EFFECT OF AGING ON MACHINABILITY OF 6061 ALUMINIUM ALLOY

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I certify that the project entitled "*Effect of Aging on Machinability of 6061 Aluminium Alloy*" is written by *Emir Izwandy Bin Dzulkafli*. I have examined the final copy of this project and in our opinion; it is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

DR. MD MUSTAFIZUR RAHMAN

Examiner Signature

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Report submitted in partial fulfilment of the requirements
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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In recent years, aluminium alloys have attracted attention of many researcher, engineers and designers as promising structural materials for automotive industry or aerospace applications. Aluminium alloys are alloys in which aluminium is the predominant metal. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Extensive studies have been done on the 6xxx aluminium alloys because of their benefits compared to the other type of aluminium (Demir and Gündüz, 2008). For this project, it will focus on 6061 aluminium alloys. The 6061 aluminium alloy is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements (Anson, 2007). It has good mechanical properties and exhibits good weldability. The 6061 aluminium alloys has been used in the automotive industry for the fabrication of several types of automobile parts such as wheel spacers, panels and even in the vehicle structure.

Several of aluminium alloy mechanical properties can be change by doing a specific heat treatment. Generally aluminium alloys can be heat treated to increase their mechanical properties especially their strength, hardness and also improves their fatigue resistance. There are two process of heat treatment applicable for aluminium alloy which are solution heat treatment and precipitation heat treatment. For 6061 aluminium alloy, the processes that involve are solution heat treated and artificial aging. This consists of heating the alloy to a temperature between 460°C and 530°C at which all the alloying elements are in solution. The precipitation will accelerates and the strength is

further increased by heating the solution heat - treated material to a temperature above room temperature and holding it there, compared to natural aging and accompanied by a clear drop in ductility. Usually, it will be carried out at temperature up to approximately 200°C and it is called artificial aging (Demir and Gündüz, 2008).

Machining is one of the most important manufacturing processes and parts manufactured by casting, forming and various other shaping processes often require a further machining operation before the product is ready for use. These operations are generally necessary and often the most expensive part of the manufacture. Machinability, by definition, is a system property that indicates how easily a material can be machined at low cost. It may be described in terms of tool life, ease of metal removal, and workpiece quality. It is assumed that the solution heat treated aluminium alloys possess different mechanical properties that contribute to different machinability properties. This project investigated the effect of different aging times at 160°C and 200°C on the hardness and surface roughness when milling eight 6061 aluminium alloy workpieces under control, solution heat treated (SHT), solution heat treated and aged (SHTA) conditions (Demir and Gündüz, 2008).

1.2 PROBLEM STATEMENT

A lot of researches have been done by the researcher all around the world on this aluminium alloy especially for industrial use. They have studied about the strength, formability, weldability and many more. The effect of variation aging time on machinability of 6061 aluminium alloy which has been heat treated to specific temperature has been investigate in this project. The purpose is to see whether the 6061 aluminium alloy mechanical properties is being affected or not by the variation aging time at specific temperature. Then the result is being compared to the result from the previous experiment that has been done by other researchers.

1.3 OBJECTIVES

The objectives of the project that need to be achieved are:

1. To study the effect of aging on machinability of 6061 aluminium alloy.
2. To investigate the effect of variation aging time and temperature of heat treatment 6061 aluminium alloy.

1.4 PROJECT SCOPES

The focus area will be done based on the following aspect:

1. 6061 aluminium alloy sample preparation.
2. Metallography to reveal the microstructure of the sample.
3. Heating of sample at different temperature at 160°C, 200°C.
4. Artificial aging of sample at 1 hour, 3 hours and 5 hours.
5. Milling process by using the manual milling machine.
6. Surface analysis by using optical microscope.
7. Machinability performance analysis; surface roughness.
8. Hardness test by using Vickers hardness test machine.

1.5 OVERVIEW OF THE REPORT

This project has been sort into five chapters. The introduction of the project has been show in chapter 1. In chapter 2, the literature review has been explained. Methodology is being told in chapter 3 while the result of the experiment is being discussed in chapter 4. Conclusion and recommendations is in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Literature review is a body of text that aims to review the critical points of current knowledge and or methodological approaches on a particular topic. In this chapter, the literature that will give information about this project and what happen during this experiment is being discussed.

2.2 ALUMINIUM ALLOY

Aluminium alloys are alloys in which aluminium is the predominant metal. Typical alloying elements are copper, zinc, manganese, silicon, and magnesium. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4-13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required (Robert, 2009).

The most commonly used aluminium alloys designation system in the United States is that of the Aluminium Association is the wrought aluminium alloys. For this kind of aluminium alloy, it is based on four digits corresponding to the principle alloying elements are shown in Table 2.1 (Budinski and Budinski, 2002).

The second digit in this system is the designate mill control on specific elements. There is no significance for the last two digits except that in the 1xxx series because their content of aluminium is above 99% in hundredths. For example, 1040 aluminium alloy has 99.4% of aluminium.

All of these elements have a similar phase diagram. They show good solubility of the alloying element at elevated temperature but low solubility at room temperature as shown in Figure 2.1 (Budinski and Budinski, 2002).

Table 2.1: Type of wrought aluminium

Type	Series
Commercially pure aluminium (99% min)	1xxx
Copper (major alloying element)	2xxx
Manganese containing alloy	3xxx
Silicon containing alloy	4xxx
Magnesium containing alloy	5xxx
Magnesium and silicon containing alloy	6xxx
Zinc containing alloy	7xxx
Other elements containing alloy	8xxx
Unused series containing alloy	9xxx

Source: Budinski (2002)

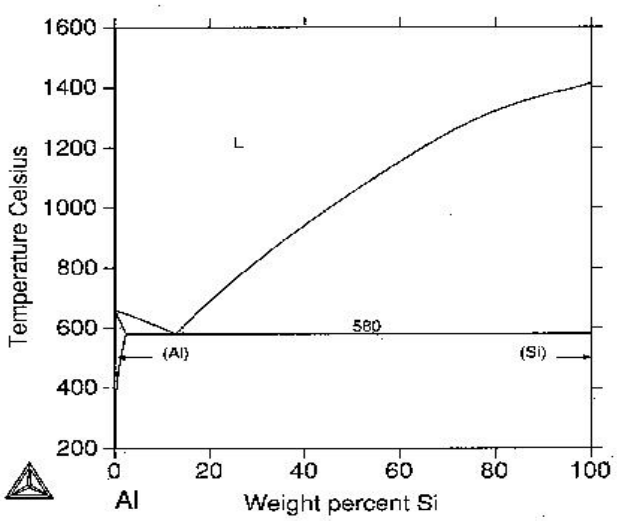

Figure 2.1: Phase diagram of aluminium alloy

2.3 6061 ALUMINIUM ALLOY

6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use. It is commonly available in pre-tempered grades such as, 6061- O (solutionized), 6061-T6 (solutionized and artificially aged), 6061-T651 (solutionized, stress-relieved stretched and artificially aged) (Anson, 2007).

The chemical composition of 6061 aluminium alloy is listed in Table 2.2 and the optical microstructure of the 6061 aluminium alloy is shown in Figure 2.2 (Lee et al,. 2001).

Table 2.2: Chemical composition of 6061 aluminium alloy.

Composition	Fe	Cu	Si	Zn	Mn	Mg	Cr	Ti	Al
Weight (%)	0.16	0.19	0.71	0.04	0.02	0.94	0.08	0.03	Bal

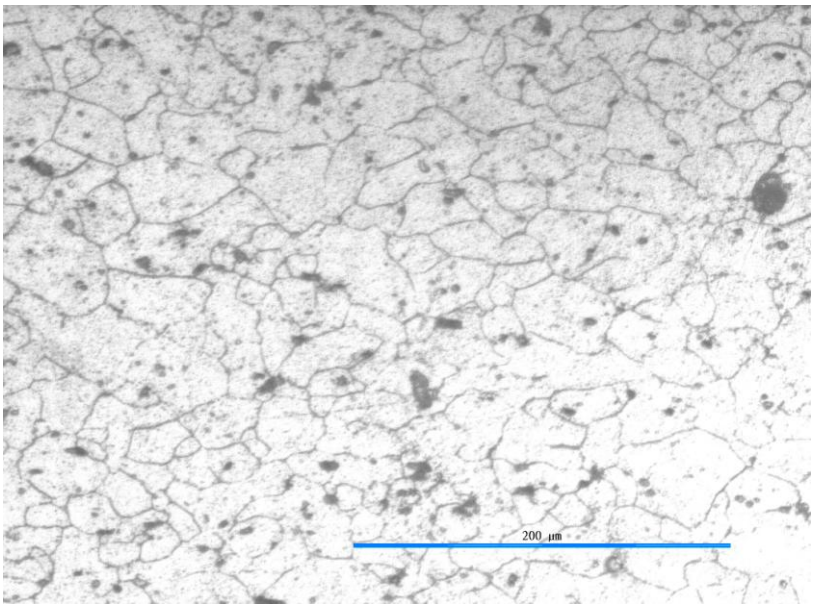

Figure 2.2: Microstructure of 6061 aluminium alloy.

2.4 HEAT TREATMENT

The purpose of heat treatment is to alter the physical and maybe the chemical properties of the materials. The most common application is metallurgical. There are also many materials that are manufacture from the heat treatment such as glass. It involves the use of heating or chilling and normally it will be heated to extreme temperatures and to get a result such as hardening or softening of a material. In this process the techniques are include annealing, case hardening, tempering and quenching. Annealing is performed on cold-worked alloys to aids forming. Annealing typically results in a soft, ductile metal. When an annealed part is allowed to cool in the furnace, it is called a "full anneal" heat treatment. When an annealed part is removed from the furnace and allowed to cool in air, it is called a "normalizing" heat treatment. During annealing, small grains recrystallize to form larger grains. In precipitation hardening alloys, precipitates dissolve into the matrix, "solutionizing" the alloy (Ezugwu and Kim, 2001).

Quenching is a hardness process and they are quenched using air, water, oil, or liquid polymers. The purpose of quenching is to gain certain hardness and the requirement properties of the material. Tempering is a process where the material is being heat and then cooled down and usually it was cooled in the air. It will alter the properties of the materials. Case hardening is a process of hardening of the material surface and usually low carbon steel by make a thin layer of harder alloy. This process is also to increase the hardening element content of bars to be used in a pattern welding.

2.5 SOLUTION HEAT TREATED

Solution heat treated is the first step in the age-hardening process. The purpose of this step is to put the precipitating elements in solid solution. The water quench has traps these elements in solution and because of that, it may cause distortion. So it is good to purchase wrought alloys in the age-hardened condition from the mill, where they have equipment to perform straightening.

W suffix as list in Table 2.3 is used to designate a solution-treated condition. This is unstable condition and parts are not normally used in this condition since properties change with time. An exception would be an alloy that natural age-hardened at room temperature (Budinski and Budinski, 2002).

Table 2.3: Temper designations

Suffix	Condition
xxxx-F	As fabricated, no special control
xxxx-W	Solution heat treated (used only on alloys that naturally age harden)
xxxx-O	Annealed (wrought alloy only)
xxxx-H	Strain hardened (cold work to increase strength), wrought alloy only
xxxx-T	Thermally treated to produce effects other than F, O and H

Source: Budinski and Budinski (2002)

2.6 AGING

Age hardening, also called precipitation hardening, is a heat treatment technique used to increase the yield strength of the materials, including most structural alloys of aluminium, magnesium, nickel and titanium, and also some stainless steels. It relies on changes in solid solubility with temperature to produce fine particles of an impurity phase, which block the movement of dislocations, or defects in a crystal's lattice. Since dislocations are often the dominant carriers of plasticity, this serves to harden the material (Callister and Rethwisch, 2007).

