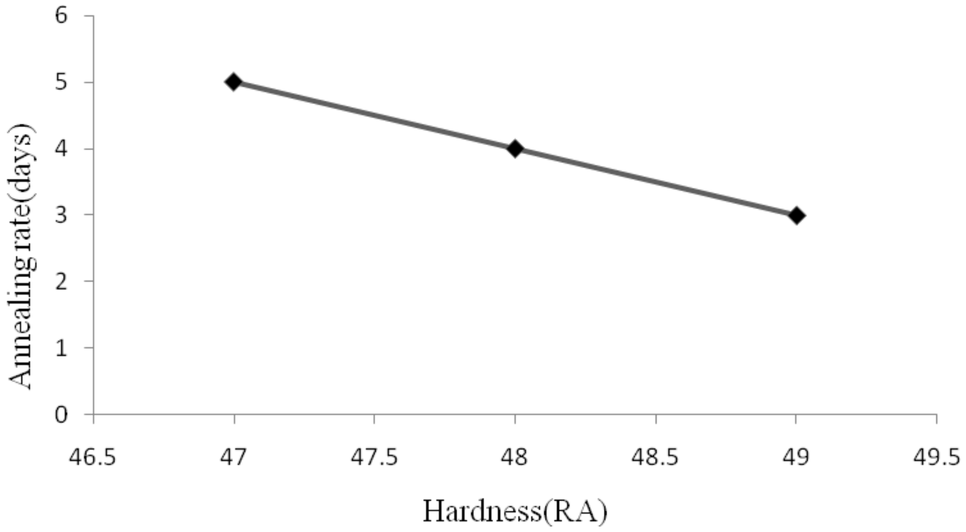


Figure 4.1: Annealing rate versus hardness

4.2.2 Tensile Strength and Elongation

Figure 4.2 and Figure 4.3 show the graph of tensile strength versus annealing rate and percent of elongation versus annealing rate respectively. From the graphs, it is observed that, there is a slight change in their properties. The U.T.S of annealed samples keeps on decreasing as the rate of annealing increases. Annealed samples tend to have lower tensile properties. The percentage of elongation also keep decreasing because the formation of martensite. Although malleable cast iron shows higher ductility, but it has lower values of hardness and strength.

