EFFECT OF GRINDING PROCESS PARAMETERS ON SURFACE ROUGHNESS OF ALUMINIUM ALLOY 6061-T6

AZIEMA BINTI MOHAMAD AZIZI

UNIVERSITI MALAYSIA PAHANG

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AZIEMA BINTI MOHAMAD AZIZI

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing.

Signature : …………………………

Name of Supervisor: Mr. Mohd Azmir Bin Mohd Azhari

Position : Lecturer

Date : 5 November 2008

Signature : …………………………

Name of Panel : Madam Siti Haryani Binti Tomadi

Position : Lecturer

Date : 6 November 2008

STUDENT'S DECLARATION

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

Signature : ....

Name : Aziema Binti Mohamad Azizi

ID Number : ME05011

Date : 5 November 2008

“Dedicated to all my beloved family especially father, mother, sisters, brothers and supervisor that gave me encouragement and supported towards my thesis”

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ABSTRACT

In manufacturing industry, surface quality of the material very important for certain applications such as in aerospace industry. There are demands for grinding manufacturers in aerospace industry to get good surface finish and tolerance requirements for aerospace components such as wings to reduce the friction and wear resistance. The grinding process is the most suitable process to obtain a very good surface finish and accuracy. The objectives of this research are to investigate and analyze the effects of grinding process parameters on surface roughness of aluminium alloy 6061-T6 (AA 6061-T6). The machining parameters used in this research are the depth of cut, number of passes and use of coolant. A full factorial experiment design was used as the approach for the design of experiment. It was found that the surface roughness of aluminium alloy 6061-T6 decreased when the number of passes increased. Oppositely, surface roughness increased when the depth of cut increased. Meanwhile the surface quality became smoother when using the coolant in this project compared to dry grinding.

ABSTRAK

Dalam industri pembuatan, kualiti permukaan bagi sesuatu bahan sangat penting terutama dalam sesetengah aplikasi seperti industri aeroangkasa. Terdapat permintaan dalam industri aeroangkasa untuk pengeluar-pengeluar pemipisan bagi mendapatkan kesan permukaan yang baik dan rata serta memenuhi syarat toleransi untuk komponen aeroangkasa seperti sayap kapal terbang iaitu untuk mengurangkan geseran dan kehausan. Pemipisan adalah proses paling sesuai untuk mendapatkan satu kekemasan permukaan yang sebenar dan dengan ketepatan. Objektif-objektif untuk penyelidikan ini adalah untuk mengetahui dan menganalisis kesan-kesan proses parameter pemipisan di permukaan yang kasar bagi aluminium aloi 6061-T6 (AA 6061-T6). Parameter seperti kedalaman pemotongan, bilangan laluan pemipisan dan penggunaan pelincir akan digunakan dalam penyelidikan ini. Satu kaedah faktorial telah digunakan dalam eksperimen ini sebagai pendekatan rekabentuk ujikaji. Ia telah didapati bahawa kekasaran permukaan aluminium aloi 6061-T6 menjadi rendah apabila jumlah laluan pemipisan bertambah. Kemudian sebaliknya, kekasaran permukaan pula akan bertambah apabila kedalaman pemotongan semakin bertambah. Manakala, kualiti permukaan akan menjadi lebih rata dan baik apabila menggunakan pelincir ketika proses pemipisan berbanding tidak menggunakan pelicir iaitu kering.

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LIST OF SYMBOLS

mm	Millimeter
m/s	Meter per second
n	Number
mm/s	Millimeter per second
µm	Micron meter
rpm	Revolutions per minute
in	Inch
Ra	Arithmetic mean value for surface roughness
µ in	Micron inch
g/cm^3	Gram per centimeter cube
GPa	Giga pascal
°C	Degree celsius

LIST OF ABBREVIATIONS

AA	Aluminium alloy
FKM	Faculty of mechanical engineering
ASME	American society mechanical engineering
FYP	Final year project
Si	Silicon
Cu	Copper
Mg	Magnesium
Cr	Chromium
CNC	Computer numerical control
DOC	Depth of cut
ANOVA	Analysis of variance
SS	Sum of squares
df	Degree of freedom
MS	Mean Square
F	Fisher’s ratio
P	Probability value

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nowadays, the grinding process is widely used especially in mechanical engineering field. The grinding process is the material removal and surface process to shape the finish part of any materials example steel, aluminium alloys and the others. The process of surface finish and precision from grinding process can be ten times better from the other process example milling or turning process [1]. Besides that, the grinding process can do in two ways which are in single stage or multi-pass grinding. The single stage of grinding process gives the surface of work piece not smooth but when done with the multi-pass grinding at certain depth of cut and number of passes the surface roughness can be improved and better than before. Therefore, the author chose the multi-pass grinding process for this project to get a good result of surface finish and by consider some parameters. Then, the parameters considered consist of different depth of cut, use coolant and without coolant also the number of passes.

The selection of material type also needed in this project. The author had decided to use aluminium alloys as the work piece. The main reasons are because the aluminium alloys are extensively use in engineering structures and have many properties of behavior. Furthermore the aluminium alloys have several type series in the world which are 1xxx until 7xxx series. Those aluminium alloys series very important to the certain application examples the aluminium alloys 7075 that use for construction of aircrafts structures such as wings. Besides that, from all types 6000 series of aluminium alloys, the 6061-T6 is the most widely use in industry. The properties of aluminium alloy 6061-T6 are high strength, good surface finish, good toughness, excellent in corrosion resistance to atmospheric conditions and others. The example of applications are aircraft and aerospace components, marine fittings transport, camera lenses, bicycle frames, electrical fittings and connectors, brake components, valves , couplings and others. [2]

1.2 PROBLEM STATEMENT

Grinding is the most precise machining process that is used to improve surface roughness of the work piece. It has tactile contact where when it touches the surface of the object can feel the surface roughness, waviness, texture and other scratches. The single stage of grinding process will give bad results for the surface quality. So the author needs to increase the number of passes to see the comparison of surface roughness than single passes. Besides that the effect of coolant very important because to reduce surface cracking and subsurface damage. Therefore the author will use coolant and do dry grinding to see the consequences. The suitable depth of cut is also needs because it can affect the surface texture been rougher and the surface is not shining. The results of experiment must consider in different perspective of parameter to get accurate results.

1.3 OBJECTIVE

The objective of this project is to investigate and analyze the effects on grinding process parameters on surface roughness of Aluminium Alloy 6061-T6.

1.4 SCOPE

1.4.1 To Study About Machine And Material.

This study focus based on grinding machine especially in multi-pass method to analyze the effect of the surface roughness according number of passes increases. The author had made a lot of research from books, journals and internet to achieve the objective of this project. Besides that the author focuses on the effect to the surface roughness of the grinding process when adjust some of the parameters example depth of cut, using coolant and without coolant. Moreover, the author has learned about the procedures to setup and run the grinding machine. The important things are the author has known all the cautions when operate the grinding machine to avoid from any injuries.

In spite of that, the study and the research of this project also include the material chosen that is the aluminium alloy 6061-T6. The author considered the properties and the characteristic of this material because it using as the author's work piece.

1.4.2. To Design The Experiment.

For design of the experiment, the author will consider the grinding parameters such as depth of cut (mm), number of passes of the multi-pass grinding (n), type of coolant, cutting speed (m/s) and feed rate. The author will be grinded the work piece with three levels number of cut passes 3, 6 and 9 for each experiment. Besides that, the depth of cut also will use in three levels which are 0.1, 0.5 and 1.0µm each passes. Moreover, this experiment will be running under coolant and without coolant (dry grinding). The cutting speed and the feed rate will be constant for all of this experiment which is 35 m/s and 50 mm/s. The design of experiment is using the approach of full factorial experiment design. Therefore the experiments will be conducting by 18 readings = (3^2 x 2^1).

1.4.3 Analysis The Data

For analyzing the data, it will see base on the surface roughness by adjusting the parameters of the material example depth of cut, number of passes and the others. Surface roughness of the work piece will be measured with a tester device that called Mahr Perthometer S2. It will represent the characteristic curves, profile diagrams and measuring records as well as carrying out statistical analyses.

1.4.4 Interpreting The Data

All the data will be gathered after through the device of Mahr Perthometer S2 and will be plotted in a graph based on depth of cut, passes of the grinding process with coolant and without coolant and the value of surface roughness. The plotted graph will be analyzed according to the relationship that proportional or inverse proportional base on controlling the parameters and to see the pattern of the graph. The results will be interpreted and perform the discussion. After that the author will create the conclusion and state if this project will achieve the objective and successful. Lastly, any result of the experiment can not be as standardized for any manufacturing field and any for experimental used.

1.5 ARRANGEMENT OF THESIS

1.5.1 Chapter 1

Chapter 1 of this project is about the introduction of grinding process and background of the project with the selection of parameters. Then it includes the problem statement and objective concerning about the effect of surface roughness when use different dimension for certain parameters selected. The scope of this project is to describe about how experiment will be conducted from beginning until get the result. The design flowchart of processes for this project presented as shown in figure 1.1. Besides that, the development or work progress from final year project 1 and 2 had been shown in table 1.1 and 1.2.

1.5.2 Chapter 2

Chapter 2 is about the literature review that will focus on recent studies or research by authors related to the effect of grinding process parameters on surface roughness of aluminium alloy 6061-T6 or approximately close to the titles of the project. From this chapter, the author will get more knowledge and the results based on previous researches and can predict the result for the project.

1.5.3 Chapter 3

Chapter 3 is about the methodology that will conduct for this process by the design of experiment, setup of machine, selection of parameters, experiment layout and others.

1.5.4 Chapter 4

Chapter 4 is about the result that gets from this project due to surface roughness when increasing the depth of cut, number of passes and effect surface roughness when using coolant or without coolant.

1.5.5 Chapter 5

Chapter 5 is about the conclusion of this project from all the experiment conducted and gets the results. This chapter also will summarize both the results and objectives of the project.