The impurities play the same role as the particle substances in particle-reinforced composite materials. Unlike ordinary tenpering, alloys must be kept at elevated temperature for hour to allow age hardening to take place. This time delay is called aging. This process is possible if the line of solid solubility slopes directly toward the centre of a phase diagram. While a large volume of precipitate particles is desirable, little enough of the alloying element should be added that it remains easily soluble at some reasonable annealing temperature. The element for precipitation hardening is about 10% from the material composition.

The age hardening phase diagram may be illustrated by the phase diagram as shown in Figure 2.3 (Kumar, 2007).

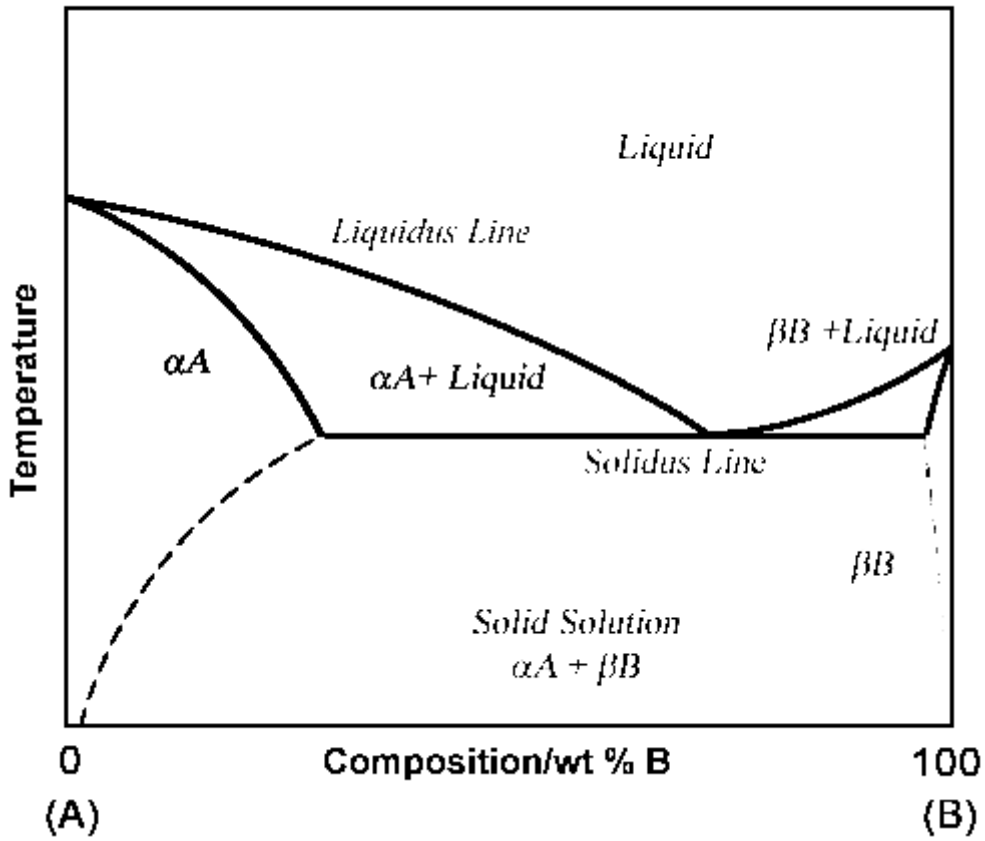

Figure 2.3: Age hardening mechanism

2.7 MILLING

Milling is a material removal process, which can create a variety of features on a part by cutting away the unwanted material is the most common machining process. This process requires a milling machine as in Figure 2.4, workpiece, fixture, and cutter. The workpiece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to a platform inside the milling machine. The cutter is a cutting tool with sharp teeth that is also secured in the milling machine and rotates at high speeds. By feeding the workpiece into the rotating cutter, material is cut away from this workpiece in the form of small chips to create the desired shape (Lucas, 2005).

Milling is typically used to produce parts that are not axially symmetric and have many features, such as holes, slots, pockets and even three dimensional surface contours. Parts that are fabricated completely through milling often include components that are used in limited quantities, perhaps for prototypes, such as custom designed fasteners or brackets. Another application of milling is the fabrication of tooling for other processes.

Milling machines can also be classified by the type of control that is used. A manual milling machine that is located in the general mechanic lab requires the operator to control the motion of the cutter during the milling operation. The operator adjusts the position of the cutter by using hand cranks that move the table, saddle, and knee. Milling machines are also able to be computer controlled, in which case they are referred to as a computer numerical control (CNC) milling machine as shown in Figure 2.5.

CNC milling machines move the workpiece and cutter based on commands that are pre-programmed and it has a very high precision. The programs that are written are often called G-codes or NC-codes. Normally, the CNC milling machines also contain another axis of motion besides the standard X-Y-Z motion. The angle of the spindle and cutter can be changed, allowing for even more complex shapes to be milled.

Figure 2.4: Manual vertical milling machine

Figure 2.5: CNC milling machine

2.8 METALLOGRAPHIC

Metallographic is the study of the physical structure and components of metals, typically using microscopy (Sagalowicz, 2001). In these modern days, the word that is much prefers is materialography since we are examining the microstructure of all solid materials. This process includes a wide field in material investigation. The microstructure is characterized through size, shape, arrangement, amount, type and orientation of the phases and the defects of the phase (Geels, 2007).

The surface of a metallographic specimen is prepared by various methods of grinding, polishing, and etching. The goal or the purpose of metallographic preparation is to obtain the true microstructure of the material which mean it can be analyzed in an inverted optical microscope as shown in Figure 2.6 that is located in material mechanic lab refer.

Mechanical preparation is the most common preparation method. In a series of steps, successively finer abrasive particles are used to remove material from the sample surface until the desired surface quality is achieved. Many different machines are available for doing this grinding and polishing, able to meet different demands for quality, capacity, and reproducibility (Sagalowicz, 2001).

Figure 2.6: Inverted optical microscope

2.9 SURFACE ROUGHNESS

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface (Hirth and Marshall, 2001).

The instrument that is use to measured the surface roughness is called surface phertometer as in Figure 2.7 that is located in metrology lab. It is use to measured and records the surface roughness of the material surface. It has diamond stylus that travels along a straight line over the surface as show in Figure 2.8. The distance that the stylus travel is called the cut-off, this generally ranges from 0.08 to 25 mm. A cut-off of 0.8 mm is typical for most engineering applications. The rule of thumb is that the cut-off must be large enough to include 10 to 15 roughness's irregularities (Kalpakjian and Schmid, 2006).

Figure 2.7: Surface phertometer

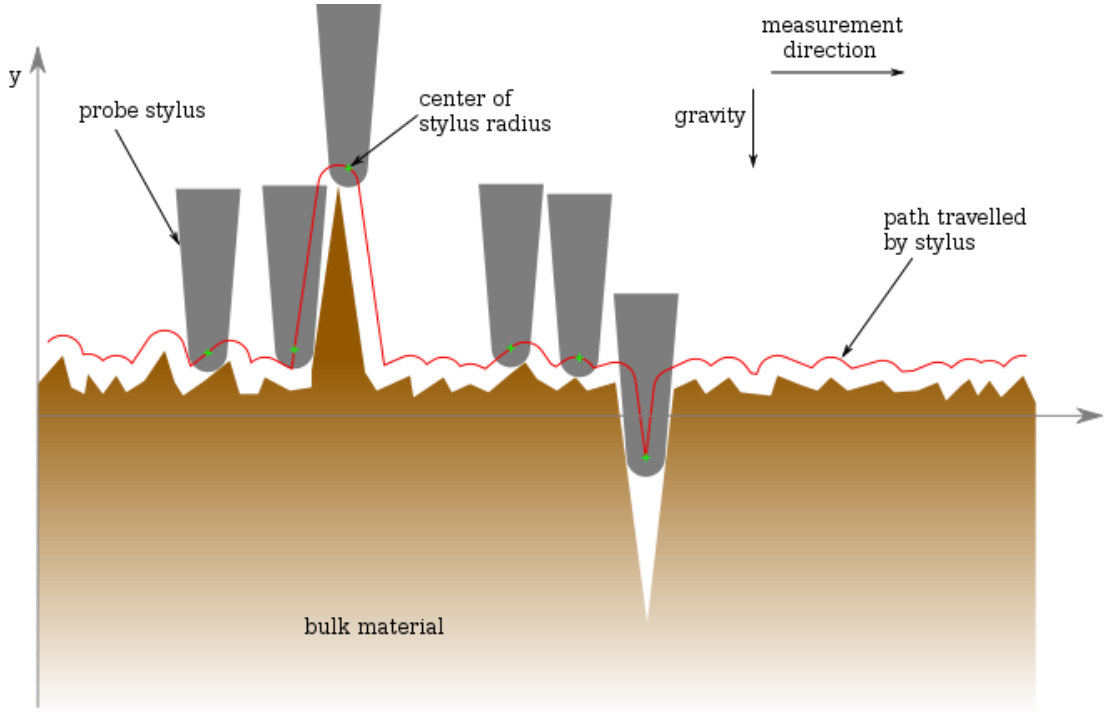

Figure 2.8: Sketch depicting how a probe stylus travels over a surface

Source: Kalpakjian and Schmid (2006)

2.10 VICKERS HARDNESS TEST

The Vickers hardness test method consists of indenting the test material with a diamond indenter as in Figure 2.10, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.

This test can be used for all metals and it also has one of the widest scales among hardness tests. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH). The hardness number can be converted into units of Pascal, but it should not be confused with a pressure unit

that use Pascal as the units. The hardness number is determined by the load over the surface area of the indentation and not the area normal to the force, and is therefore not a pressure.

The hardness number is not really a true property of the material and is an empirical value that should be seen in conjunction with the experimental methods and hardness scale used. When doing the hardness tests the distance between indentations must be more than 2.5 indentation diameters apart to avoid interaction between the work-hardened regions.

The angle was varied experimentally and it was found that the hardness value obtained on a homogeneous piece of material remained constant, irrespective of load. Accordingly, loads of various magnitudes are applied to a flat surface, depending on the hardness of the material to be measured. The HV number is then determined by the ratio *F/A* where *F* is the force applied to the diamond in kilograms-force and *A* is the surface area of the resulting indentation in square millimetres (Edwards, 2008). The Vickers hardness test machine as shown in Figure 2.9 is located in material mechanic lab.