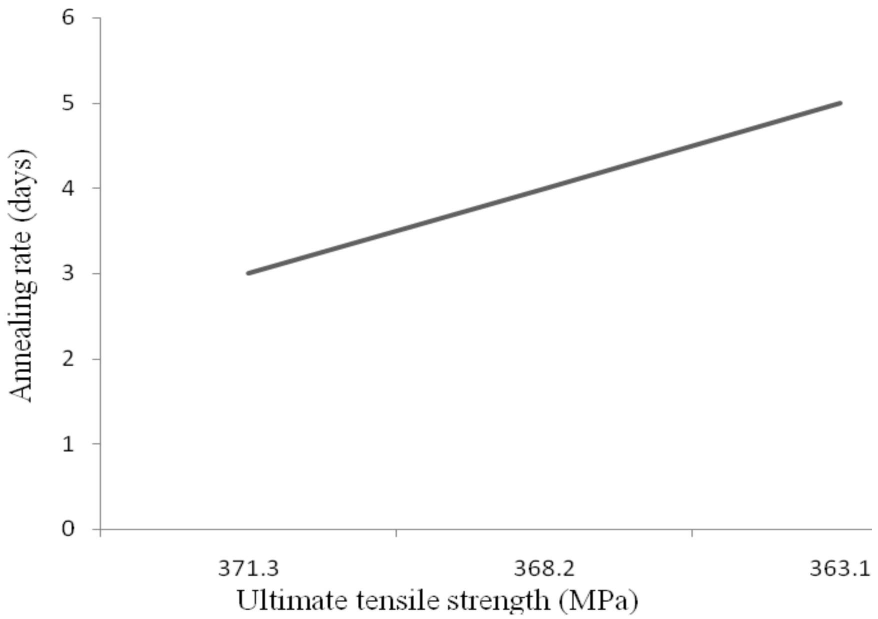


Figure 4.2: Annealing rate versus ultimate tensile strength

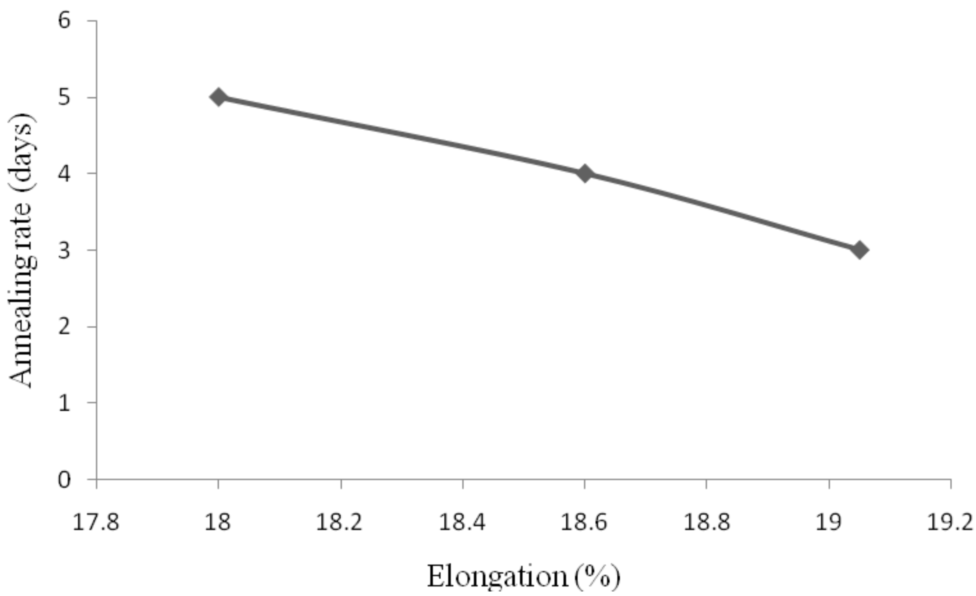
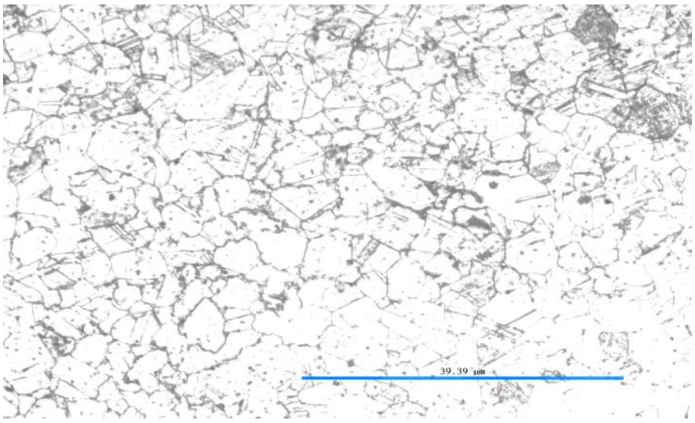


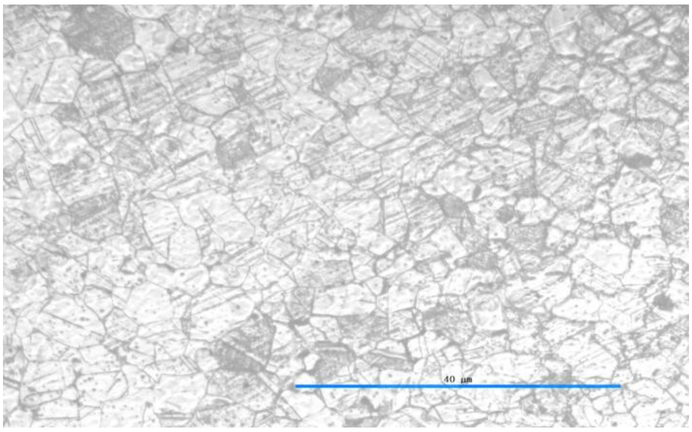
Figure 4.3: Annealing rate versus percent of elongation