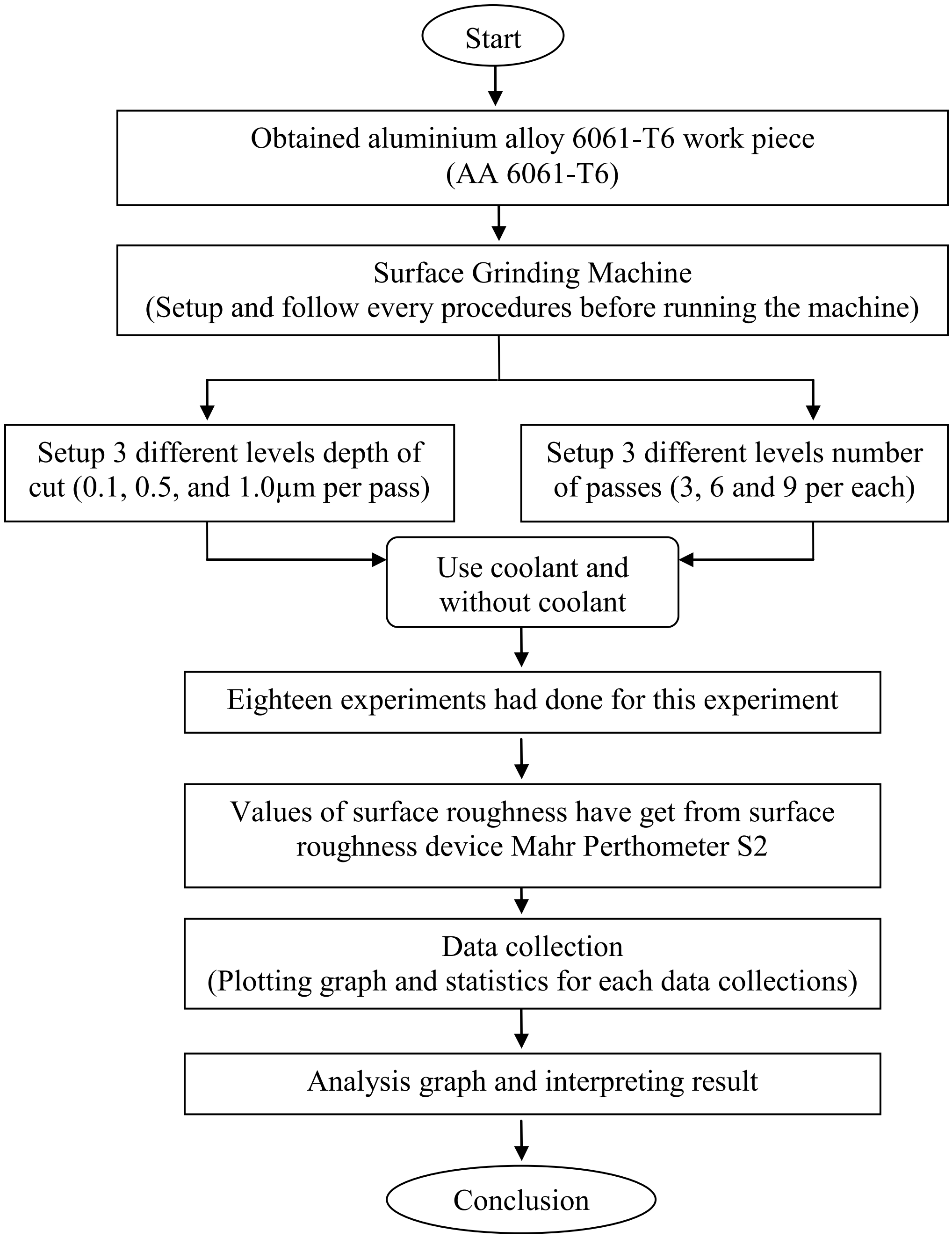

Figure 1.1: Research design flowchart

Table 1.1: Gant chart final year project 1

Num	Work progress	Week															
		1/1	7/1	14/1	21/1	28/1	11/2	18/2	25/2	3/3	10/3	17/3	24/3	31/3	7/4	14/4	21/4
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Find source on material, grinding machine, grinding parameters.																
2	Verify the title																
3	Find journal regarding the title, objective and problem statement.																
4	Verify the objectives and problem statement																
5	Discuss chapter 2 [literature review]																
6	Show the complete introduction [chapter 1]																
7	Make a summary on literature review																
8	Show the complete summary literature review																
9	Find source for methodology of project [chapter 3]																
10	Show the complete of chapter 3																
11	Make the expected result and graph [chapter 4]																
12	Complete the conclusion [chapter 5]																
13	Compile the report																
14	Submission report and proposal																
15	Start doing the slide presentation																
16	Presentation																

Table 1.2: Gant chart final year project 2

Num	Work progress	Week															
		7/7	14/7	21/7	28/7	4/8	11/8	18/8	25/8	1/9	8/9	15/9	22/9	29/9	6/10	13/10	20/10
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Cutting the work piece into 2 block by bend saw																
2	Cut the work piece into T- shape by using milling machine																
3	Make four holes with drilling machine																
4	Learn to use appropriate grinding machine and Mahr Perthometer S2																
5	Grinding machining according setup parameters																
7	Making graph, analysis and result interpretation																
8	Report Writing																
9	Complete all FYP 2 report and compile																
10	FYP 2 Presentation																
11	Log Book and Report Submission																

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The aluminum alloy 6061-T6 is available with own unique strength, hardness and other mechanical properties. The element consists of silicon (Si) 0.4-0.8 %, copper (Cu) 0.15-0.4 %, magnesium (Mg) 0.8- 1.2 %, and chromium (Cr) 0.004 -0.35%. [3]. It has a good mechanical properties, weld ability, versatile structural alloy and high corrosion resistance. Besides that, the aluminium alloy 6061-T6 is three times lighter than steel and have high strength when alloyed with the right process. Moreover aluminium alloy 6061-T6 is easy to cut and form. But the aluminum alloy 6061-T6 is a non-magnetic material because it is not pure aluminium and combining by two, three or above substances [4]. The typical applications of aluminum alloy 6061-T6 are automotive parts, rail and marine transport, bridges, pipe flanges and the others.

The grinding process very important because it is one of the complex manufacturing processes with a large of variables that related each other. The geometry influencing by many variables for example wheel characteristics (wheel diameter, grit type, size, grade and others), machine characteristics (spindle, table of motion and others) and operating conditions(wheel speed, depth of cut, grinding fluid and others) [5].

2.2 MACHINING OF ALUMINIUM ALLOY 6061-T6

There are a lot of machining processes that may affect the surface roughness of the work piece. The author had make the comparison according to the three types of machining processes which are milling, turning and grinding process.

2.2.1 Effect Of CNC End Milling Process On Surface Roughness Of Aluminium Alloys 6061-T6

Dr. Mike et. al. had investigated the case study about surface roughness prediction technique for CNC end milling. The spindle speed is 750, 1000, 1250 and 1500 revolutions per minute (rpm) with three level the depth of cut which are 0.01, 0.03 and 0.05 inches. After 84 specimens were cut for experiment, they were measure off-line with stylus type profile meter to obtain the surface roughness value, Ra. Table 2.1 and figure 2.1 shows the data of results and the multiple regression line. Therefore they found a new approach for finish surface prediction in end milling operations. For the conclusion, the experimentation of predicting multiple regression model the surface roughness, Ra is about 90 % accuracy. It means that the surface roughness, Ra could be predicted effectively by applying spindle speed, feed rate, depth of cut and their interactions in the multiple regression models [6].

Table 2.1: The data of results from journal

No	Spindle Speed(rpm)	Feed Rate (rpm)	Depth of Cut(in)	Ra (μ in)
1	1000	18	0.01	138
2	1500	9	0.03	73
3	1250	6	0.01	50
4	750	24	0.03	170
5	1250	21	0.05	105
6	750	21	0.05	150
7	1250	21	0.01	125
8	1000	21	0.03	145
9	1250	9	0.01	79
10	1500	15	0.01	106
11	1000	6	0.03	78
12	750	18	0.05	121
13	1000	6	0.01	58
14	1000	12	0.05	92
15	1000	9	0.05	102
16	1250	24	0.01	155

17	750	9	0.05	95
18	1250	18	0.03	92
19	1500	12	0.01	88
20	1000	15	0.05	105
21	1250	24	0.03	109
22	750	18	0.01	185
23	1500	21	0.01	118
24	750	15	0.03	122
25	1000	24	0.03	153
26	1000	15	0.03	108
27	750	6	0.05	72
28	1500	9	0.01	34
29	750	9	0.01	109
30	1000	12	0.03	84
31	1000	6	0.05	62
32	1500	21	0.05	113
33	1250	12	0.01	101
34	1000	12	0.01	130
35	1250	18	0.05	95
36	750	9	0.03	99
37	1500	24	0.03	103
38	750	6	0.03	63
39	750	21	0.03	163
40	1500	24	0.01	119
41	1500	24	0.05	109
42	1250	9	0.03	81
43	750	6	0.01	65
44	1000	21	0.01	149
45	1250	18	0.01	115
46	750	12	0.03	102
47	1250	6	0.05	71
48	1250	15	0.03	96
49	1250	9	0.05	92
50	1250	6	0.03	63
51	1250	18	0.01	119
52	750	15	0.05	104
53	750	12	0.05	94
54	1500	6	0.01	37
55	1250	21	0.03	100
56	1000	24	0.01	163
57	1000	15	0.01	101
58	1250	12	0.05	85
59	1500	15	0.05	99
60	1500	18	0.05	104

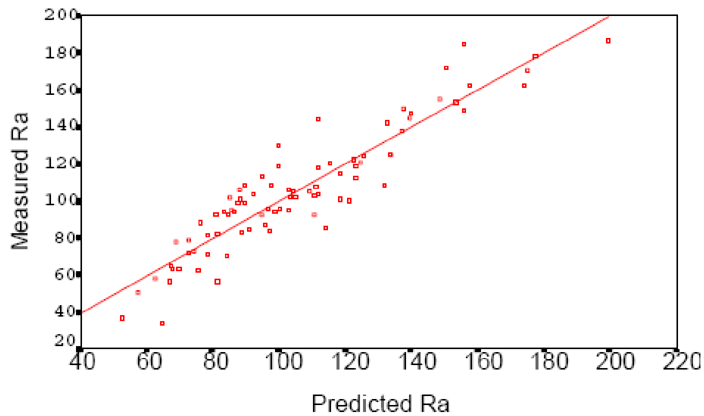

Figure 2.1: Scatter plot of measured Ra and the predicted Ra of the multiple regression prediction model

The second author, Khabeery was investigated the milling roller burnishing process. Milling roller burnishing is the one of the unconventional machining for finishing process of aluminium alloy 6061-T6. He had to improve the surface integrity means that reduce surface roughness, increase surface micro hardness and residual stress The material is from aluminium alloy 6061-T6. As the conclusion when low burnishing speeds and high depth penetrations, the surface becomes smoother. The best surface finish is produced when the number of passes is 3 or 4 [7].

2.2.2 Effect Of Grinding Process On Surface Roughness Of Copper And Zinc

Atzeni et.al, investigated the surface roughness after a grinding operation of an innovative sintered friction material. The material is using from metallic matrix which is copper and zinc. Parameter considerations are the cutting speed (15- 34 m/s) and the feed per grain (0.01-0.016 mm/rev). The result from this research was when the table speed increases the surface roughness also will increase but the wheel speed decreasing. The surface roughness get is in range 1.97-2.68 µm [8].

2.3 GRINDING OF ALUMINIUM ALLOY 6061-T6

2.3.1 Effect Of Multi-Pass Grinding To The Surface Roughness.

Bi Zhang et.al investigated the effect of stock removal rate and work piece strength in multi-pass grinding of ceramics. It said that when the number of passes in grinding process increases, the stiffness also will increase. They found that the best stiffness when 9 passes with feed 2 µm per pass. Then, they conclude that at that passes also gives the good surface finish of the ceramics [9].