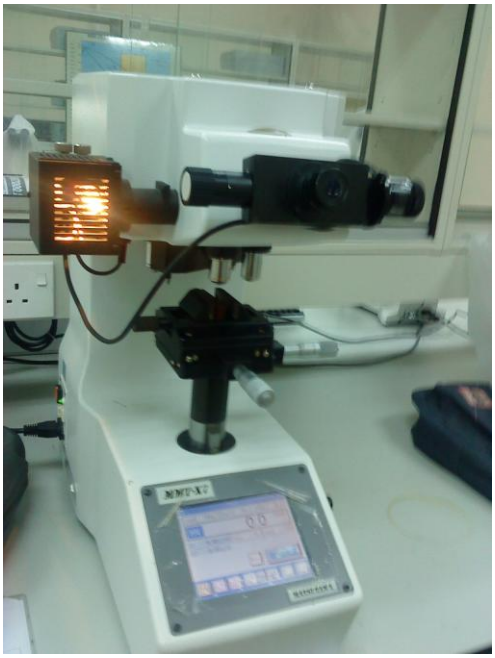

Figure 2.9: Vickers hardness test machine

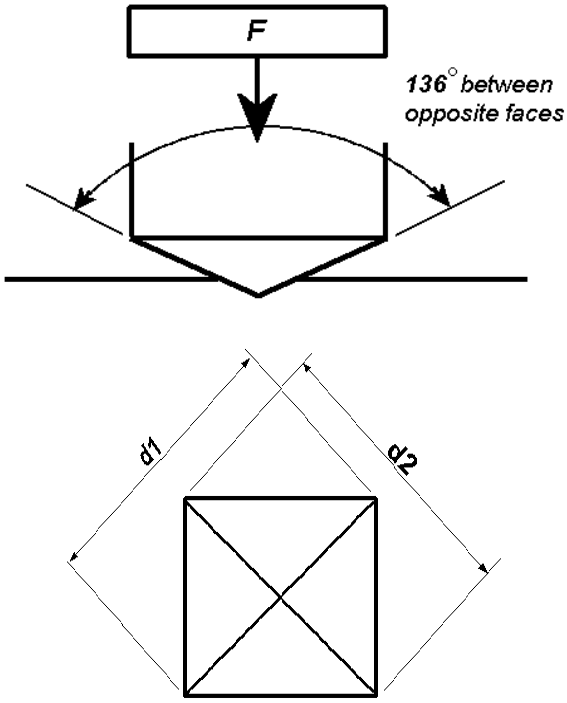

Figure 2.10: The indenter shape

2.11 CONCLUSION

It can be conclude that all the process that is needed in this project is being discussed briefly in this chapter. It is important to know the basic of what is going to happen during this project. So, with the information in this chapter, the flow of the experiment can be predicted and it will help the readers to understand about the project.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is one of the important things to be considered in order to complete any research. The main reason is because this methodology wills make sure that our job following a right track until the project is complete. By doing the methodology, it will ensure that the project is following the objectives that have been stated earlier which mean it will follow the guideline based on the objectives.

The main thing in methodology is the step or the structure of the research. By using the objectives and scopes as a guideline, methodology can be described as the structure of the research. Another key usage for methodology does not refer to research or to the specific analysis techniques. This often refers to anything and everything that can be encapsulated for a series of processes, activities and tasks. This use of the term is typified by the outline who, what, where, when, and why. In the documentation of the processes that make up the discipline, which is being supported by “this” methodology, that is where we would find the "methods" or processes of the research. With this methodology, it is easier to indicate the problem in our research because it has step by step procedure. The research will move smoother and faster with this structured methodology.

3.2 METHODOLOGY FLOW CHART

To achieve the objectives of this project, a methodology has been constructed like Figure 3.1. The methodology flow chart is purposed to give guidelines and directions to successfully accomplish the main goal of this project.

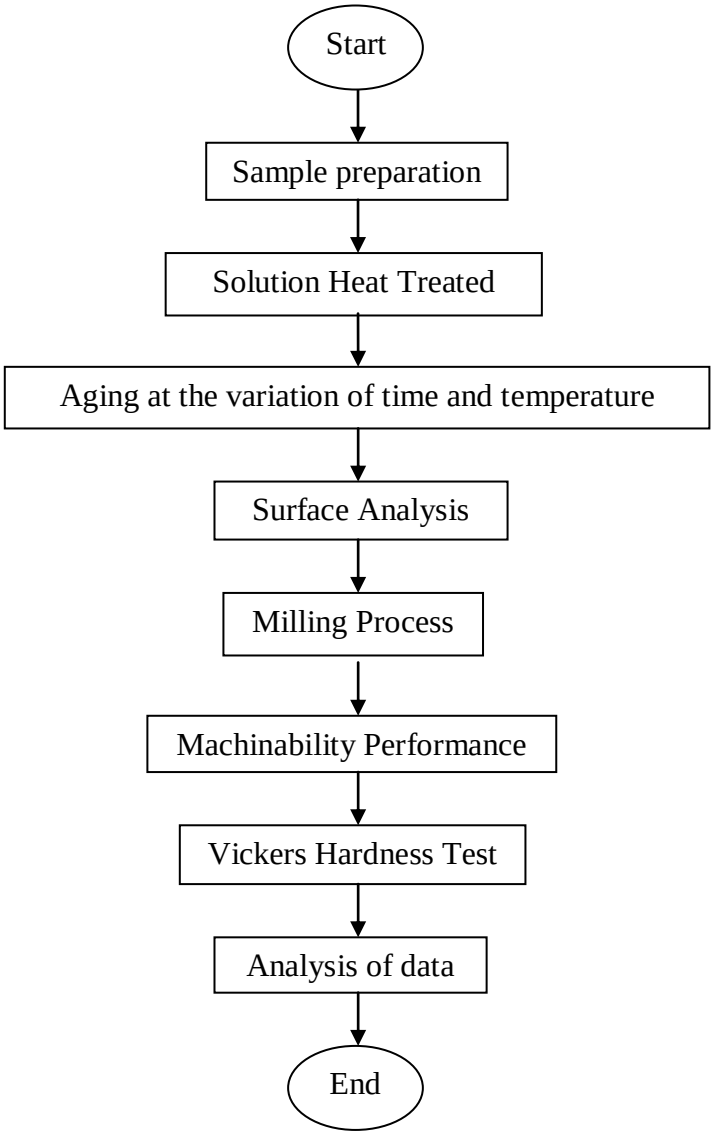

Figure 3.1: Project Flow Chart

3.3 SAMPLE PREPARATION

In this project, 6061 aluminium alloy has been use. Initially, 6061 aluminium alloy was cut into 150 mm length by using the bend saw in mechanical laboratory. So, according to the project scopes, there are about 8 specimens has been use in this project. It is because in this project, the specimens have been heated at two different temperatures at variation of aging time. The temperatures are 160°C and 200°C. Meanwhile the aging times are 1 hour, 3 hours and 5 hours as list in Table 3.1. The shape of the specimen after it had been cut is in the shape of cubic with 40 mm x 40 mm dimensions as shown in Figure 3.2.

Table 3.1: Sample preparation

Specimen	Process
1	Control
2	SHT at 530°C for 4 hours
3	SHT at 530°C for 4 hours and aging at 160°C for 1 hour
4	SHT at 530°C for 4 hours and aging at 160°C for 3 hours
5	SHT at 530°C for 4 hours and aging at 160°C for 5 hours
6	SHT at 530°C for 4 hours and aging at 200°C for 1 hour
7	SHT at 530°C for 4 hours and aging at 200°C for 3 hours
8	SHT at 530°C for 4 hours and aging at 200°C for 5 hours

Figure 3.2: The specimen after being cut

3.4 SOLUTION HEAT TREATED

Solution heat treated is the second step in this process. First of all, 7 of the specimens has been solution heat treated at temperature 530°C for 4 hours by using the furnace as in Figure 3.3. This step is to preserve the super saturated solid solution at room temperature and also to alter the physical properties and chemical properties of the material. The melting point of 6061 aluminium alloy is 660°C, that why we solution heat treated the specimens at 530°C, so it will not exceed the melting point temperature. After that, all the specimens had been quenched in water at the room temperature except the control specimen.

Figure 3.3: Furnace

3.5 AGING

The next step is aging. In this project, the specimens were aged at various time and temperature. This is the main purpose of this project; to see the effect of aging on machinability of 6061 aluminium alloy. The temperatures are 160°C and 200°C while

the times are 1 hour, 3 hours and 5 hours. The arrangement of the aging process for this project is like in Table 3.2;

Table 3.2: Arrangement of the aging process

Sample	Temperature (°C)	Time (hour)
A	160°C	1
B	200°C	
C	160°C	3
D	200°C	
E	160°C	5
F	200°C	

All the specimens were going through this step except two of the specimens; one is control and the other one is solution heat treatment only.

3.6 MILLING PROCESS

The next step in this project is milling by using milling machine as in Figure 3.4. After the specimens were aged, all of it were going through milling process as to get a smooth surface for the surface analysis as shown in Figure 3.5. This project used the face milling for this process. 6061 aluminium alloy were used as the specimens. These specimens contains high amount of silicon compare to the other chemical composition. There is the recommendation of milling operations for this specimen, 6061 aluminium alloy as state in Table 3.3. For this process, the cutting speed that has been use is 620 rpm and the depth of cut is 0.5 mm.

Table 3.3: Recommendation of milling operations for aluminium alloy

Material	Cutting tool	General-purpose starting condition		Range of condition	
		Feed mm/tooth	Speed m/min	Feed mm/tooth	Speed m/min
Aluminium alloys High silicon	High Speed Steel	0.13	610	0.08-0.38	370-910

Figure 3.4: Milling Machine

Figure 3.5: Milling process

3.7 SURFACE ANALYSIS

After milling process is done, the surface analysis had been done. For this experiment, metallography method is being used. The microstructure of all the 6061 aluminium alloy specimens including the control and solution heat treated specimen. This process was done by using the optical microscope like shown in Figure 3.6 which is located in the material laboratory. The purpose of this step is to analyse the surface microstructure of the specimens before and after undergoing all the process earlier. The processes that were undergoing in this surface analysis were hot mounting, grinding, polishing and etching.

Figure 3.6: Inverted optical microscope

For the hot mounting as shown in Figure 3.7 and 3.8, the specimens have been cut into a small cube shape. The purpose of this process is to provide a safe, standardized, and ergonomic way by which to hold a sample during the grinding and polishing operations (Vander Voort, 1999).

Figure 3.7: Hot mounting machine

Figure 3.8: Specimen after the hot mounting process

For the grinding process as shown in Figure 3.9 to 3.13, the grits that have been used are 240, 320, 400 and 600. It starts from the rough sand paper to the finer one.

Figure 3.9: Grinding machine

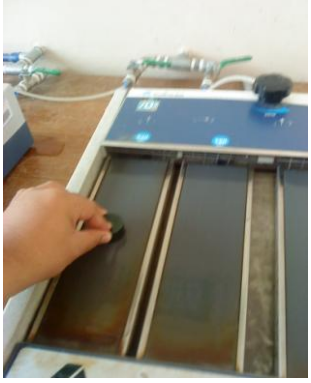

Figure 3.10: Grinding at the grit of 240

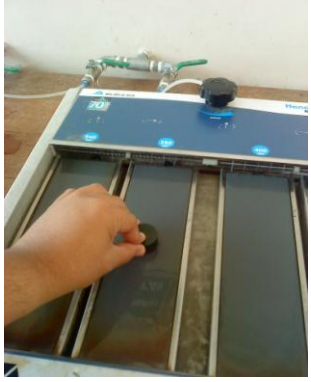

Figure 3.11: Grinding at the grit of 320

Figure 3.12: Grinding at the grit of 400

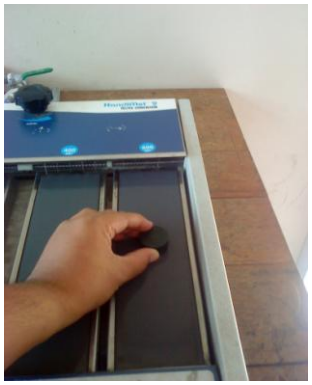

Figure 3.13: Grinding at the grit of 600

Polishing the specimens after the grinding as shown in Figure 3.14 and 3.15 is to make sure that the surface of the specimens has no scratches.

Figure 3.14: Polishing machine

Figure 3.15: Polishing process

Before the microstructure can be seen, the specimens need to go through the etching process as shown in Figure 3.16. Etching process is to reveal the microstructural constituent of the specimens. The composition of the etchant is list in Table 3.4 as shown below.