4.3 MICROSTRUCTURE OBSERVATION

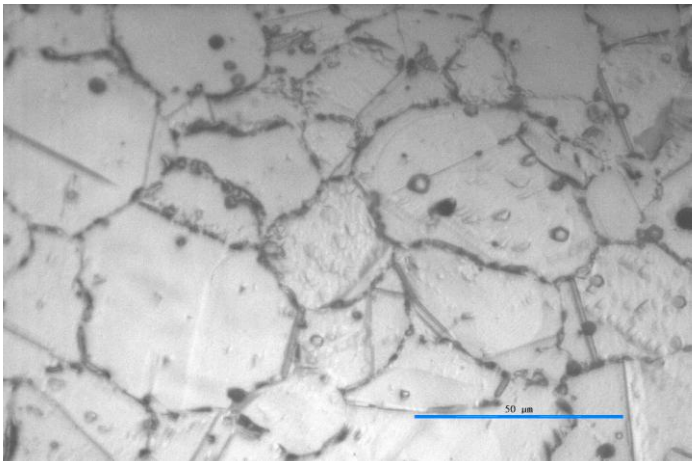
From the microstructure studies, these are the results that obtained. Figure 4.4 (a), (b), and (c) show the observed microstructure according to the number of days the samples were annealed. After annealing treatment, the microstructure consists of spheroidal graphite embedded in a ferrite matrix but the number of nodules is higher in the sample of 5^{th} day. The microstructures show very fine needle-type graphite nodules. After annealed until the 5^{th} day, it relieves the internal stresses and increasing and ductility, compromising with hardness.



(a) Annealed (3 days)



(b) Annealed (4 days)



(c) Annealed (5 Days)

Figure 4.4: Annealing rate with different number of days

From the experiment, the chemical composition study of pig iron before metal casting and the composition of malleable iron after metal casting process are as shown in Table 4.2. Both tables show the comparison on the percent of carbon content. This shows that the carbon content reduces as it was used during the metal casting process.

Table 4.2: Composition of pig iron and malleable iron (before and after metal casting)

Pig Iron	
Element	**Wt%**
Fe	88.8
C	>4.50
Si	2.09
Mn	0.571
P	0.0668
S	0.0269
Cr	0.0125
Mo	<0.01
Ni	0.101
Malleable Iron	
Element	Wt %
Fe	64.3
C	>3.53
Si	2.09
Mn	0.571
P	0.0668

S	0.0269
Cr	0.0122
Mo	<0.01
Ni	0.211

4.4 CONCLUSIONS

As an overview from this chapter, the annealing rate will affect the mechanical properties and microstructure of malleable cast iron. This was proved by the results and data that were obtained from the experiment during the project.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter mainly discuss about the conclusions that can be derived from this experiment. Besides that, it also suggests some future recommendations for the purpose of further studies in the field of metal casting.

5.2 CONCLUSION

The correlation between the microstructures and mechanical properties of malleable cast iron were studied along this project. We observed that as the annealing rate increases, ductility of the samples also increased but compromising with hardness and strength. The microstructure shows the graphite nodules in the 5^{th} day annealed sample, thus shows the strength and elongation decreases with the hardness. As overall conclusion, the purpose of this project to investigate the microstructure and mechanical properties of malleable cast iron using different annealing rate has meet the objective. The second objective to study the effect of different annealing rate to the mechanical properties of malleable cast iron was achieved in this report.