2.3.2 Effect Of Depth Of Cut To The Surface Roughness.

Kwak et al. had investigated the changes of depth of cut in grinding process. They said that the maximum of the surface roughness increases proportionally to the depth of cut but the centerline average height (Ra) changed a little especially in the case of the traverse speed of 1.46 m/min. Figure 2.2 shows the effect of depth cut on surface roughness of the work piece which is measure along transverse direction. Figure 2.3 shows the surface roughness for depth of cut and work piece speeds. It can conclude that the centerline average height of the surface roughness is for different depths of cut and traverse speeds [10].

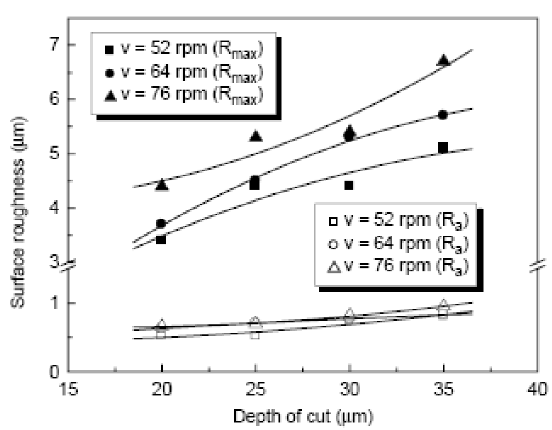

Figure 2.2: The graph surface roughness against depth of cut when transverse speed 1.46 m/min

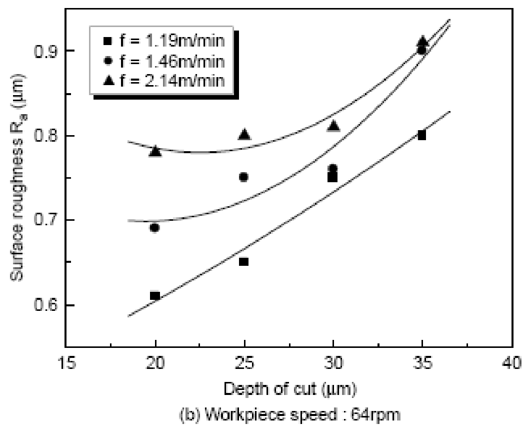

Figure 2.3: The graph surface roughness against depth of cut when work piece speed 64 rpm

2.3.3 Effect Of Coolant To The Surface Roughness.

N.R. Dhar et. al. investigated the effect of high pressure coolant jet on grinding temperature, chip and surface roughness in grinding. Material is use from AISI-1040 steel. The results for respect to the surface finish said that at high-pressure of coolant grinding it had extensively less surface roughness in compare to dry grinding. When high pressure coolant jet grinding it worked as efficient cooling, reduce friction between the tool work pieces, flashing the chips from the grinding zone, remove the adhesive chips between the grits space of the wheel [11].

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The methodology is the one of the important part from this project. It needs a lot of steps to achieving the research objectives. The methodology must fulfill the purposes and objective of this project by knowing the properties of material, the grinding machine, design of experiment and others. So from this chapter we will get the data of experiment and will use for analyzing objectively and practically due to experiment of the project.

3.2 MATERIAL

Aluminum alloy 6061-T6 is use as the material for this project. It will be investigating on effect of the surface roughness when do the grinding process. The properties of aluminum alloy from 6xxx (AA 6061-T6) can be improved by furnace solution heat treated quenched and furnace aged [2]. The table 3.1 shows the composition of aluminium alloy 6061-T6.

Table 3.1: Typical composition of aluminium alloys 6061-T6 [2]

Components	**Aluminium**	**Magnesium**	**Silicon**	**Iron**	**Copper**
Amount (wt.%)	Balance	0.8-1.2	0.4 – 0.8	Max. 0.7	0.15-0.40
Components	**Manganese**	**Titanium**	**Zinc**	**Chromium**	**Others**
Amount (wt.%)	Max. 0.15	Max. 0.15	Max. 0.25	0.04-0.35	0.05

Tables 3.2 below shows the physical properties of aluminium alloy 6061-T6 according the density, melting point, modulus elasticity and poisons ratio. The density is about 2.7 g/cm^3 with melting point approximately 580°C. Then, the modulus elasticity between 70 until 80 GPa and the poisons ratio is 0.33.

Table 3.2: Physical properties of aluminium alloys 6061-T6 [2]

Physical Properties	**Value**
Density	2.7 g/cm^3
Melting point	Approx 580°C
Modulus of elasticity	70-80 GPa
Poissons ratio	0.33

Tables 3.3 shows the mechanical properties of aluminium alloy 6061-T6 base on ultimate tensile strength, 0.2% proof stress, brinell hardness and elongation. The ultimate tensile strength of aluminium alloy 6061-T6 is between the ranges 260 until 310 MPa. The value of hardness on this material base on brinell hardness analysis is 95 until 87.

Table 3.3: Mechanical Properties of aluminium alloys 6061-T6 [2]

Mechanical Properties	**Value**
Ultimate Tensile Strength	260-310 MPa
0.2% Proof Stress	240-276 MPa
Brinell Hardness (500kg load, 10mm ball)	95-97
Elongation 50mm diameter	9-13 %

3.3 GRINDING PROCESS

The grinding process is a material removal process at high surface speeds. The process is similar to the face milling but actually it has a lot of different from each other. The grinding process permits the achievement of a specific dimensional accuracy and surface quality [12]. Then, the abrasive grains in the wheel of grinding are smaller than amount of teeth of milling cutter [13]. The cutting speed in grinding is much higher than milling process. It gives low of surface roughness means that better surface finish in grinding process [13]. The grinding machine use is horizontal spindle and table motion can moves horizontal direction to form contour of flat surfaces. The author use aluminium oxide as the grinding wheel for this process. The figure below shows the grinding machine in FKM laboratory, University Malaysia Pahang:

Figure 3.1: Grinding Machine in FKM laboratory, University Malaysia Pahang.

Figure 3.2: Operation panel

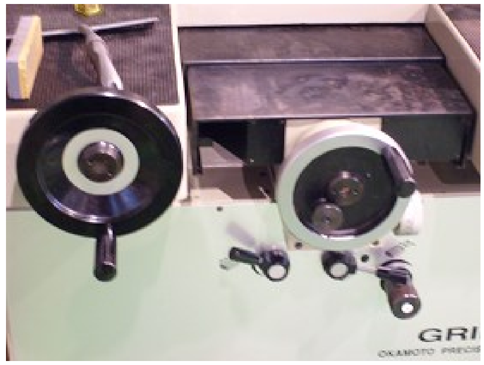

Figure 3.3: Left side is hand wheel for manual movement of working table and the right side is hand wheel for feeding of saddle.

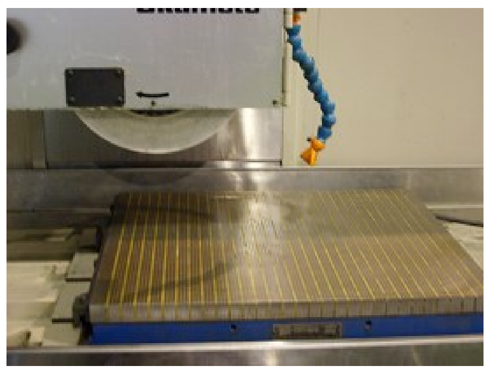

Figure 3.4: The working table, wheel head and coolant hose.

3.4 DESIGN OF EXPERIMENT

3.4.1 Selection Of Parameters

Table 3.4: Table of experimental conditions

Num	Parameters	Values
1	Depth of cut	0.1, 0.5, and 1.0μm each passes
2	Numbers of passes	3, 6 and 9 passes for each experiment.
3	Coolant	Using coolant and without coolant
4	Type of grinding wheel	Aluminium oxide
5	Wheel speed	35 m/s
6	Feed rate	50 mm/s

This project had been using two blocks of aluminium alloy 6061-T6 with dimension 100 mm in length, 100 mm in width and 64 mm in thickness presented in figure 3.5 and 3.6 The parameter of the wheel surface speed and feed rate was constant for each experiment which was 35 m/s and 50 mm/s. Then, the depth of cut was using in three levels 0.1, 0.5, and 1.0μm each passes. The surface roughness had been measured when the number of passes 3, 6 and 9 passes for each experiment. The experiments had been run under the coolant and without coolant means that dry grinding. The highly effect on surface roughness had been seen between the two different ways in coolant influences.

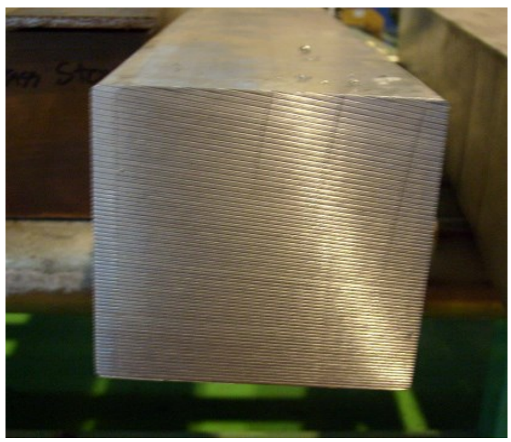

Figure 3.5: The material of aluminium 6061-T6

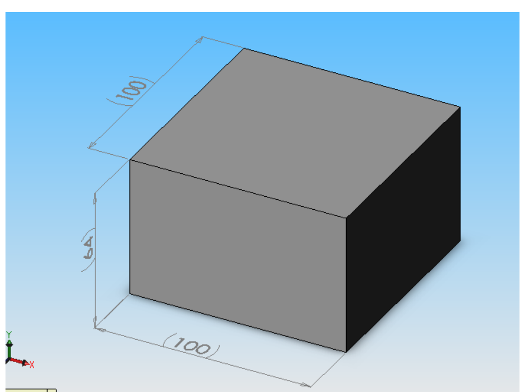

Figure 3.6: The dimension of blocks (100 x 100 x 64) mm

3.4.2 Experiment Design Layout

The grinding experiment was using the of full factorial experiment design. Therefore the experimental layout that be conducted was 18 experiments = (3^2 x 2^1).