Table 3.4: Composition of etchant for aluminium alloys

Etchant	Conc.	Condition	Comment
Methanol Hydrochloric acid Nitric acid Hydrofluoric acid	25 ml 25 ml 25 ml 1 drop	10-60 seconds	Pure aluminium, aluminium-magnesium alloys and aluminium-magnesium-silicon alloys

Source: Metallographic Etchants (2009)

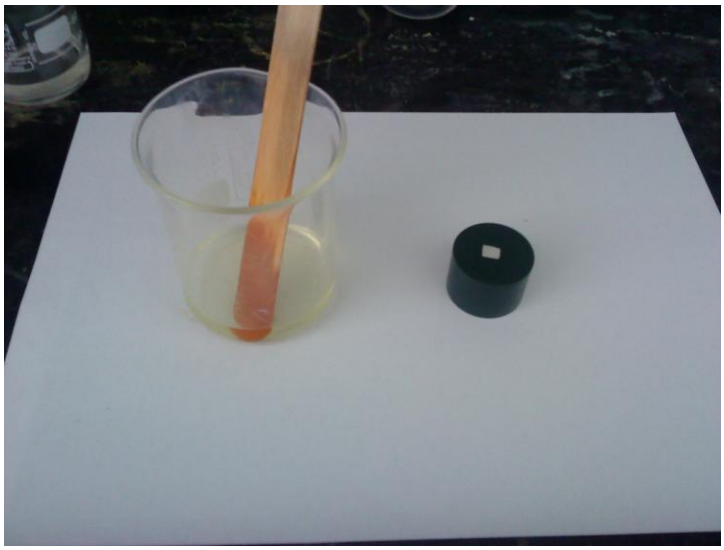

Figure 3.16: Etching process

After that, the microstructure of the specimen has been revealed by using the inverted microscope as shown in Figure 3.17.

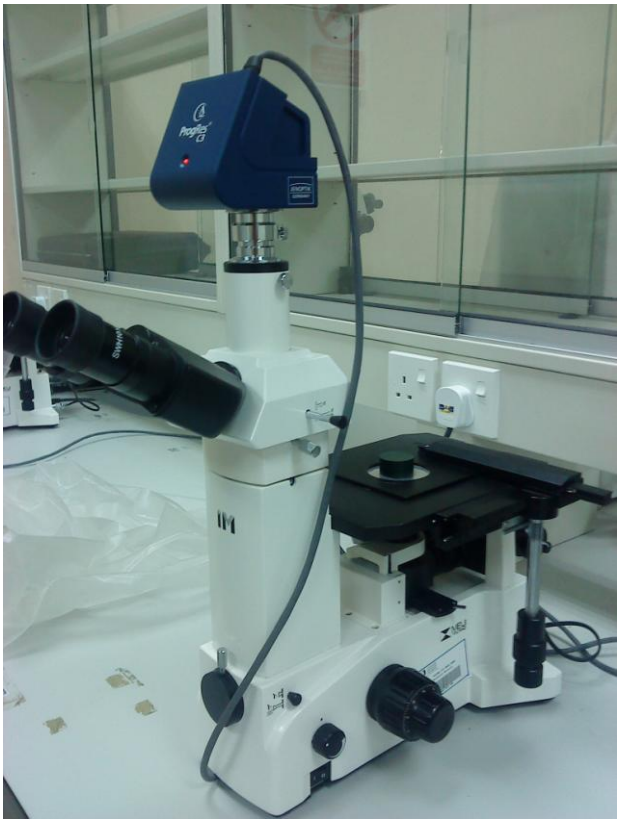

Figure 3.17: Revealing of microstructure using the inverted optical microscope

3.8 MACHINABILITY PERFORMANCE

The next step is machinability performance. In this step, the surface roughness by using perthometer of the specimen is being found. This experiment is being done in the mechanical's metrology laboratory. The perthometer as shown in Figure 3.18 is needed to be calibrating first before it can be used.

Figure 3.18: Surface phertometer

The perthometer which has been calibrated was turn on. Put the specimen that under the stylus as shown in Figure 3.19. The specimens' surface's roughness was detected by using the perthometer and all the data was shown on the perthometer screen.

Figure 3.19: The specimen is being put under the stylus

3.9 VICKERS HARDNESS TEST

All the specimens then undergo the hardness test. For this experiment, Vickers hardness test were used in order to reveal the microhardness value of the specimens. The machine as shown in Figure 3.20 was done in the surface treatment laboratory with the help of the laboratory person in charge.

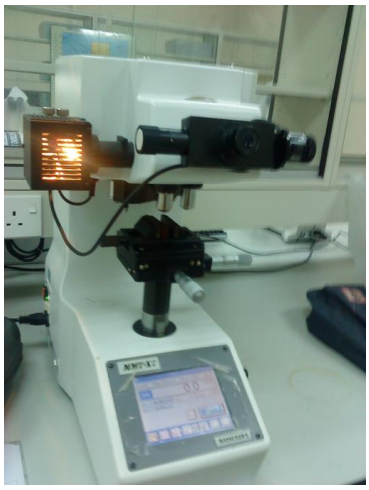

Figure 3.20: Vickers hardness machine

For this experiment, the location need to be observed for the indenter to be pressed and make sure the surface of the specimen is flat as shown in Figure 3.21. Then the indenter was pressed into the specimen by an accurately controlled test force about 100 g load. The force has been maintained for about 10 seconds to get the specific dwell time. The indenter is removed after the dwell time is complete and leaving an indent on the specimen surface with the shape of square. The size of the indentation has been measured in order to get the diagonal measurement of the indentation. Ten hardness readings were performed per sample and then were averaged.

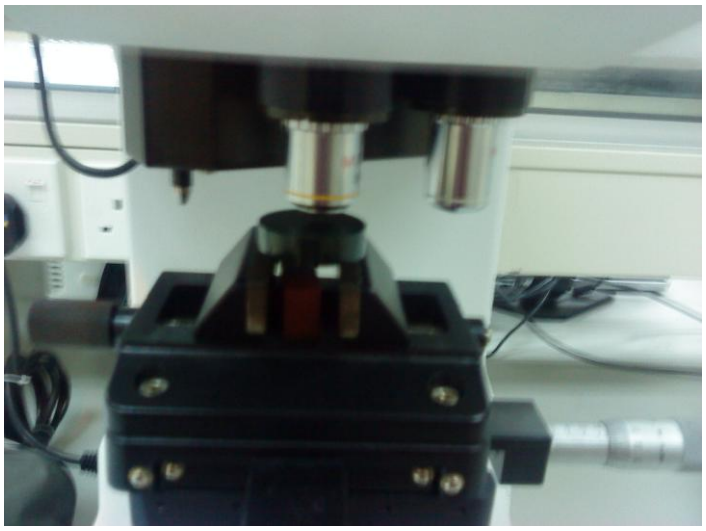

Figure 3.21: The specimen is put under the microscope

3.10 ANALYSIS OF DATA

The next step is analysis of data, which include data cleaning, initial data analysis, main data analysis and final data analysis. First of all, the data cleaning will be done. This is the very important step in analysis data step. In this step, all the data that has been collect will be inspect and got it corrected if there are any erroneous.

After that, do the initial data analysis. In this step, inspect whether all the data that have been collect were base on project objectives and scopes. Then do the main data analysis and followed by the final data analysis. In main data analysis, this is where the data that is not base the objectives and scopes ware put aside. In final data analysis,

inspect once again all the data because the data have finally got the data that is according to the objectives and scopes.

3.11 CONCLUSION

The whole process is important for this project since the purpose is to know the effect of aging on machinability of 6061 aluminium alloy. The experiment must follow the entire step to make sure that it has proceeded according to the project flow chart. All the steps is conduct to the next step which is analysis based on the result that has been getting in the experiment.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter is to discuss the results that have been obtained from the previous experiment. The experiment that have been done were solution heat treatment, aging at various time and temperature, milling process, surface analysis, machining process and Vickers hardness test. The process involved in attaining those results has been discussed thoroughly by the prior chapter. The objective of this chapter is to determine the effects of aging on machinability of 6061 aluminium alloy. The outcome of the experiment will be discussed in detail by next topic.

4.2 EFFECT OF METALLURGICAL PARAMETERS

Heat treatment is one of the most important controlling factors used to enhance the mechanical properties and machinability of aluminium alloys, through optimization of both the solution and aging heat treatments given to such alloys. Hardness is one of the most important metallurgical parameters that can control the alloy machinability. In fact, aluminium alloys differ from many other metals in that the machinability of aluminium generally improves as the hardness increases. (Demir and Gündüz, 2008)

The hardness as a function of artificial aging time for control, solution heat treated (SHT) and solution heat treated with aging (SHTA) workpieces are shown in Figure 4.1 and 4.2 below. As the result shown, the hardness of the specimens is decrease from the control specimen and the solution heat treated specimen. As the aging process was done, the hardness value of the specimen seems increasing.

From Figure 4.1, the hardness value of SHT is 20.7 HV. The hardness value for specimen that go through the aging process at 160°C for 1 hour is 22.6 HV, 3 hours is 23.1 HV and 5 hours is 23.5 HV. The value is keep increasing from the solution heat treated to the aging at temperature of 160°C although it is decrease from the control to the solution heat treated specimens. The hardness value for aging process at 200°C for 1 hour is 20.7 HV, 3 hours is 22.7 HV and 5 hours is 24.7 HV. It can be seen in Figure 4.2 where the result shown that the hardness is keep increasing from the solution heat treated to the aging at temperature of 200°C.

This can be explained by interference with the motion of dislocation, due to the formation of precipitates. As the conclusion that can be make from this hardness test, the longer the time it takes for the aging process, the harder the specimen is going to be. For the different temperature, it also can be said that the higher temperature of the aging process, the harder the specimen is going to be.

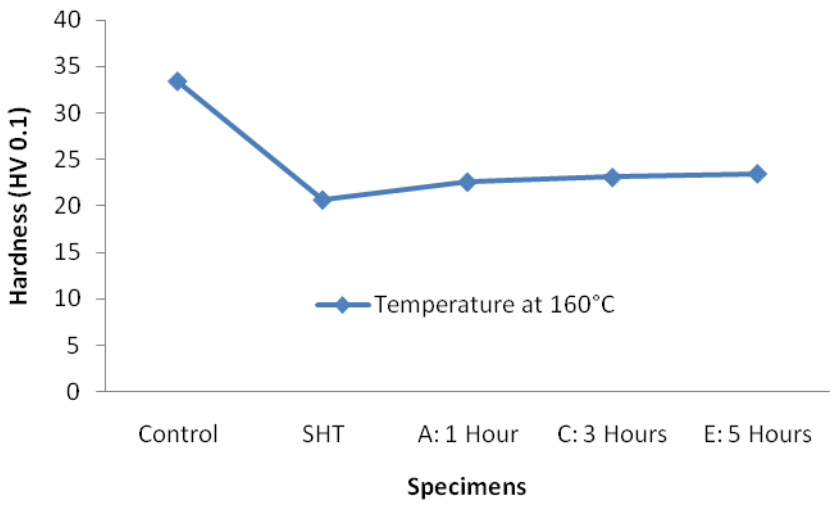

Figure 4.1: Hardness value of the control, solution heat treated and solution heat treated with aging at temperature 160°C

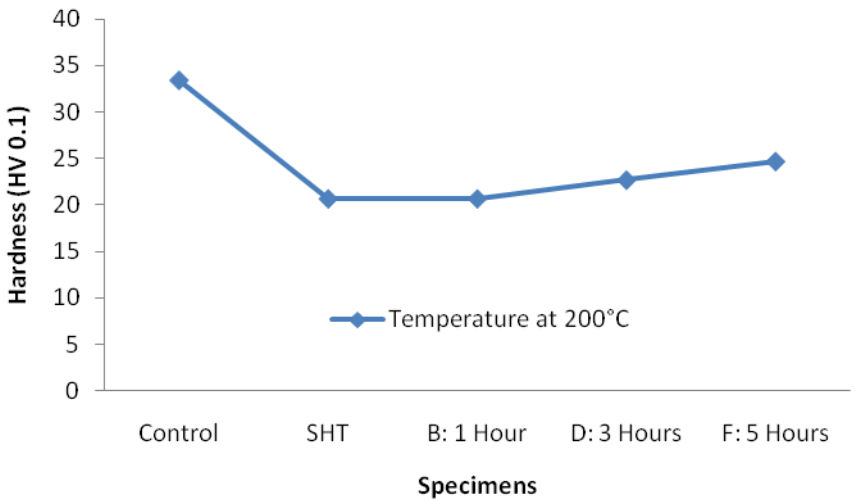

Figure 4.2: Hardness value of the control, solution heat treated and solution heat treated with aging at temperature 200°C

4.3 SURFACE ANALYSIS

After all the specimens have gone through the solution heat treated and aging process, the surface analysis of the specimens have been done to find the microstructure. The microstructure of the control specimen is at 200x and 500x magnifications are shown Figure 4.3 and 4.4 respectively.