5.3 FUTURE RECOMMENDATIONS

Engineering applications of malleable cast iron at different heat treated conditions are growing day by day. It has tremendous applications in automobile sector which includes crankshafts, disc-brake calipers, axle housings, and so on. For all these applications, we need to take into consideration many other mechanical properties like, wear and erosion resistance, impact resistance, fracture toughness, creep resistance, noise reduction and energy saving properties. So in future, we can measure the above mentioned mechanical properties to optimally select a material for its specific application.

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UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "Investigation of Microstructure and Mechanical Properties of Malleable Cast Iron Using Metal Casting Process" is written by Geetha A/P Muniandy. I have examined the final copy of this project and in my 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 fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing.

Dr. Md Mustafizur Rahman

Examiner Signature

SUPERVISOR'S DECLARATION

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

Signature:
Name of Supervisor: PN. NOR IMRAH BINTI YUSOFF
Position: LECTURER
Date: 22 NOVEMBER 2010

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature:
Name: GEETHA A/P MUNIANDY
ID Number: ME07011
Date: 1 DECEMBER 2010

Dedicated to my beloved parents

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I hope this research project will be helpful for those who need reference in the field of metal casting process. Finally I would like to express my gratefulness to all of them who involved directly or indirectly in the completion of my final year project and thesis. Thank you.

ABSTRACT

This thesis deals with the investigation of microstructure and mechanical properties of malleable cast iron using metal casting process. The objective of this thesis is to investigate the influence of different annealing rate to the mechanical properties and microstructure of malleable cast iron. The thesis describes the proper sand casting process in order to investigate the effect on microstructure and mechanical properties of malleable cast iron. The CO_2 sand was used as the mould and pig iron as the raw material to produce malleable iron in this thesis. The studies of mechanical properties that are involved in this thesis consists of hardness, tensile strength, percent of elongation, carbon content, and the composition of malleable iron before and after metal casting process. Three different annealing rate was used in order to determine the correlation between mechanical properties and microstructure of malleable cast iron. As result, we observed that as the annealing rate increases, ductility of the samples also increased but compromising with hardness and strength. The microstructure shows graphite nodules in the samples , however it decreases the strength and percent of elongation. As for the recommendation, the mechanical properties including the wear, corrosion resistance, impact resistance, and noise reduction should be considered in order to optimally select a material for its specific application.

ABSTRAK

Tesis ini membentangkan penyelidikan mikrostruktur dan cirri-ciri mekanikal besi perisian dengan menggunakan proses pencetakan pasir. Objektif tesis ini ialah mengkaji kesan kadar pemanasan yang berlainan ke atas mikrostruktur dan cirri-ciri mekanikal besi perisian. Selain itu, tesis ini juga menerangkan proses pencetakan pasir yang betul bagi menghasilkan besi perisian yang berkualiti. Antara skopnya ialah pasir CO_2 digunakan untuk membuat acuan spesimen dan besi kasar digunakan sebagai bahan mentah bagi menghasilkan besi perisian tersebut. Antara spesifikasi projek ini adalah merangkumi cirri-ciri mekanikal yang terdiri daripada kekuatan, daya tarikan, kesan pemanjangan, kandungan karbon, dan komposisi kandungan mineral dalam besi kasar dan besi perisian. Oleh yang demikian , tiga jenis kadar pemanasan telah ditetapkan bagi mengkaji dan memenuhi spesifikasi projek ini. Keputusan yang diperoleh membuktikan bahawa kadar pemansan yang berbeza mampu mempengaruhi cirri-ciri mekanikal dan mikrostruktur besi perisian tersebut. Dalam kajian dari segi mikrostrukturnya, ia membuktikan bahawa kehadiran nodul-nodul grafit member kesan ke atas kekuatan tensil,daya tarikan dan juga kesan pemanjangan. Secara konklusinya, kita perlu menjalankan kajian ke atas ciri mekanikal yang lain dimana ia dapat dihasilkan dalam kombinasi terbaik untuk kegunaan bidang kejuruteraan.

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