Table 3.5: Table of experimental layout

Number of experiments	**Depth of cut, µm**	**Number of passes, n**	**Use of coolant**	**Surface roughness, Ra µm**			
				1st	**2nd**	**3rd**	**Average**
1	0.1	3	ON				
2	0.1	6	ON				
3	0.1	9	ON				
4	0.5	3	ON				
5	0.5	6	ON				
6	0.5	9	ON				
7	1.0	3	ON				
8	1.0	6	ON				
9	1.0	9	ON				
10	0.1	3	OFF				
11	0.1	6	OFF				
12	0.1	9	OFF				
13	0.5	3	OFF				
14	0.5	6	OFF				
15	0.5	9	OFF				
16	1.0	3	OFF				
17	1.0	6	OFF				
18	1.0	9	OFF				

3.4.3 Conducting Experiment

The experiment had begun with cutting the 1 meter of aluminium alloy 6061-T6 into two blocks with dimension 100 mm in length, 100 mm in width and 64 mm in thickness by using bend saw. Then, the work piece had been cut into T- shape by using milling machine and drilled into four holes as describe in figure 3.7. The author needs the holes to clamp the work piece by screw with bolt diameter 8 mm on steel plate or dynamometer device. The reason because the characteristic of aluminium alloy 6061-T6 is nonmagnetic. So it needs another plate to stick on the magnetic table of grinding machine. The experiment of grinding process had been start after finish all the setup of machine and work piece with the dimensions and parameters that use according design of experiment. The first experiment be grinded with depth of cut 0.1µm followed by 0.5 µm, and 1.0µm each passes with coolant and without coolant. The value of surface roughness will measure when 3, 6 and 9 passes for each experiment. The table 3.5 filled up when obtain the measure value of surface roughness using Mahr Perthometer S2 device.

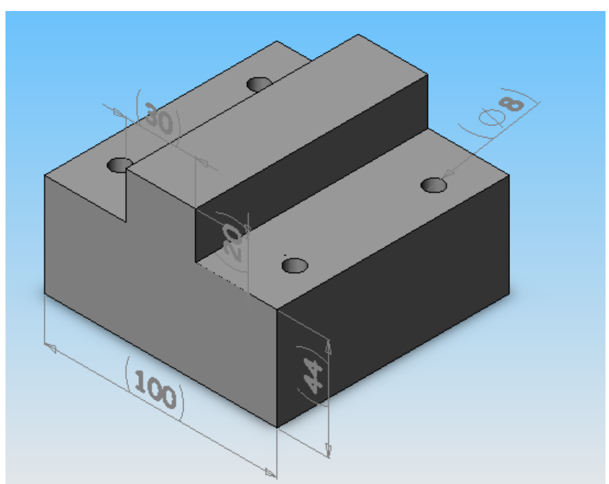

Figure 3.7: The T-shape of work piece

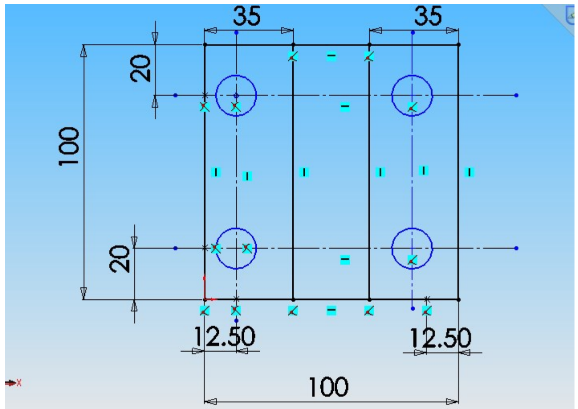

Figure 3.8: Top view of work piece with the dimension in millimeters (mm)

Figure 3.9: The work piece had been cut with bend saw

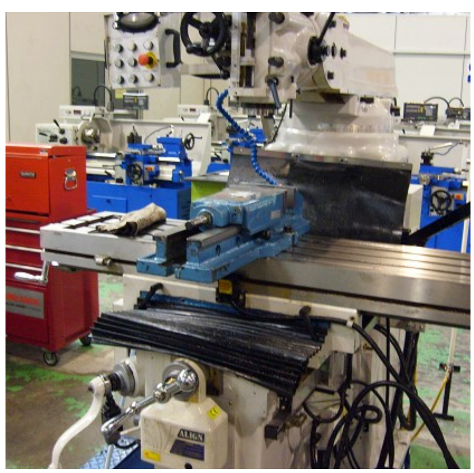

Figure 3.10: The milling machine.

Figure 3.11: Shows face milling to remove slightly surface of workpiece before start.

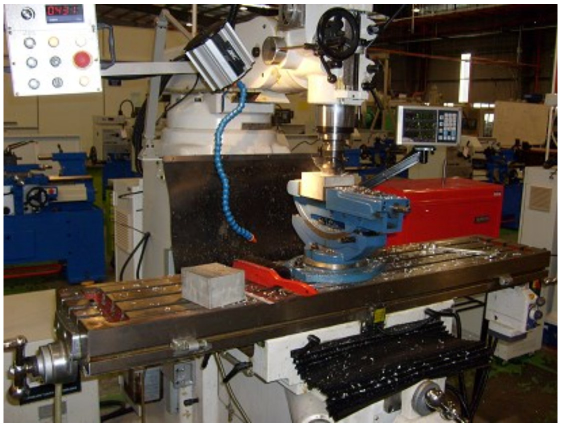

Figure 3.12: The four holes had been done by using milling machine**.**

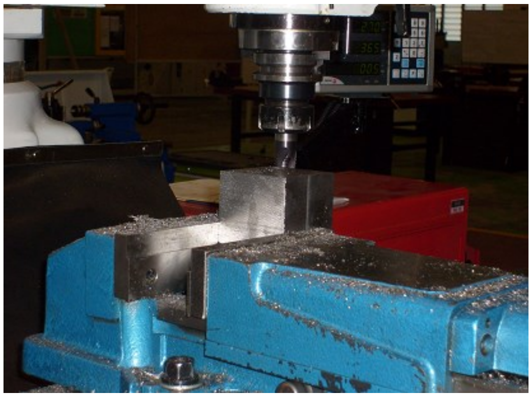

Figure 3.13: The milling machine to make the T- shape

Figure 3.14: shows when grinding process was running.

3.5 MEASUREMENT AND RESULT

The measured values of surface roughness have been obtained from Mahr Perthometer S2 device like figure 3.15. It is a high level of supply and service device that not complicated to operate and handling. The level of quality also high and the results in nanometer range with high performance. The Mahr Perthometer S2 is a measuring device for determine all surface roughness and waviness measurement according current standards DIN*, ISO* 12085, JIS*, and ASME*. It is low weight and has large high resolution graphics display to show of the results and profiles. It also has quick documentation with integrate high resolution thermal printer. The Mahr Perthometer S2 is an ergonomic design because enables to be used while sitting or standing. The Mahr Perthometer S2 allows the results perform in characteristic curves, profile diagrams and measuring records also carrying out statistical analyses. If the drive unit uses a reference surface, waviness measurement can be carried out and profile parameter can be determined (Pt, Wr, and W parameter).

A large, easy to read, graphic display, and a clearly arranged, robust touch-sensitive keyboard with a minimum of keys provide direct and transparent operation. The background lighting can be switched on for better visibility of the display. A warning display indicates specials settings which normally do not occur in everyday measuring. In program-controlled operation, even unpractised user can work easily with the device. Both complete measurement records with characteristic curves and profile diagrams can be printed as well as individual functions such as a single list or curve using an integrated, graphic-capable thermal printer.

Figure 3.15: Mahr Perthometer S2 device**.**

3.6 SURFACE ROUGHNESS

Surface roughness is generally described using two methods: arithmetic mean value and root-mean-square average. The arithmetic mean value (R_a, formerly identified as AA for arithmetic average or CLA for center-line average) is based on the schematic illustration of a rough surface, which in Fig. The arithmetic mean value, R_a, is defined as

$$R_a = \frac{a + b + c + d + \ldots\ldots}{n} \qquad (1)$$

Source by Serope Kapakjian and Steven R. Schmind (2000) [14]

where all ordinates, a, b, c,……are absolute values, and n is the number of readings. The root-mean-square (R_q, formerly identified as RMS) is defined as

$$Rq = \sqrt{\left[\frac{a^2 + b^2 + c^2 + d^2 + \ldots}{n} \right]} \qquad (2)$$

Source by Serope Kapakjian and Steven R. Schmind (2000) [14]

The datum line in Fig. 3.16 is located so that the sum of the areas above the line is equal to the sum of areas below the line. The units generally used for surface roughness are µm (micrometer, or micron) or µin. (microinch).

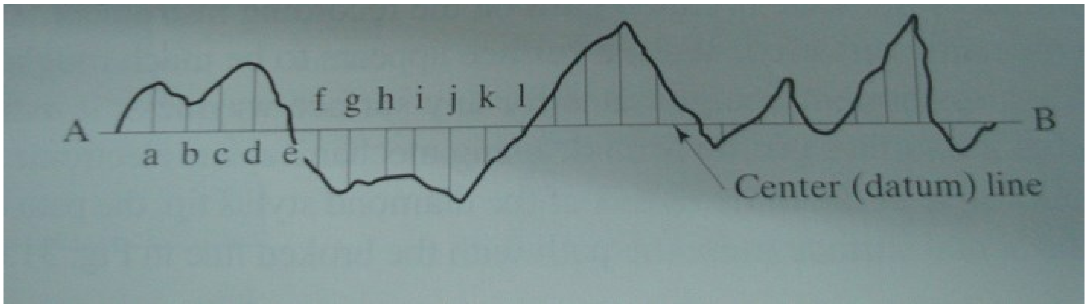

Figure 3.16: Coordinates used for surface roughness measurement by using Eqs.(1) and (2). Courtesy: Serope Kapakjian and Steven R. Schmind (2000) [14]

Besides that, the theoretical value of surface roughness can be obtained in the range of value according to the surface roughness table from the engineer's handbook. From the table 3.6 shows the roughness average for different manufacturing processes in micrometers and micro inches. The value is shown with a typical range and less frequent range for grinding process. It shows that the average range value surface roughness for grinding process is between 0.10 µm until 1.6 µm. Besides that the value of surface roughness those less frequent range are 0.025 µm until 0.05 µm and 3.2 µm until 6.3 µm.

TABLE 3.6: Surface roughness table from engineer's handbook [15]

	Average Range
	Less Frequent Range

Unit (µm)	6.3	3.2	1.6	0.80	0.40	0.20	0.10	0.05	0.025
Grinding									

Surface roughness is one of the most important parameters to determine quality of machined parts. Many investigations have been performed to verify the relations between surface roughness and cutting parameters like cutting speed, depth of cut and the others.

3.7 ANALYSIS OF THE RESULT

The data had been analyze based on effects of depth of cut, number of passes and using coolant and without coolant on surface roughness of aluminium alloys 6061-T6. The graph had been plotted by two graphs which were:

i) Graph value of surface roughness, Ra against number of passes, n. with coolant and without coolant.

ii) Graph value of surface roughness, Ra against depth of cut, DOC with coolant and without coolant.

The data from each experiment had been inserted into Microsoft office excel and make a graph. The pattern of graph had been analyzed according the parameters considerations. Then, the author concluded the results and summarized the objective of the project.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will mainly discuss about the experimental result and summarized all the data of material aluminium alloy 6061-T6 that has been grinding with three levels of depth of cut and number of passes also under uses of coolant. All the results that obtained from the grinding process were recorded and analyze. For more systematic and precise of the interpreting the result, the data had been transformed into the table of results, graphs and ANOVA analysis. Therefore, it much easier to interpret the effect of grinding process parameters on surface roughness aluminium alloy 6061-T6 before any conclusion can be made.