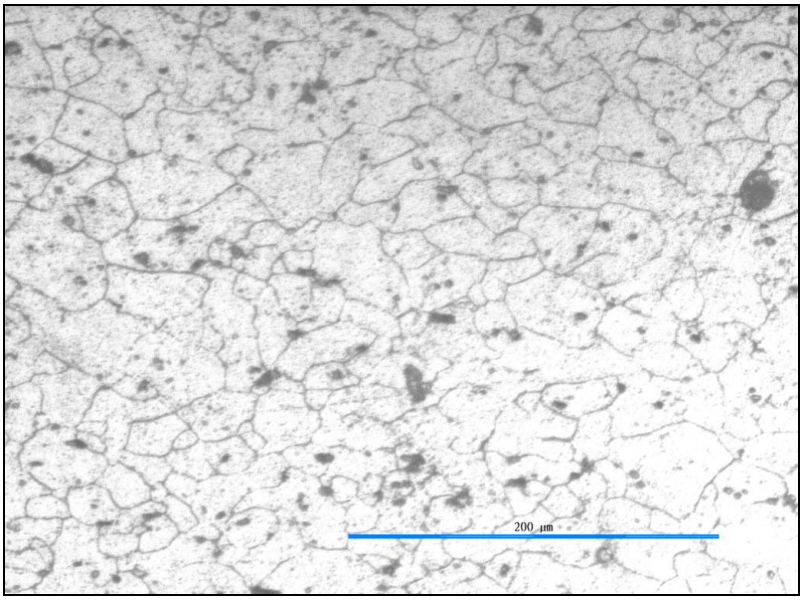

Figure 4.3: Microstructure of control specimen at 200x magnifications

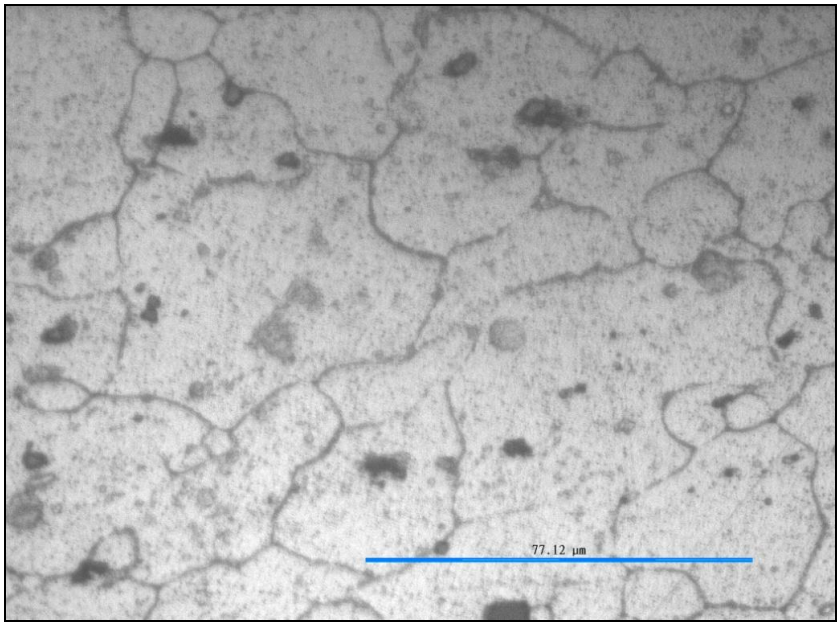

Figure 4.4: Microstructure of control specimen at 500x magnifications

The microstructure of the solution heat treated specimen is at 200x and 500x magnifications are shown Figure 4.5 and 4.6 respectively.

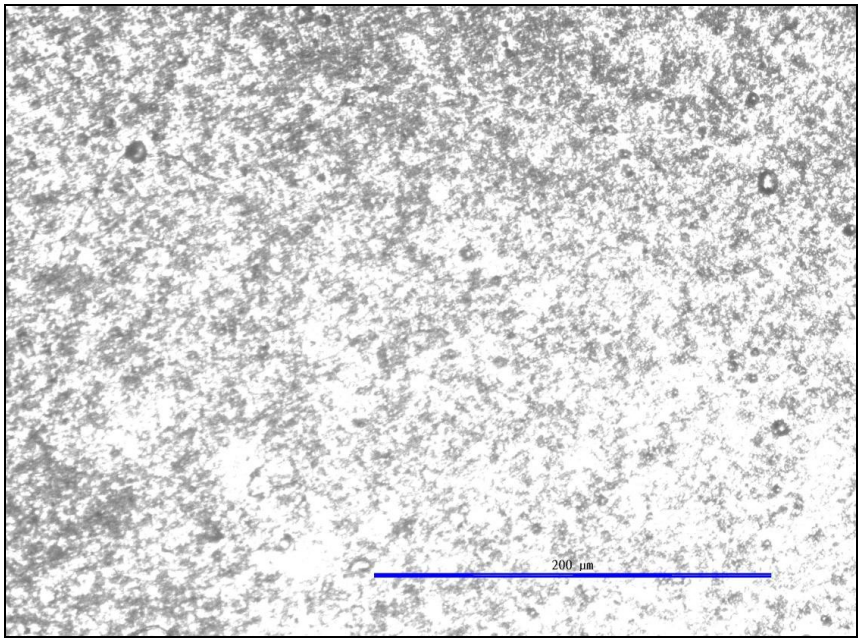

Figure 4.5: Microstructure of solution heat treated specimen at 200x magnifications

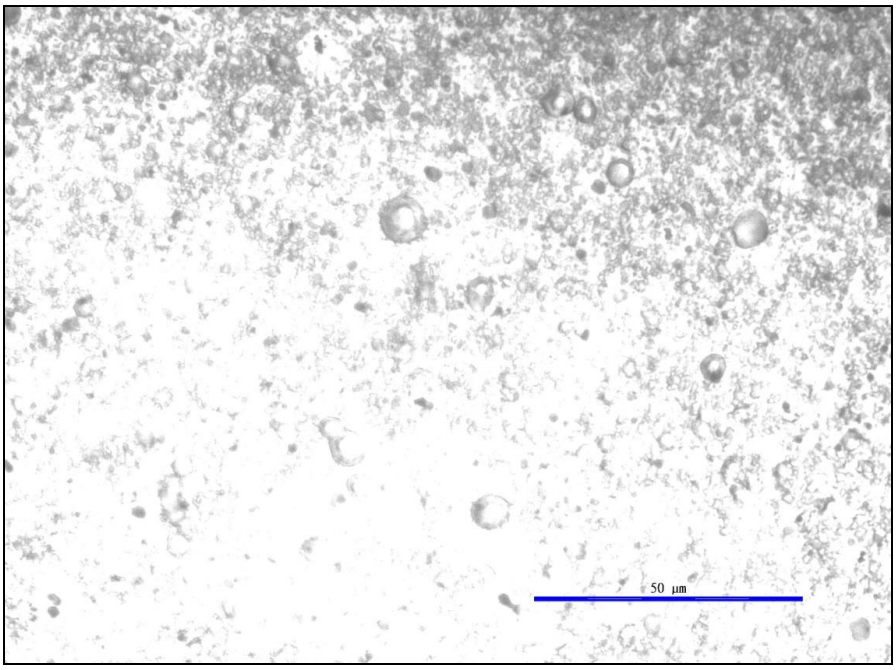

Figure 4.6: Microstructure of solution heat treated specimen at 500x magnifications

The microstructure of the aged 6061 aluminium alloy at 160°C temperature for 1 hour is at 200x and 500x magnifications are shown Figure 4.7 and 4.8 respectively.

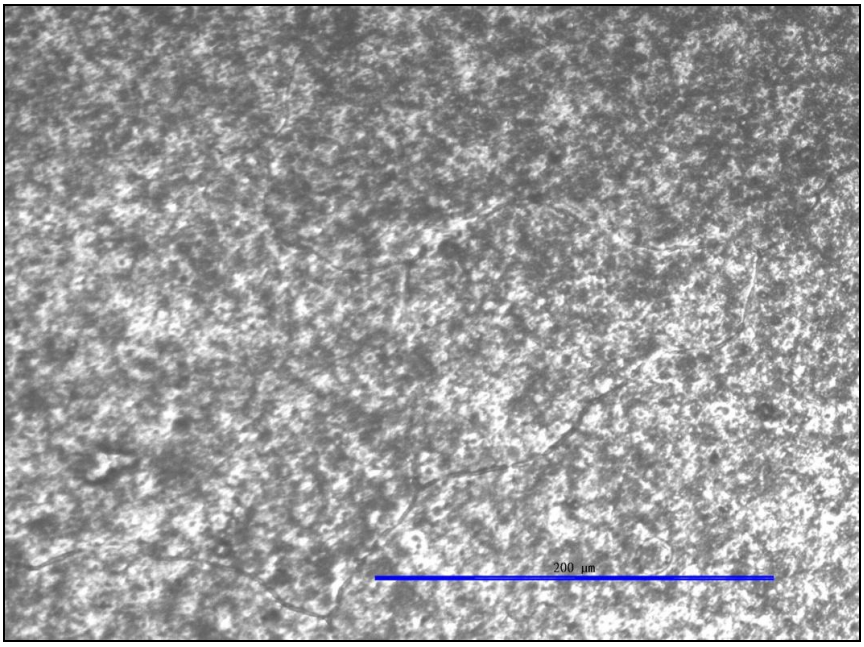

Figure 4.7: Microstructure of the aged 6061 aluminium alloy at 160°C temperature for 1 hour at 200x magnifications

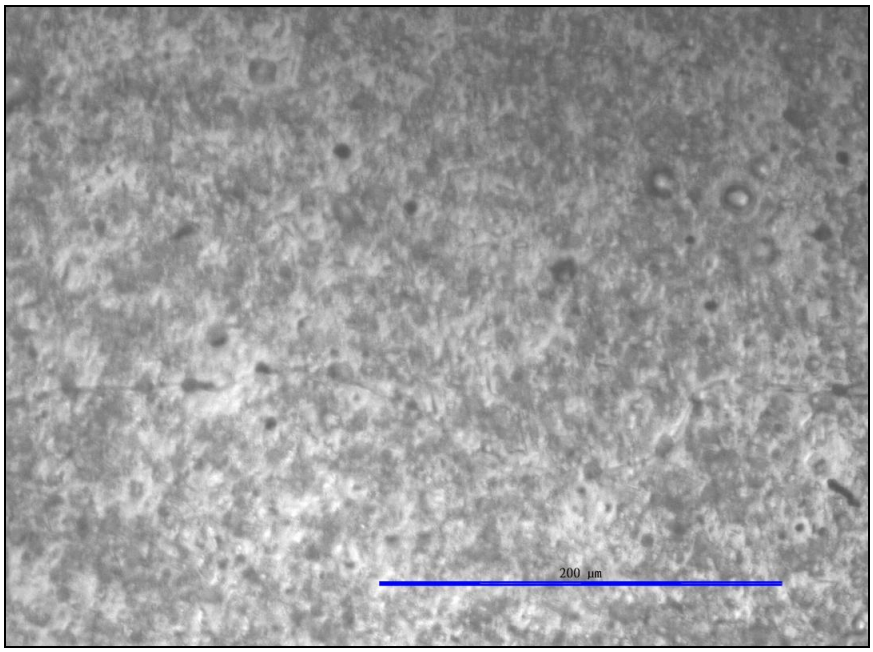

Figure 4.8: Microstructure of the aged 6061 aluminium alloy at 160°C temperature for 1 hour at 500x magnifications

The microstructure of the aged 6061 aluminium alloy at 200°C temperature for 1 hour is at 200x and 500x magnifications are shown Figure 4.9 and 4.10 respectively.