4.2 RESULTS OF EXPERIMENTS

According to the table of result 4.1 that obtained from this experiment, those parameters consideration gives highly affect and relationship surface roughness with variables for the work piece. The surface quality of material when use coolant (oil) much better than using dry grinding. The table 4.1 was drawn based on two different levels of lubricant, three different level of depth of cut and number of passes. The surface roughness that obtained from the experiment satisfies according to the engineer's handbook that shown in table 3.6. The engineer's handbook said that the average range value surface roughness for grinding process is between 0.05 µm until 1.6 µm. Moreover, the value of surface roughness that gets from the experiments as shown in table 4.1 is in that range which is 0.076 µm until 0.971 µm. Therefore, it approve that these experiment was successful and the value reliable.

Table 4.1: The results surface roughness when use coolant (oil) and without coolant (dry grinding).

Number of experiments	**Depth of cut, µm**	**Number of passes, n**	**Use of coolant**	**Surface roughness, Ra µm**			
				1st	**2nd**	**3rd**	**Average**
1	0.1	3	ON	0.060	0.136	0.097	0.098
2	0.1	6	ON	0.090	0.090	0.093	0.091
3	0.1	9	ON	0.055	0.086	0.087	0.076
4	0.5	3	ON	0.114	0.107	0.113	0.111
5	0.5	6	ON	0.082	0.086	0.084	0.084
6	0.5	9	ON	0.073	0.075	0.077	0.075
7	1.0	3	ON	0.118	0.111	0.096	0.108
8	1.0	6	ON	0.113	0.101	0.107	0.107
9	1.0	9	ON	0.081	0.082	0.084	0.082
10	0.1	3	OFF	0.653	0.620	0.607	0.627
11	0.1	6	OFF	0.688	0.831	0.790	0.769
12	0.1	9	OFF	0.563	0.605	0.664	0.611
13	0.5	3	OFF	0.816	0.809	0.815	0.813
14	0.5	6	OFF	0.768	0.757	0.845	0.790
15	0.5	9	OFF	0.823	0.820	0.775	0.806
16	1.0	3	OFF	0.903	1.022	0.988	0.971
17	1.0	6	OFF	0.823	0.869	0.805	0.832
18	1.0	9	OFF	0.858	0.847	0.876	0.860

4.3 ANALYSIS GRAPH OF RESULTS

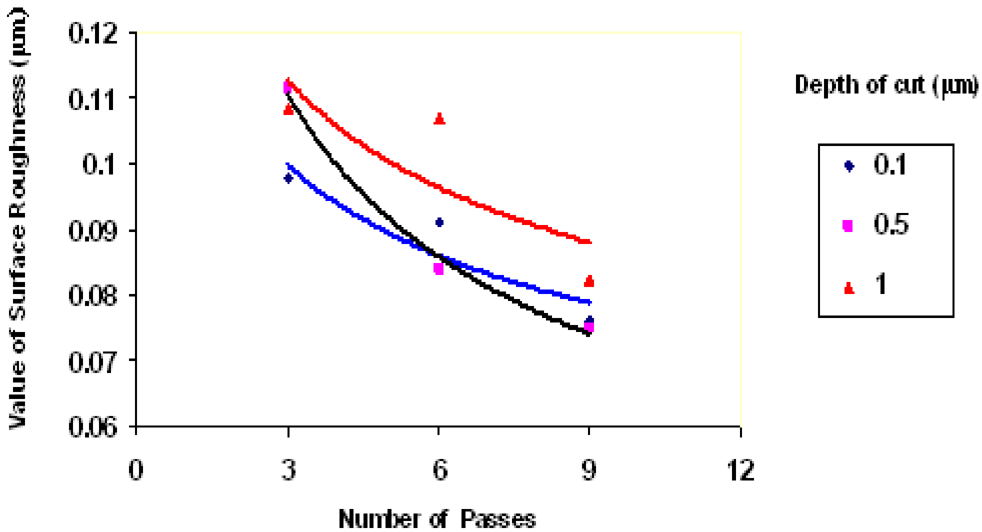

Figure 4.1: Effect of number of passes on surface roughness (with coolant)

Based on Figure 4.1, it shows that when the number of passes increases the value of surface roughness are decreases. It means that when the passes 9 of different levels of depth of cut, all the value of surface roughness lower compared when the passes 3. It strongly shows same like the Bi Zhang et.al. They found that the best stiffness when 9 passes with feed 2 µm per pass. Then, they conclude that at that passes also gives the good surface finish of the ceramics [9].

It is because the single grinding process can cut off large amounts of material and still can produce better surface finish. But, when do the multi-pass grinding the amount of cut off can be a smaller and grind for repeatedly according number of passes. Hence, increasing number of passes the surface quality also produce as desired finish. In addition, the effect coolant also gives highly impact to this grinding process. It reduces energy consumed by sliding interactions occurring in the grinding zone. Therefore, because of the temperature reducing the wheel life can be extending and save the cost.

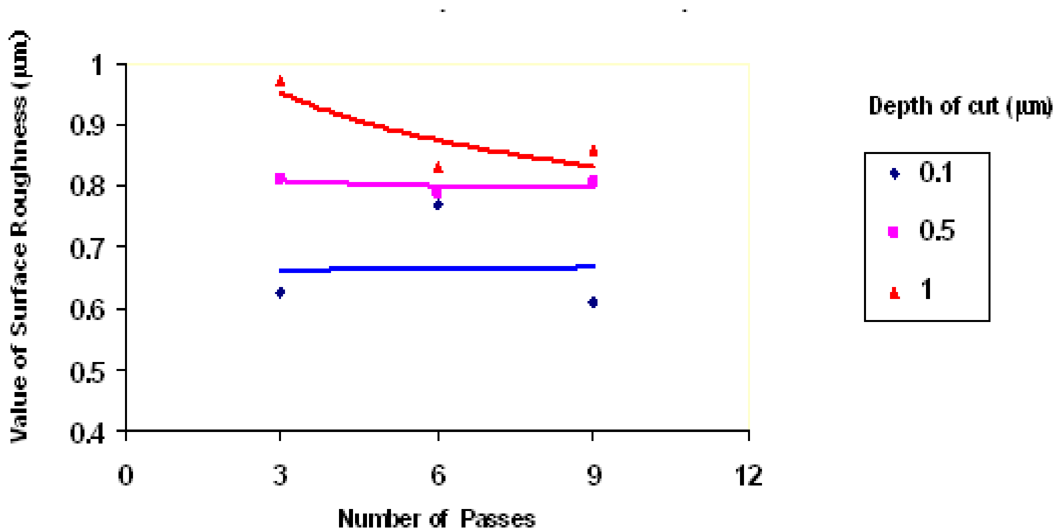

Figure 4.2: Effect of number of passes on surface roughness (dry grinding)

Figure 4.2 shows the graph surface roughness versus number of passes for without coolant. The graph was a little bit different from the graph before. This graph shows when the number of passes increases, the graph of surface roughness seems like a constant especially when the depth of cut 0.5 µm and 0.1 µm. But when the depth of cut 1.0, the graph slowly decreases when increases the number of passes for the experiment running under dry grinding.

The pattern of graph is being like that because of the uses of coolant. It is because when the grinding process was running without the coolant, the surface contact with the work piece not smooth. An interaction with the grinding wheel was increases than use oil. The energy consumes by sliding interaction in the grinding zone and temperature gives higher. Therefore the value of surface roughness became higher and between 0.627 µm until 0.971 µm.

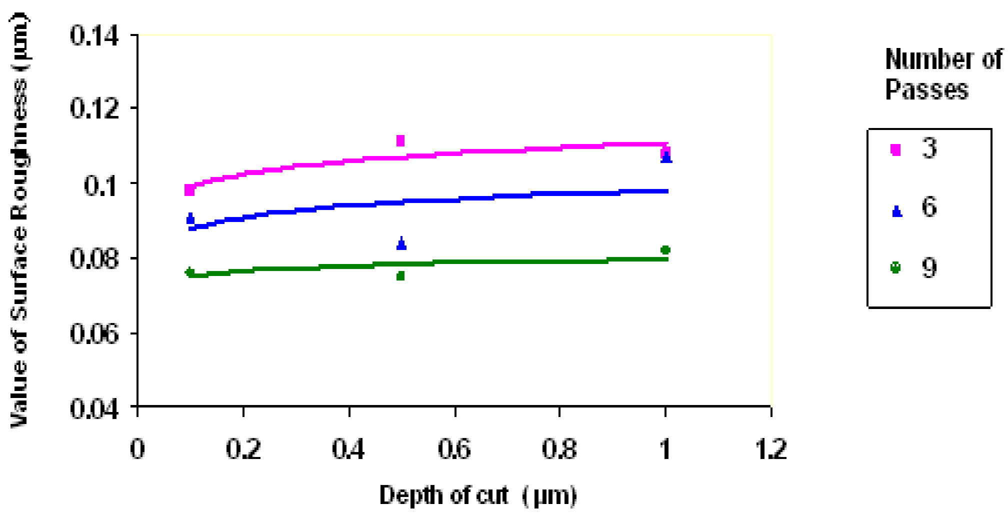

Figure 4.3: Effect of depth of cut on surface roughness (with coolant)

Besides that, from figure 4.3 the graph shows the surface roughness versus depth of cut. As from the graph, the pattern of graph is linear and increasing. As an observation, when the depth of cut increasing, the surface roughness also increasing. It is because more force needed to grind when the depth of cut increase. So the value of surface roughness increases as an affect of the grinding wheel and the touch of surface work piece.

Besides that, to achieve a good surface finish small depth of cut needed. The reasons are because the higher depth of cut can contribute higher grinding force and chatter reproduced when the grinding process. The increases of forces and chatter can generated those grits of wheel actively involved in the material removal process during grinding. So the surface quality became waviness and value of surface roughness higher than use lower depth of cut.

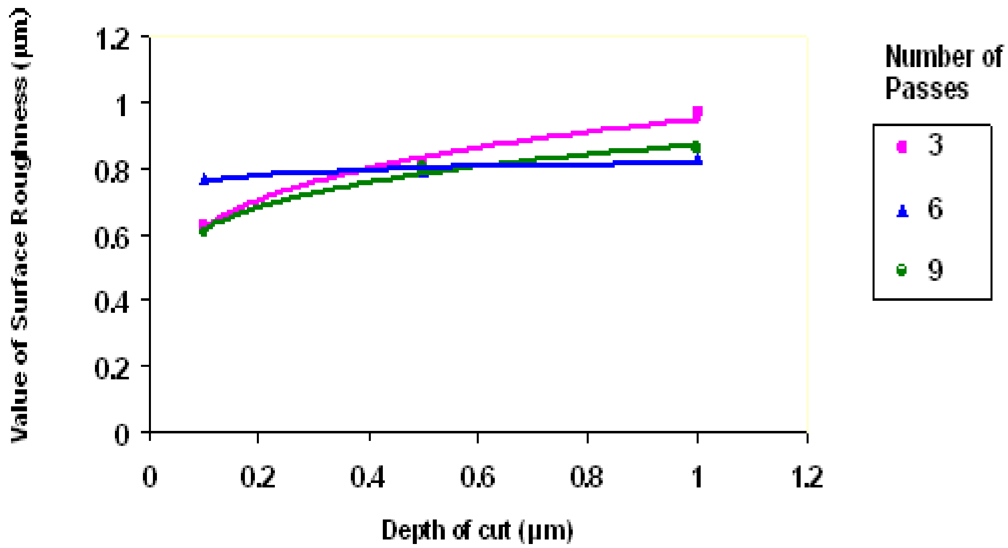

Figure 4.4: Effect of depth of cut on surface roughness (dry grinding)

In this research, the graph from figure 4.4 shows the graph of surface roughness versus depth of cut for without coolant. As observed, the value of surface roughness increasing when the increasing of depth of cut. In spite of that, the graph also linear but the slope for depth of cut 0.1 µm, 0.5 µm and 1.0 µm higher that figure 4.3. Kwak et al also proves from his research that said the maximum of the surface roughness increases proportionally to the depth of cut.

The graph quite drastically increases because effect from dry grinding gives the surface not smooth. The factors of grinding force and temperature also will affect the quality of surface. The surface of work piece can feel a little bit rougher and waviness than the work piece when using the oil.

4.4 ANALYSIS FOR VARIANCE (ANOVA) BY USING MINITAB SOFTWARE

4.4.1 Introduction of ANOVA

The ANOVA is an analysis of the variation present in an experiment. In general, the purpose of analysis ANOVA is to test for significant differences between means. The ANOVA is based on hypothesis testing that the variation in an experiment is no greater than due to normal variation of individuals' characteristics and error in their measurement. A factor is an independent variable whose settings are controlled and varied by the experimenter. The intensity setting of factor is the level. Levels may be quantitative numbers or, in many cases, simply "present" which is "1" or "not present" which is "0" or “2”.

For 1 way ANOVA, there is only one factor will be using to analyze the effect of experiment. For the 2-way ANOVA, the variables would be two. The possible null hypotheses are:

1. There is no difference in the means of factor A
2. There is no difference in means of factor B
3. There is no interaction between factors A and B

The alternative hypothesis for cases 1 and 2 is the means are not equal. Then, the alternative hypothesis for case 3 is that there is an interaction between A and B. For the 3-way ANOVA in means that it has 3 factors in the experiment. The main effects are factors A, B and C. The 2-factor interactions are: AB, AC, and BC. There is also a three-factor interaction: ABC. For each of the seven cases the null hypothesis is the same: there is no difference in means, and the alternative hypothesis is the means are not equal.

4.4.2 Analysis of ANOVA

For this experiment, the purpose of ANOVA is to know which process parameters significantly affect to the surface roughness in grinding process. In this case, the techniques of an ANOVA that have been used were general linear model. The general linear model underlines most statistical analyses that used in applied and social research. It is the foundation for the t-test, Analysis of Variance (ANOVA) and many multivariate methods including factor analysis and others. The value of average surface roughness and the value of each parameter which are depth of cut, no of passes and uses of coolant had been inserted in MINITAB software. Then the results of the ANOVA are presented in table 4.2 and 4.3. This table contains columns labeled "Source", "SS or Sum of Squares", "df refers for degrees of freedom", "MS refers for mean square", "F or F-ratio", and "P-value, probability".

The degree of freedom is a set of n observations with a known mean, the degrees of freedom = n - 1, since all but one could be changed with compensating change only to one other to produce the same mean. Sum of squares is the sum of the squared deviations. When scaled for the number of degrees of freedom, it becomes the variance, the sum of squares per degree of freedom. The “Adj SS”means an adjusted the sum of squares. According to the table 4.3, the “Adj SS” is same like “Seq SS” but it is adjustable by eliminate the value in total. Then, the “Adj MS” means the value of “Adj MS” divided by degree of freedom.

The result can be analyzed with F-test and P-value. The author chose the P-value for the analysis of result ANOVA because the P-value is much easier to understand and model factors to get computational accurate and specific result. The guidelines of P-value are if P-value $\leq$ 0.01, it shows that the difference is highly significant. Then, if P-value > 0.01 but P-value $\leq$ 0.0, it means that there has difference of significant. But if P-value $\geq$ 0.10, it shows that the differences of it has not significant.

Table 4.2: List of variables types of component.

Factor	Type	Levels	Values
Depth of cut, µm	Fixed	3	0.1, 0.5, 1.0
Number of passes, n	Fixed	3	3, 6, 9
With or without coolant	Fixed	2	1, 2

* 1 & 2 refers to: with coolant “1” and without coolant “2”

* General Linear Model: Surface roughness versus Depth of Cut, Number of passes.

Table 4.3: Result from ANOVA analysis

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Depth of cut, µm	2	0.04005	0.04005	0.02002	4.24	0.040
Number of passes, n	2	0.00429	0.00429	0.00215	0.45	0.645
With or without coolant	1	2.16833	2.16833	2.16833	459.11	0.000
Error	12	0.05667	0.05667	0.00472		
Total	17	2.26935				

4.4.3 Discussion of ANOVA

According to the Table 4.3, the ANOVA analysis can be discussed that:

1) The P-value of parameter uses of coolant is 0.000 therefore it is highly significant to the surface roughness. It is because the effect of coolant really contributes the effect of surface roughness. If use the coolant either oil, water base or any coolant the value of surface roughness lower. But when do the grinding process in dry grinding the value of surface roughness higher and surface quality not smooth. It is because in occurring of the grinding zone, when the uses of coolant there can reduce energy consumed by sliding interactions. Therefore, the temperature of work piece and grinding wheel also reducing and the consequences the wheel life can be extending and save the cost.

2) The P-value of parameter depth of cut is 0.040 and it means the depth of cut give significant to the surface roughness but not strongly. Although from that, the depth of cut still can influence the surface roughness in grinding process. The reasons are because the higher depth of cut can contribute higher grinding force and chatter. The increases of forces and chatter can generated those grits of grinding wheel actively involved surface penetrates through the work piece that the stock removal rate increases as it penetrates deeper. So the surface quality became waviness and value of surface roughness higher than use lower depth of cut.

3) The P-value of parameter number of passes is 0.645. It means that the number of passes not significant for the surface roughness. The number of passes in this analysis shows not significant because there have another two other parameters that gives highly affect to surface roughness. But from the analysis of graphs it

shows that there still have the effects for the number of passes. It is because refers to the figure 4.1, the effect of number of passes on surface roughness (with coolant) the graphs shows when increases the number of passes the surface roughness have been decreases. It means that when the passes 9 for any depth of cut, all the value of surface roughness lower compared when the passes 3. Hence, increasing number of passes the surface quality also produce as desired finish.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter is about summarization from the expected results and objectives of research. The data results that obtain from the experiment will compare to the result with other previous research studied. The theoretical review may be used as guidelines when interpreting and comparing the results. The final conclusion for these studies will be compiled and listed in a more systematic and organized ways of presentation.

5.2 CONCLUSIONS

As a conclusion, this experiment satisfies the objective and problem statement of this project which is to investigate and analyze the effects on surface roughness of multi-pass grinding process parameter of Aluminium Alloy 6061-T6.

i) Experiments conducted with coolant produces a good surface quality and a low value of surface roughness than experiments conducted without the coolant (dry grinding).

ii) The depth of cut will influence the surface quality, when the depth of cut increases the surface roughness increases.

iii) Based on observation and data collected it shows that the surface quality of aluminium alloy 6061-T6 will become smoother when the number of passes increases.

5.3 RECOMMENDATION FOR THE FUTURE RESEARCH

From the conclusion that given, some recommendation for further research can be do for investigate and analyze the effect of grinding process parameters on surface roughness of aluminium alloy 6061- T6. First, the author suggests that the parameters will change into cutting speed. According some journals and the author's researches, the surface roughness will decrease when the cutting speed increase. Second, the other parameter than can affect for the surface roughness is the feed rate. The surface quality decreases when the feed rate increases according to the some research. However, it depends on the desire of surface quality needed especially for the product example lenses of camera or spectacles it needs really good surface quality from the grinding process. The third recommendation is the selection of material. As known, the characteristics of aluminium alloy 6061-T6 are nonmagnetic. Therefore the material can be change into steel. It is because the characteristic of steel is non-magnetic to the table of grinding machine. It much easier to clamp and no need any other medium to clamp the work piece. Then, if these three parameters which is cutting speed ,feed rate and the material will be consider, the other parameters like the depth of cut, the number of passes, type of coolant can be a constant to see the good of surface quality and lower of surface roughness.

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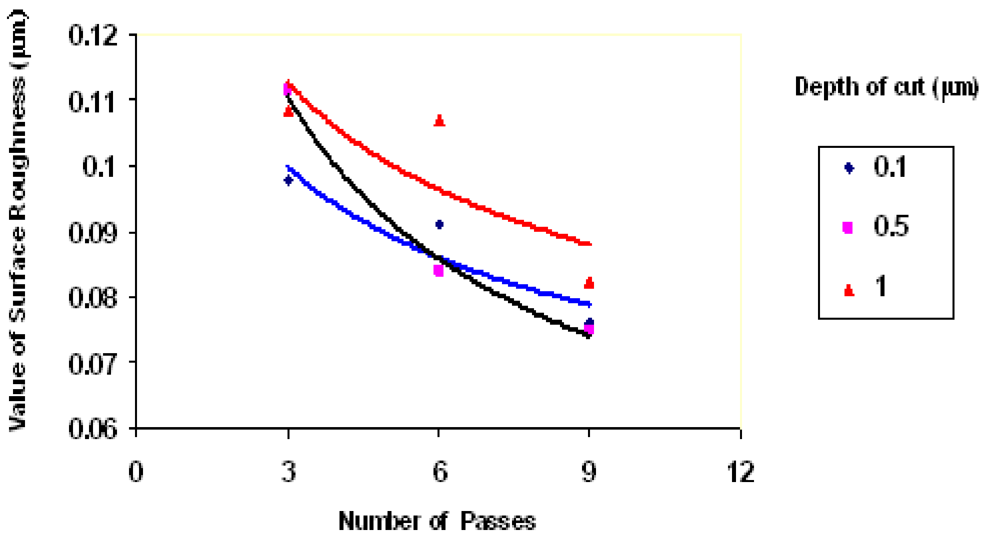
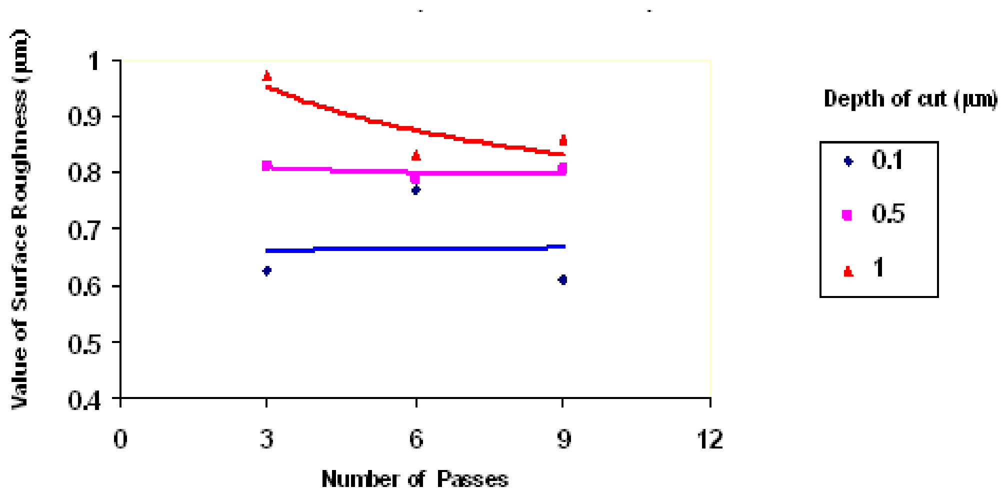
APPENDIX A