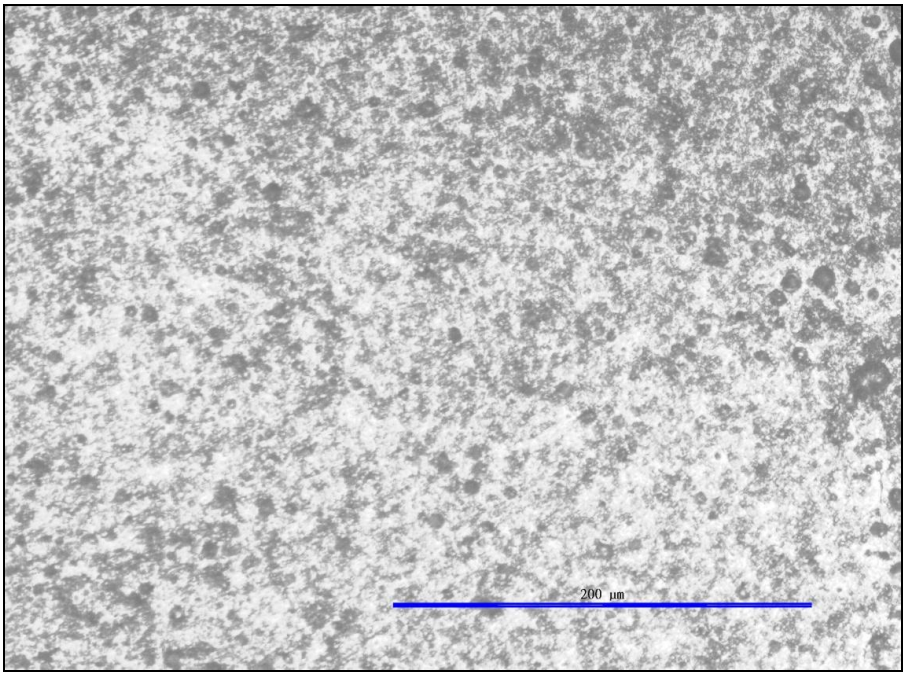

Figure 4.9: Microstructure of the aged 6061 aluminium alloy at 200°C temperature for 1 hour at 200x magnifications

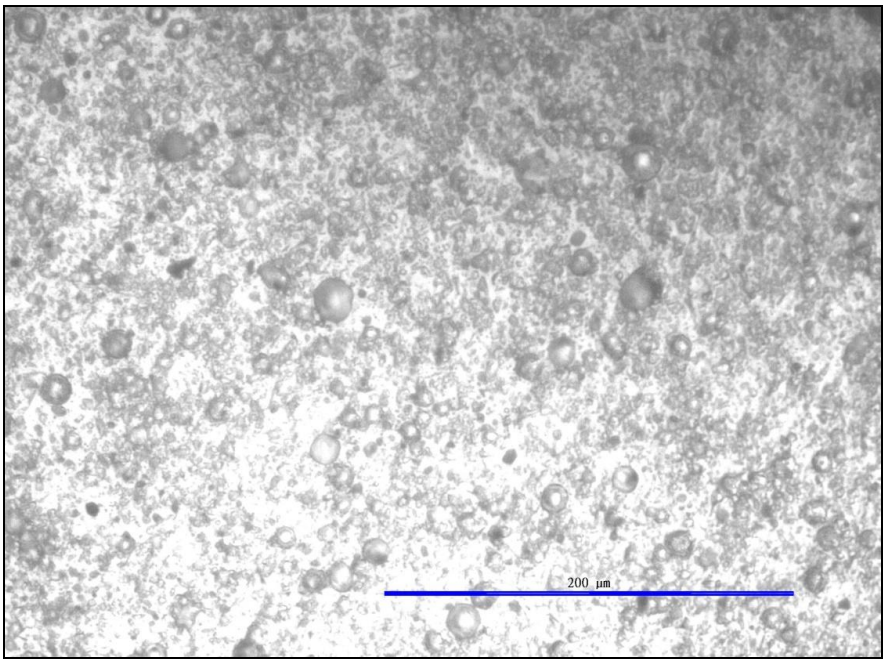

Figure 4.10: Microstructure of the aged 6061 aluminium alloy at 200°C temperature for 1 hour at 500x magnifications

The microstructure of the aged 6061 aluminium alloy at 160°C temperature for 3 hours is at 200x and 500x magnifications are shown Figure 4.11 and 4.12 respectively.

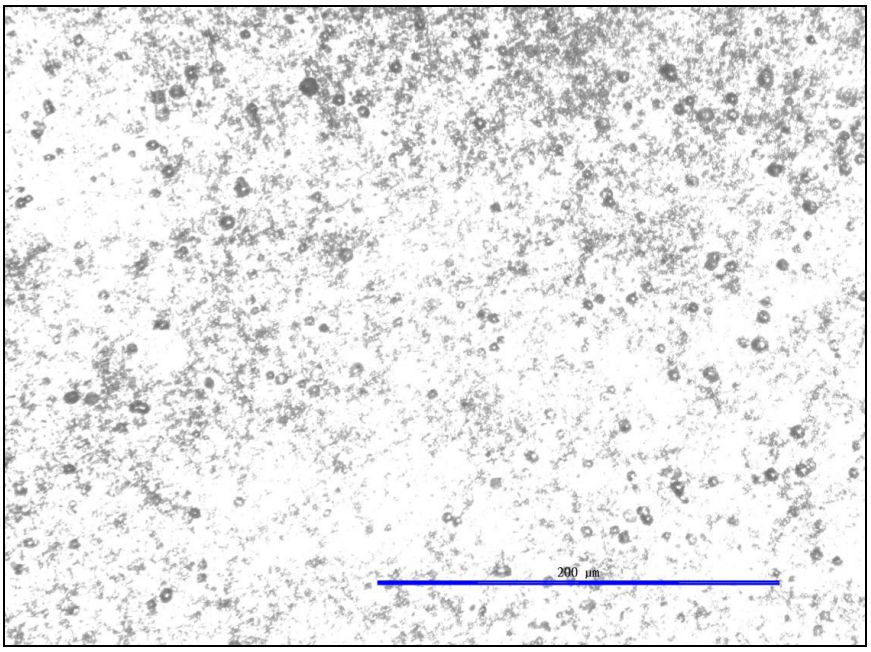

Figure 4.11: Microstructure of the aged 6061 aluminium alloy at 160°C temperature for 3 hours at 200x magnifications

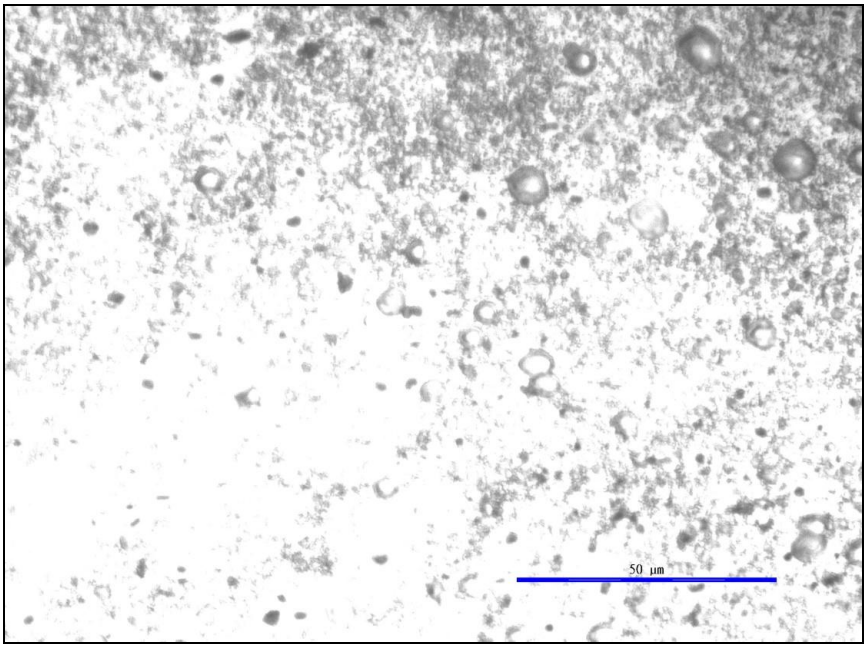

Figure 4.12: Microstructure of the aged 6061 aluminium alloy at 160°C temperature for 3 hours at 500x magnifications

The microstructure of the aged 6061 aluminium alloy at 200°C temperature for 3 hours is at 200x and 500x magnifications are shown Figure 4.13 and 4.14 respectively.

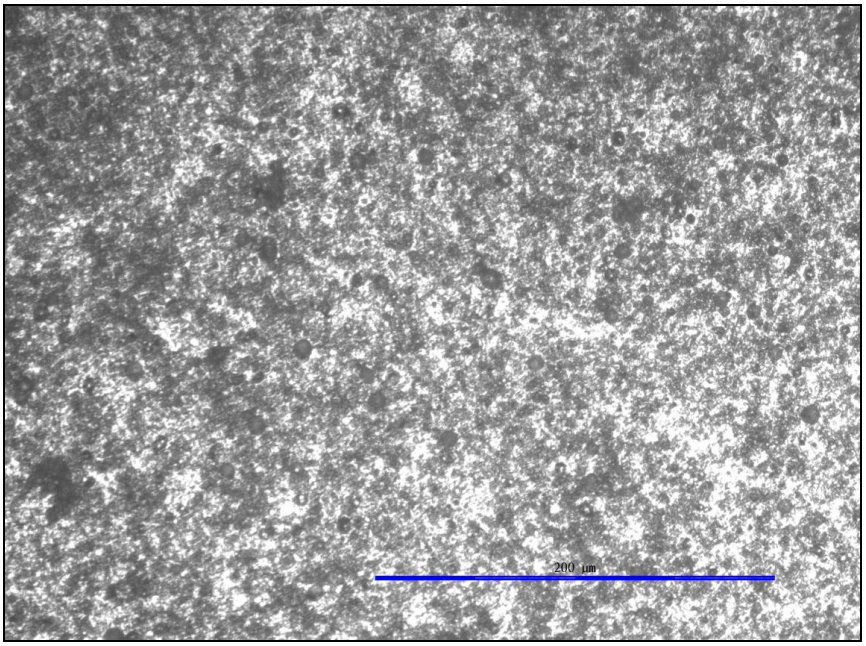

Figure 4.13: Microstructure of the aged 6061 aluminium alloy at 200°C temperature for 3 hours at 200x magnifications

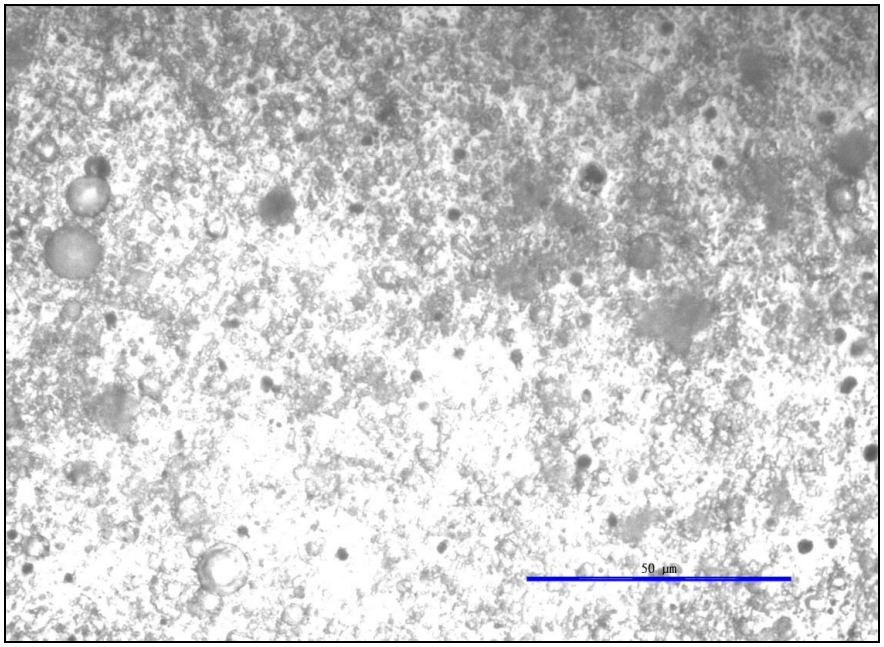

Figure 4.14: Microstructure of the aged 6061 aluminium alloy at 200°C temperature for 3 hours at 500x magnifications

The microstructure of the aged 6061 aluminium alloy at 160°C temperature for 5 hours is at 200x and 500x magnifications are shown Figure 4.15 and 4.16 respectively.

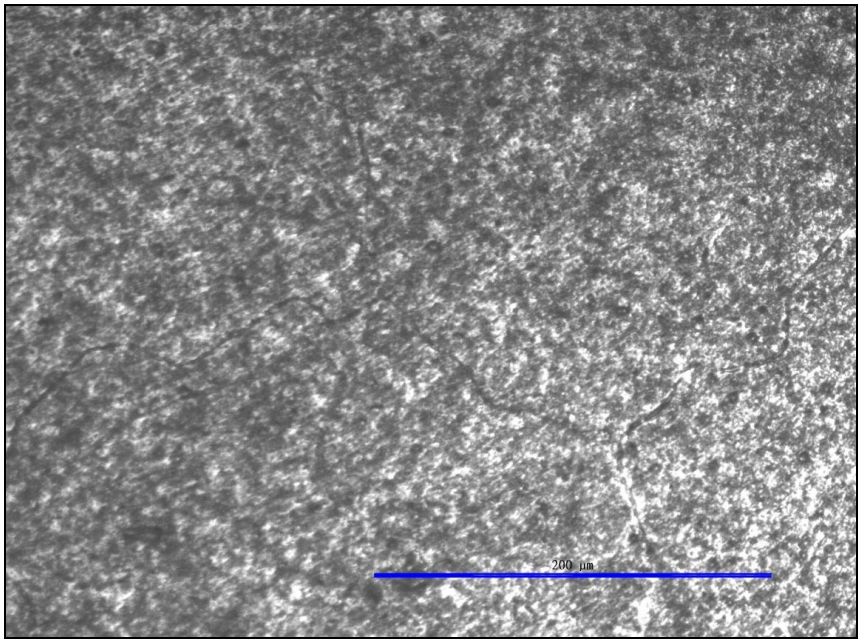

Figure 4.15: Microstructure of the aged 6061 aluminium alloy at 160°C temperature for 5 hours at 200x magnifications

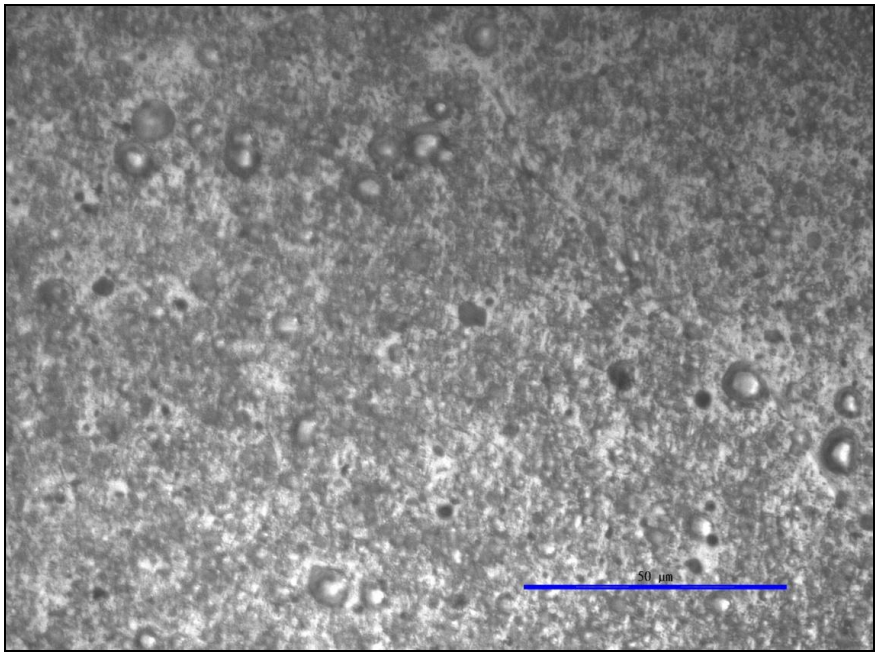

Figure 4.16: Microstructure of the aged 6061 aluminium alloy at 160°C temperature for 5 hours at 500x magnifications

The microstructure of the aged 6061 aluminium alloy at 200°C temperature for 5 hours is at 200x and 500x magnifications are shown Figure 4.17 and 4.18 respectively.

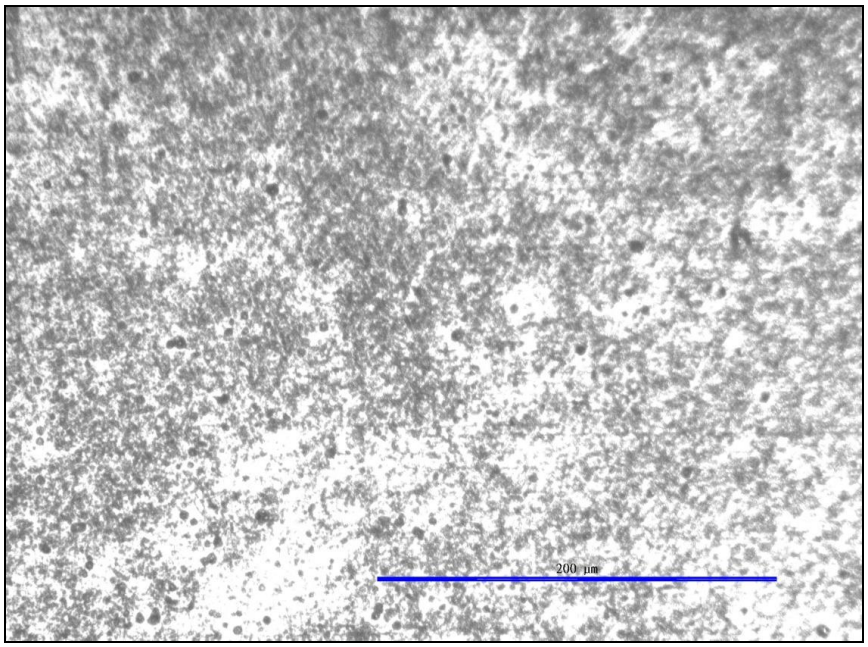

Figure 4.17: Microstructure of the aged 6061 aluminium alloy at 200°C temperature for 5 hours at 200x magnifications

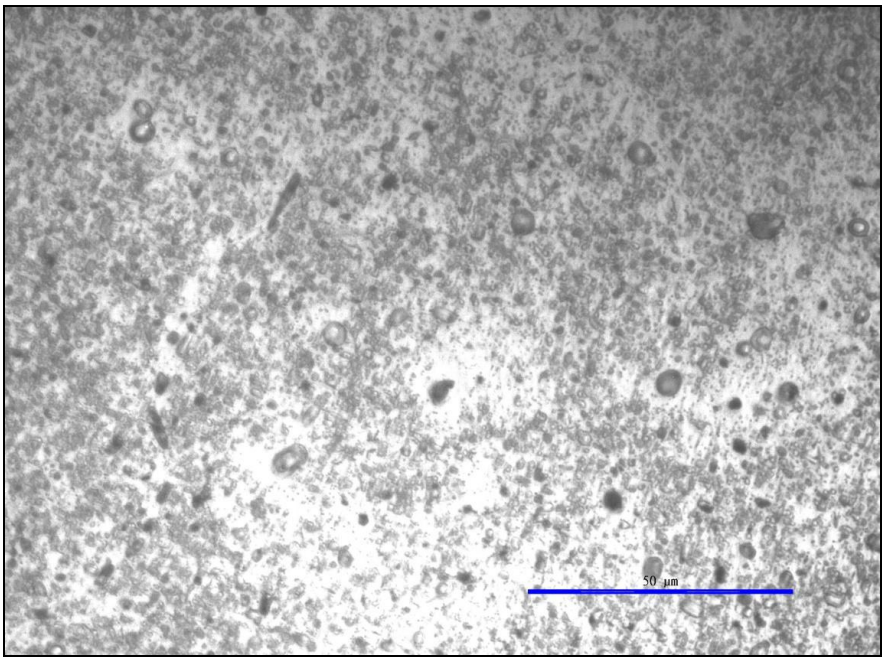

Figure 4.18: Microstructure of the aged 6061 aluminium alloy at 200°C temperature for 5 hours at 500x magnifications

From the experiment, the different between the microstructure of the specimens can be seen. From the result, the grain boundary shape of the control specimen's is much clearer compare to the specimens that have gone through the solution heat treated and solution heat treated continue with aging.

From the aging process, the microstructure of the specimens can be seen through Figure 4.7 until Figure 4.18. The size of the grain size after the aging process is smaller than the grain size of the control and solution heat treated specimen. This can be explaining by the age hardening process of the specimen. The age hardening process has changes in solid solubility with temperature to produce fine particles of an impurity phase, which prevent the movement of dislocations. Since dislocations are often the dominant carriers of plasticity, this serves to harden the material.

The hardness of the material is inversely proportional to the grain size. The hardness of the material is decrease with the increase the particle size. So, from the figure above, the grain size of the specimen is increasing from the control to the solution heat treated specimen. After that, the size of particle has decreased from the

solution heat treated to the solution heat treated and aged showing that the hardness of the specimens is increase.