GRAPHS

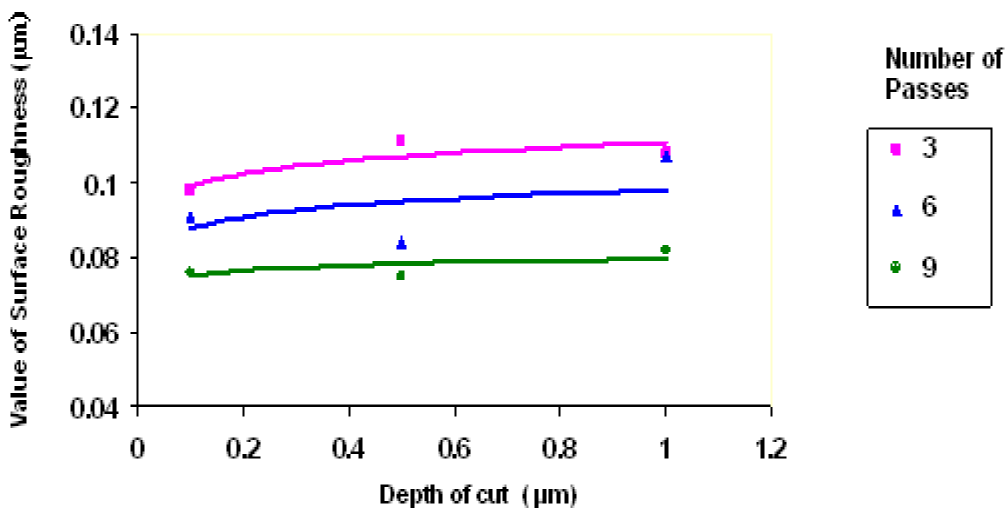
GRAPH OF SURFACE ROUGHNESS AGAINST NUMBER OF PASSES (WITH COOLANT)



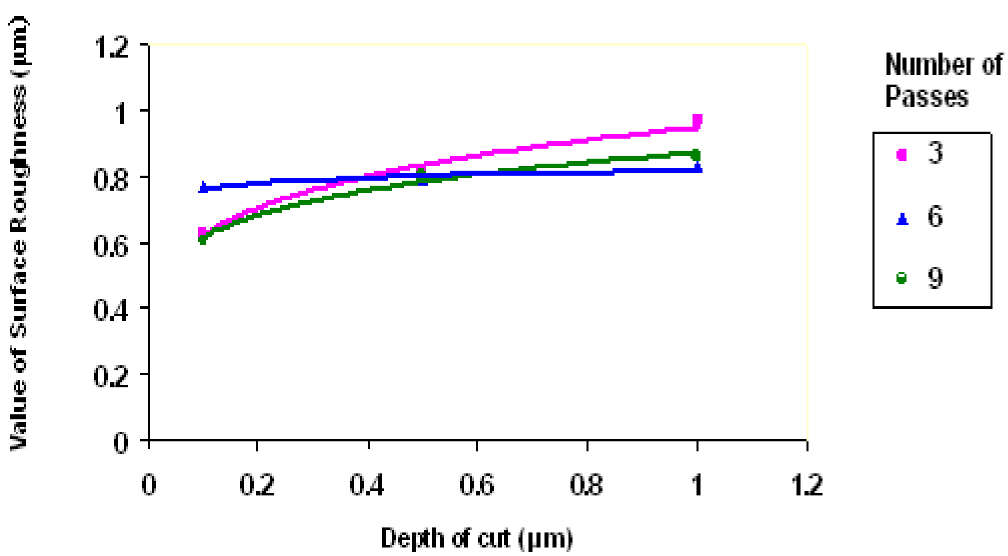
GRAPH OF SURFACE ROUGHNESS AGAINST NUMBER OF PASSES (WITHOUT COOLANT)



GRAPH OF SURFACE ROUGHNESS AGAINST DEPTH OF CUT (WITH COOLANT)



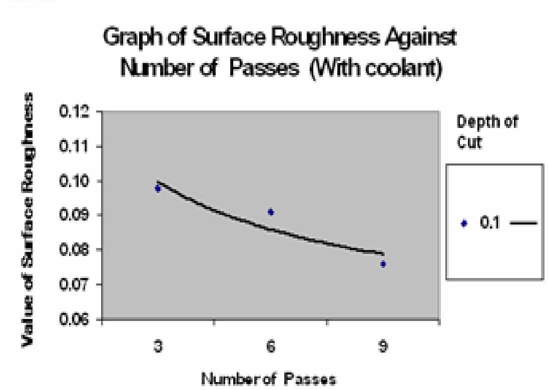
GRAPH OF SURFACE ROUGHNESS AGAINST DEPTH OF CUT (WITHOUT COOLANT)



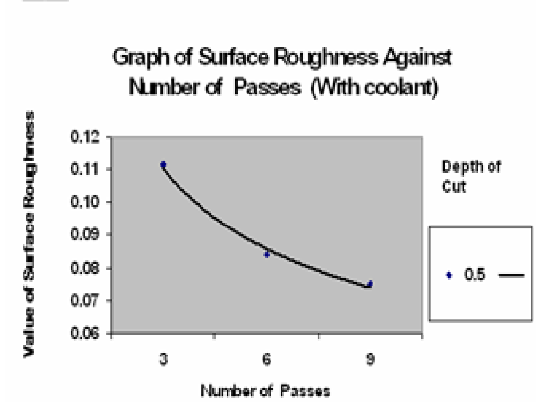
These graphs to show more specifically and clearly according each parameter that considered in this experiment the effect of grinding process parameters on surface roughness aluminium alloy 6061-T6

Graph surface roughness versus Number of passes (with coolant)

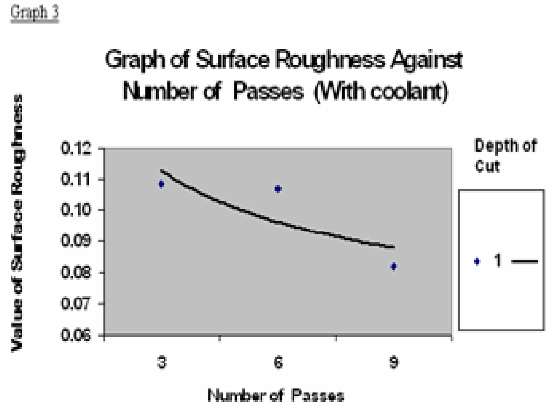
Graph 1



Graph 2

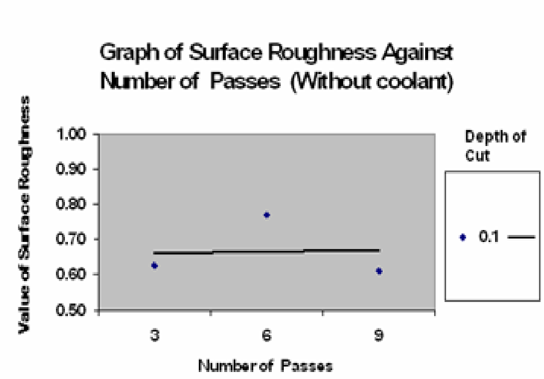


Graph 3

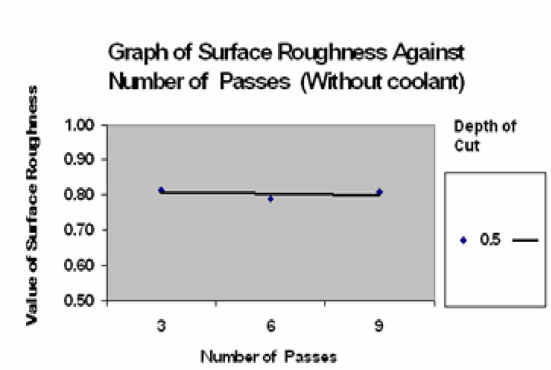


Graph surface roughness versus Number of passes (without coolant)

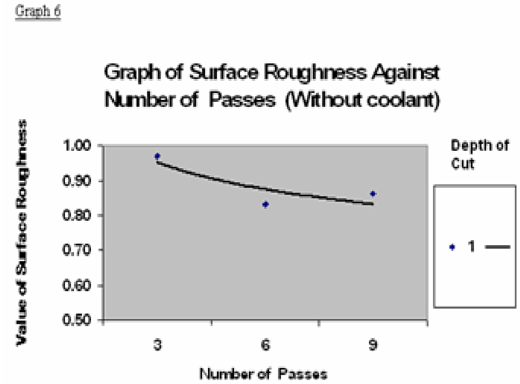
Graph 4



Graph 5

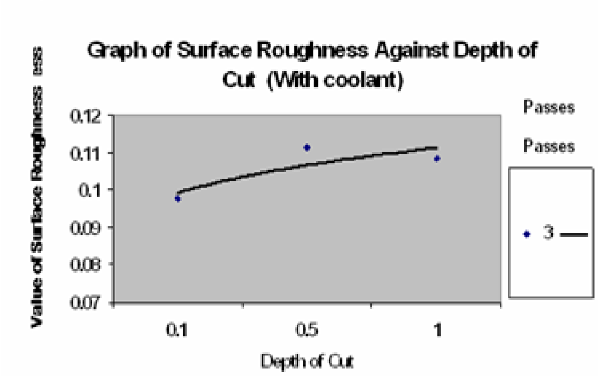


Graph 6

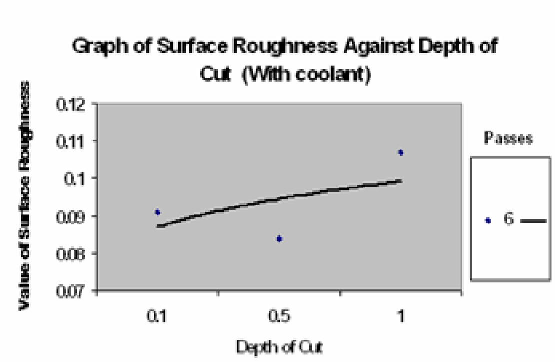


Graph surface roughness versus Depth of cut (with coolant)

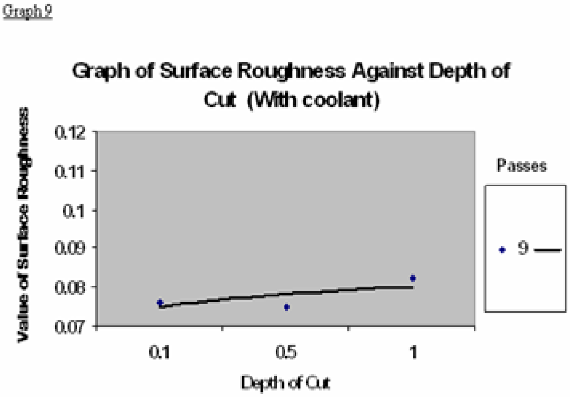
Graph 7



Graph 8

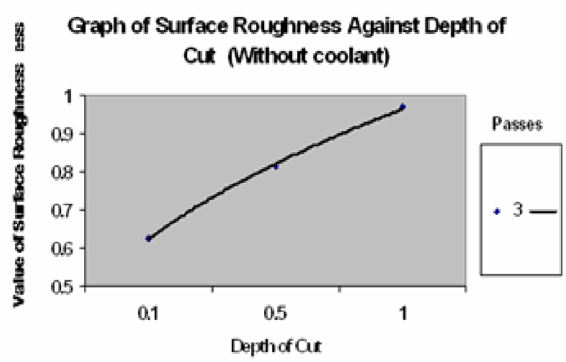


Graph 9

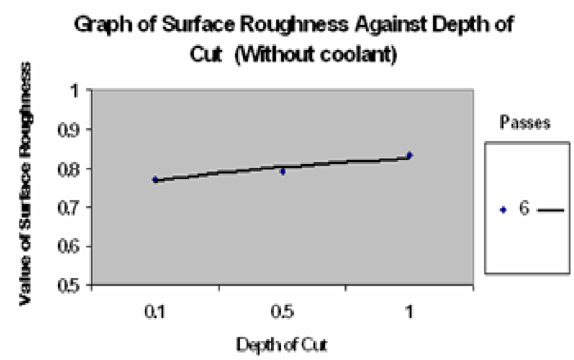


Graph surface roughness versus Depth of cut (without coolant)

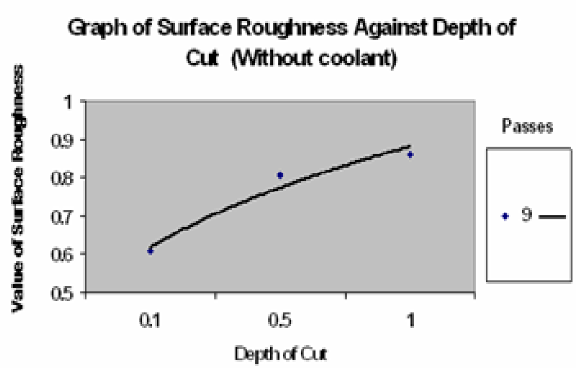
Graph 10



Graph 11



Graph 12



APPENDIX B

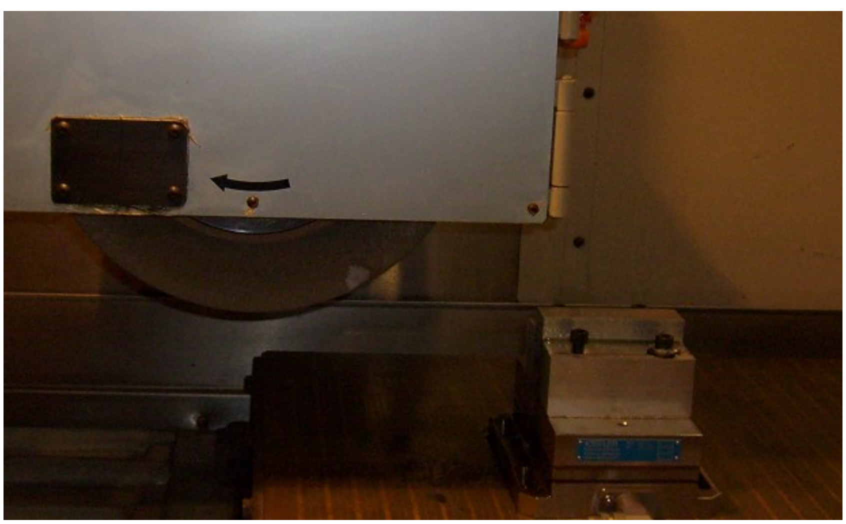
INSTRUMENT

Grinding machine Grind-X Okamoto ACC65DX

The work piece was been clamped with dynamometer type 5070 clamp & sensor

Mahr Perthometer S2

Grinding operation



Appendix C

ASM Material Data Sheet for AA6061-T6

Aluminum 6061-T6; 6061-T6

Subcategory: 6000 Series Aluminum Alloy; Aluminum Alloy; Metal; Nonferrous Metal

Close Analogs:

Composition Notes:
Aluminum content reported is calculated as remainder.
Composition information provided by the Aluminum Association and is not for design.

Key Words: al6061, UNS A96061; ISO AlMg1SiCu; Aluminium 6061-T6, AD-33 (Russia); AA6061-T6; 6061T6, UNS A96061; ISO AlMg1SiCu; Aluminium 6061-T651, AD-33 (Russia); AA6061-T651

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	95.8 - 98.6	Mg	0.8 - 1.2	Si	0.4 - 0.8
Cr	0.04 - 0.35	Mn	Max 0.15	Ti	Max 0.15
Cu	0.15 - 0.4	Other, each	Max 0.05	Zn	Max 0.25
Fe	Max 0.7	Other, total	Max 0.15		

Material Notes:
Information provided by Alcoa, Starmet and the references. General 6061 characteristics and uses: Excellent joining characteristics, good acceptance of applied coatings. Combines relatively high strength, good workability, and high resistance to corrosion; widely available. The T8 and T9 tempers offer better chipping characteristics over the T6 temper.

Applications: Aircraft fittings, camera lens mounts, couplings, marines fittings and hardware, electrical fittings and connectors, decorative or misc. hardware, hinge pins, magneto parts, brake pistons, hydraulic pistons, appliance fittings, valves and valve parts; bike frames.

Data points with the AA note have been provided by the Aluminum Association, Inc. and are NOT FOR DESIGN.

Physical Properties	**Metric**	**English**	**Comments**
Density	2.7 g/cc	0.0975 lb/in³	AA; Typical
Mechanical Properties			
Hardness, Brinell	95	95	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	120	120	Converted from Brinell Hardness Value
Hardness, Rockwell A	40	40	Converted from Brinell Hardness Value
Hardness, Rockwell B	60	60	Converted from Brinell Hardness Value
Hardness, Vickers	107	107	Converted from Brinell Hardness Value
Ultimate Tensile Strength	310 MPa	45000 psi	AA; Typical
Tensile Yield Strength	276 MPa	40000 psi	AA; Typical
Elongation at Break	12 %	12 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Elongation at Break	17 %	17 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Modulus of Elasticity	68.9 GPa	10000 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.

Notched Tensile Strength	324 MPa	47000 psi	2.5 cm width x 0.16 cm thick side-notched specimen, K_t = 17.
Ultimate Bearing Strength	607 MPa	88000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	386 MPa	56000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	Estimated from trends in similar Al alloys.
Fatigue Strength	96.5 MPa	14000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	29 MPa-m½	26.4 ksi-in½	K_{IC}; TL orientation.
Machinability	50 %	50 %	0-100 Scale of Aluminum Alloys
Shear Modulus	26 GPa	3770 ksi	Estimated from similar Al alloys.
Shear Strength	207 MPa	30000 psi	AA; Typical
Electrical Properties			
Electrical Resistivity	3.99e-006 ohm-cm	3.99e-006 ohm-cm	AA; Typical at 68°F
Thermal Properties			
CTE, linear 68°F	23.6 µm/m-°C	13.1 µin/in-°F	AA; Typical; Average over 68-212°F range.
CTE, linear 250°C	25.2 µm/m-°C	14 µin/in-°F	Estimated from trends in similar Al alloys. 20-300°C.

Specific Heat Capacity	0.896 J/g-°C	0.214 BTU/lb-°F	
Thermal Conductivity	167 W/m-K	1160 BTU-in/hr-ft²-°F	AA; Typical at 77°F
Melting Point	582 - 652 °C	1080 - 1205 °F	AA; Typical range based on typical composition for wrought products 1/4 inch thickness or greater; Eutectic melting can be completely eliminated by homogenization.
Solidus	582 °C	1080 °F	AA; Typical
Liquidus	652 °C	1205 °F	AA; Typical
Processing Properties			
Solution Temperature	529 °C	985 °F	
Aging Temperature	160 °C	320 °F	Rolled or drawn products; hold at temperature for 18 hr
Aging Temperature	177 °C	350 °F	Extrusions or forgings; hold at temperature for 8 hr

References for this datasheet.

Some of the values displayed above may have been converted from their original units and/or rounded in order to display the information in a consistant format. Users requiring more precise data for scientific or engineering calculations can click on the property value to see the original value as well as raw conversions to equivalent units. We advise that you only use the original value or one of its raw conversions in your calculations to minimize rounding error. We also ask that you refer to MatWeb's disclaimer and terms of use regarding this information. MatWeb data and tools provided by MatWeb.com, a product of Automation Creations, Inc.

Aluminum Alloy Descriptions

Sheet and Plate Typical Temper Designations

F = As Fabricated   O = Annealed   H = Strained Hardened

The letter H is always followed by two digits. The first digit indicates the particular method used to obtain the temper. Examples are as follows:

H1 = Strained hardened only.
H2 = Strained hardened, then partially annealed.
H3 = Strained hardened, then stabilized.

The temper is indicated by the second digit. Examples include:

H x 2 = 1/4 Hard
H x 4 = 1/2 Hard
H x 6 = 3/4 Hard
H x 8 = Full hard
H x 9 = Extra Hard

T = Heat treated.
T5 = Artificially aged only.
T6 = Solultion heat treated, then artificially aged.
T651 = Solultion heat treated, stretcher stress relieved, artificially aged.

Aluminum Mechanical Properties		Tensile (psi)	Yield (psi)
3003		16,000	6,000
3003	H14	22,000	21,000
5052	H32	33,000	28,000
6061	T6	45,000	40,000
6061	T651	45,000	40,000
6063	T5	27,000	21,000

Source: State Steels Supply Company