4.4 SURFACE ROUGHNESS

The influence of aging time on the machined workpiece surface roughness values (Ra) is given below as shown in Figure 4.19 and 4.20. These values are the averages of six readings for each specimen. From the figure below, the highest value of surface roughness is for the solution heat treated specimen and the lowest value of the surface roughness is for the specimen E. It shows that the longer time of aging has affected the hardness of the specimen and it also has given a small value of the surface roughness.

When the surface roughness curves are examined generally, it is seen that surface roughness values decrease with increasing of the aging time. The surface roughness values of workpieces aged at 160°C for 3 and 5 hours which have relatively higher hardness values are lower than those of lower hardness workpieces. Generally, lower surface roughness values are also obtained when machining workpiece aged at 200°C for 3 and 5 hours.

This can be explained by its highest hardness value as the result of aging heat treatment and easy disposal of the chips during machining. Artificial aging, generates precipitates that cause considerable hardening in aluminium alloys. When machining the other workpieces which had lower hardness values, the chips formed during machining were seen to be entangled around the machined workpiece and cutting tool. These entangled chips were considered to cause a poor surface finish by scratching the newly machined workpiece surface. Disposal of the chips during machining of ductile materials which cause long chips is one of the main problems encountered. (Demir and Gündüz, 2008)

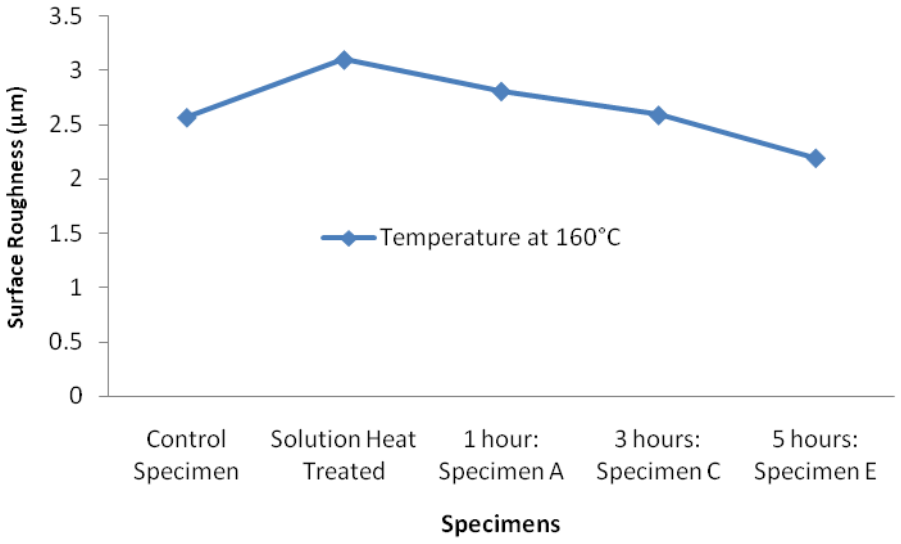

Figure 4.19: Surface roughness at temperature 160°C

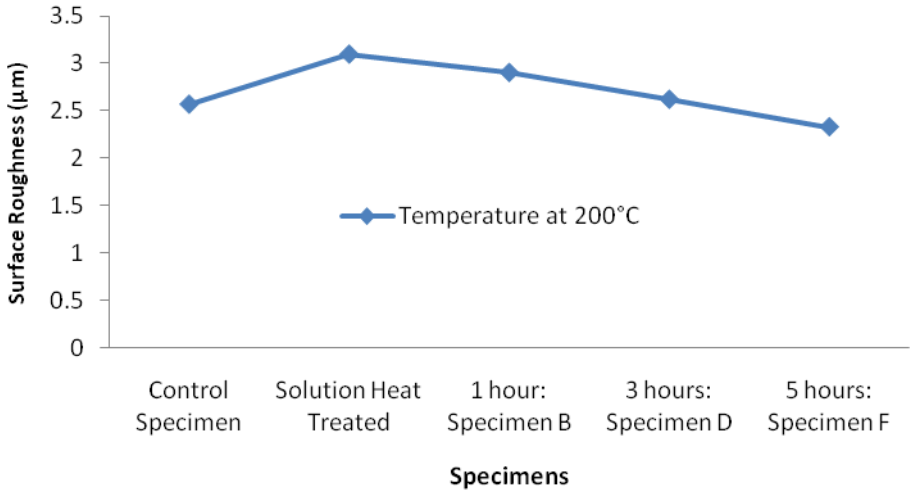

Figure 4.20: Surface roughness at temperature 200°C

4.5 CONCLUSION

From the experiment, the result has been affected by the aging process. The longer the time for the aging process, the hardest the specimen will be. It also shown in that microstructure of the specimens that has gone through aging process has a small grain size compared to the specimen that only gone through the solution heat treated

process. When the grain size is small, is means that the specimen that has gone through the aging process is harder than the specimen that not gone through the aging process. The surface roughness of the specimen after the milling process also shown that the harder the specimen, the lower surface roughness value has been get.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter provides conclusion of finding for this project. For future reference, some recommendations are enlisted as a topic in this chapter for enhancement of knowledge in continuing this research of studying the effect of aging on machinability of 6061 aluminium alloy.

5.2 CONCLUSION

In this project, the machinability behaviour of solution heat treated and solution heat treated and aged 6061 aluminium alloy was studied in artificially aged conditions. Milling tests were performed on the control, solution heat treated and solution heat treated and aged specimens using high speed steel tools.

An increase in hardness of solution heat treated and solution heat treated and aged of 6061 aluminium alloy with increase in aging time at 160°C and 200°C can be explained interference with the motion of dislocation, due to the formation of precipitates. The longer the time it takes for the aging process, the harder the specimen is going to be.

The grain size of the specimen is affected by the aging process of the material. When the time of aging is longer, the grain size of the specimen is becoming smaller. This can be explaining by the age hardening process of the specimen. It has changes in

solid solubility with temperature to produce fine particles of an impurity phase, which prevent the movement of dislocations.

Aging at different times for 160°C and 200°C affected the surface roughness of specimens considerably. For example, the specimen is aged at 160°C for 5 hours showed lower roughness values compare to the specimen that is aged at 160°C for 3 hours. This is due to its highest hardness value as the result of aging and easy disposal of the chips during machining.

As the conclusion of all the experiments that have been done, the aging has affected the 6061 aluminium alloy in terms of the hardness, microstructure behaviour and the surface roughness.

5.3 RECOMMENDATIONS

From the previous experiment, there are several suggestions that could be implanted as to improve results and obtained more accurate finding. The recommendations are as enlisted below:

1. Experiment repetitions are necessary.
2. Advanced technology provides better.
3. Longest of time of aging.

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APPENDIX A

DATA FOR THE HARDNESS TEST AND SURFACE ROUGHNESS TEST

HARDNESS VICKERS TEST

Control	SHT	specimen a	specimen b	specimen c	specimen d	specimen e	specimen f
26.3	16.6	25.3	19.3	21.6	23.3	24.8	27.8
30.4	17.7	24.5	19.4	24.8	24.8	22.6	22.8
31.3	18.4	24.3	18.6	23.5	20.5	25.2	23.5
32.8	20.0	20.7	23.2	22.3	22.7	23.3	24.1
36.0	19.0	24.8	23.6	21.5	20.3	25.1	26.6
41.7	21.8	24.0	20.6	20.3	22.7	23.9	23.7
30.2	22.3	21.3	19.4	25.4	21.6	21.0	22.2
33.7	24.7	19.6	23.6	21.0	25.2	21.3	24.0
31.2	21.5	20.6	18.3	24.5	23.0	22.7	25.4
30.4	25.2	20.4	21.2	26.2	23.1	25.8	27.2

Table 1: Hardness Vickers test data

SURFACE ROUGHNESS

Control Specimen	SHT	1 hour: Specimen A	1 hour: Specimen B	3 hours: Specimen C	3 hours: Specimen D	5 hours: Specimen E	5 hours: Specimen F
1.775	2.765	2.562	3.083	2.573	3.099	1.400	2.100
2.842	3.134	3.057	3.122	2.901	3.035	1.776	2.581
2.738	2.574	2.300	3.724	2.362	3.389	2.473	2.366
2.659	3.056	2.605	3.473	2.351	3.271	2.512	2.023
2.977	4.202	3.437	3.779	2.764	3.432	2.382	2.625
2.419	2.866	2.900	3.342	2.588	3.067	2.626	2.271

Table 2: Surface roughness test data

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project 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.

Signature	:	
Name of Supervisor	:	JULIAWATI BINTI ALIAS
Date	:	6th DECEMBER 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 for award of other degree.

Signature	:	
Name	:	EMIR IZWANDY BIN DZULKAFLI
ID Number	:	MA07069
Date	:	6th DECEMBER 2010

DEDICATION

My beloved parents

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Madam Juliawati Binti Alias from the Department of Mechanical Engineering for her encouragement, motivation, constructive criticism and beneficial guidance which led me through this project. She has always impressed me with his outstanding professional conduct and her belief that a Bachelor Degree program is only a start of a life-long learning experience. I really appreciate her consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for her tolerance of my mistakes and her commitment to my future career.

My sincere thanks go to all my friends who have contributed their aid in some manner, especially Ahmad Hisyam Bin Mohamad, Wan Mohamed Asyraf Bin Wan Zahari, Nik Mohd Qamarul Shafiq Bin Nik Ahmad Kamil, Wan Mohamad Dasuqi Bin Wan Ma'sor and Haslan Bin Mohd Yong for made my stay at UMP pleasant and unforgettable.

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ABSTRACT

The main purpose of this project is to study the effect of aging on machinability of 6061 aluminium alloy and also to investigate the effect of variation aging time on machinability of 6061 aluminium alloy which has been heat treated to specific temperature. The effect investigated for the as received, solution heat treated (SHT) and solution heat treated with aged (SHTA) conditions during this study. The effect of different aging times which are 1 hour, 3 hours and 5 hours at 160°C and 200°C results the effect on the milling performances. The process that has been gone through the experiment are sample preparation, solution heat treated, aging at various times and temperatures, milling process, surface analysis, surface roughness and the Vickers hardness test. From the experiment, the sample is harder after gone through all the process. As the conclusion of all the experiments that have been done, the aging has affected the 6061 aluminium alloy in terms of the hardness, microstructure behaviour and the surface roughness of the specimens.

ABSTRAK

Tujuan utama dari projek ini adalah untuk mempelajari kesan penuaan pada keupayaan mesin terhadap 6061 aluminium aloi dan juga untuk menyiasat kesan kepelbagaian masa penuaan terhadap keupayaan mesin melalui 6061 aluminium aloi yang telah dipanaskan kepada suhu tertentu. Kesannya di kaji untuk larutan rawatan haba dan larutan rawatan haba dan penuaan semasa kajian ini di jalankan. Pengaruh masa untuk penuaan yang berbeza iaitu 1 jam, 3 jam dan 5 jam pada suhu 160°C dan 200°C berpengaruh pada prestasi proses mengisar. Proses yang telah dilakukan adalah penyediaan sampel, larutan rawatan haba, penuaan pada kepelbagaian masa dan suhu, proses mengisar, analisis permukaan, ujian kekasaran permukaan dan ujian kekerasan Vickers. Daripada eksperimen yang dijalankan, sampel adalah lebih keras setelah melalui semua proses. Sebagai kesimpulan dari semua eksperimen yang telah dilakukan, penuaan telah mempengaruhi 6061 aluminium aloi dari segi kekerasan, perilaku struktur mikro dan juga kekasaran permukaan spesimen.

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