EFFECT OF ALUMINUM OXIDE AND SILICON CARBIDE ABRASIVE TYPE ON STAINLESS STEEL GROUND SURFACE INTEGRITY

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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.

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STUDENT'S DECLARATION

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

Signature:
Name: MUHD SYAKIR BIN ABDUL RAHMAN
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Dedicated to my beloved parents,

Abdul Rahman Bin Hj. Samsuddin,

Lai Lee Bte. Ahmad @ Tasar,

my supervisor,

Dr. Mahadzir Bin Ishak @ Muhammad,

my family and friends.

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ABSTRACT

High surface qualities of stainless steel product are important because the applications of stainless steel are wide in industry such as food storage, surgery tools and many more. Grinding process can produce stainless steel product with high surface quality. Grinding is an abrasive machining process that can machine up to ±0.0025 mm tolerance. Grinding is also a surface finishing process that used to improve surface finish and tighten the tolerance of a product. This study focused on the determination of the effect of Aluminum Oxide and Silicon Carbide grinder wheel on the stainless steel surface integrity. Besides that, the relation of the depth of cut and the cutting fluid usage with the crack length and surface roughness are determined. Optimum parameter that contributes to the better surface roughness and less crack length observed. The interaction among them then investigated and analyzed using ANOVA. Mixed Taguchi design of experiments approach used since there are multiple factors of parameters with multiple levels. From the result, ANOVA analysis will be carried out. Experimental results show that coolant usage is optimum in reducing the surface roughness. The interaction of coolant with the depth of cut indicates that coolant can improve surface roughness and extend the level of depth of cut. Meanwhile, crack length and it tendency to occur are less when the depth of cut are less because less residual stress and heat generated. Surface integrity of grinded stainless steel with the Aluminum Oxide grinder wheel is better comparing with the Silicon Carbide grinder wheel. The grindability of stainless steel workpiece materials was found to increase substaintially by using the Aluminum Oxide grinder wheels.

ABSTRAK

Kualiti permukaan produk stainless steel adalah penting kerana aplikasi stainless steel sangat luas dalam industri seperti penyimpanan makanan, alat-alat pembedahan dan banyak lagi. Proses grinding dapat menghasilkan produk stainless steel dengan kualiti permukaan yang tinggi. Grinding adalah proses pemesinan abrasive yang boleh memesin sehingga ±0,0025 mm tolarance. Grinding juga merupakan proses melicinkan permukaan dan digunakan untuk memperbaiki permukaan yang telah selesai dimesin serta merapatkan tolerance suatu produk. Kajian ini memfokuskan pada kesan Aluminium Oxide dan Silicon Carbide roda penggiling keatas integriti permukaan stainless steel. Selain itu, hubungan kedalaman potongan dan penggunaan cecair pemotongan dengan kepanjang retak dan kekasaran permukaan ditentukan. Optimum parameter yang memberikan sumbangan terhadap kekasaran permukaan yang lebih baik dan panjang retak yang sedikit diperhatikan. Interaksi antara mereka kemudian diteliti dan dianalisis menggunakan ANOVA. Pendekatan eksperiments Taguchi yang bercampur-campur digunakan kerana ada beberapa faktor parameter dengan beberapa tahap. Dari hasil kajian, analisis ANOVA akan dilakukan. Keputusan kajian menunjukkan bahawa penggunaan cecair penyejuk optimum dalam mengurangkan kekasaran permukaan. Interaksi cecair penyejuk dengan kedalaman potongan menunjukkan bahawa cecair penyejuk dapat mengurangkan kekasaran permukaan dan menambah tahap kedalaman potong. Sementara itu, panjang retak dan kecenderungan berlakunya keretakan kurang apabila kedalaman potong kurang kerana kurangnya residual stress dan pemansan dihasilkan. Integriti permukaan daripada bahan stainless steel yang telah digrind dengan roda penggiling Aluminium Oxide lebih baik berbanding dengan roda penggiling Silicon Carbide. Keupayaan untuk grinding bahan kerja stainless steel didapati meningkatkan dengan banyaknya menggunakan roda Aluminium Oxide.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ρ	Density
μm	Micrometer
F_n	Normal force
F_t	Tangential force

LIST OF ABBREVIATIONS

Al_2O_3	Aluminum Oxide
ANOVA	Analysis of variance
ASME	American society of mechanical engineer
DF	Degree of fredoom
F	Ratio of two variance
MS	Mean square
H_A	Null hypothesis
H_O	Alternative hypothesis
SS	Sum square
P	Probability of obtaining a test statistic
Ra	Surface roughness
SiC	Silicon Carbide

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

One of the best method to produce a part or a workpiece that the material is too hard or too brittle and it require high dimensional accuracy and surface finish is by using abrasive machining. Grinding machining is a process of removing small chips or particle from material using the mechanical action of abrasive particle. The shapes of abrasive particles are in irregular shape, size, and hardness. Grinding is a finishing process which are used to improve surface finishing of materials, abrade hard materials, and tighten the tolerance on flat and cylindrical surfaces.

The process of removing chips from material occurs when the abrasive material rubs again the workpiece and remove the tiny pieces of the worpiece, i.e abrasive and the material to be worked are brought into contact while in relative motion to each other. Commonly, for grindng machine, the abrasives are bonded and compacted in wheel or belt shape and selected based on the purpose of the grinding process and type of material need to be grind.

Grinding wheels are compacted abrasive in wheel shape that are rotated at high speed. While once worked with a foot pedal or hand crank, the introduction of electric motors has made it necessary to construct the wheel to withstand greater radial stress to prevent the wheel flying apart as it spins.

Commonly, the grinding process were selected because the materials are too brittle to be machined economically. The materials may or may not have been hardened in order to produce a low-wear finish, such as stainless steel. Beside that, the grinding machine can machine up to ±0.0025 mm flatness tolarences. Griding process also can removes the excessive material for better surface finishing of product.

For industry application, the grinding process used to obtain high precesion surface finish such as in medical tools production, dies and tool production, gear and many more. High grade stainless steel are used for medical equipment required very fine tolarence.

1.2 PROJECT BACKGROUND

Commonly, grinding machine consist of a bed with fixture to guide and hold the workpice that need to be grind. It also contain power driven wheel that spin at the required speed. The grinding head can be controlled to travel across a fixed work piece or the workpiece can be moved whilst the grind head stays in a fixed position. To control the head or table of grinding, a vernier calibrated hand wheel were used. Another way to control it is by using the features of numerical.

In this study, a surface grinding will be used. Surface grinding is one of the most common operation and comprise the largest percentage grinders used in industry. In generally involves the grinding of flat surfaces. For surface grinder, the workpice need to grind were secured on a magnetic chuck which is attached to the table grinder. Fro nonmagnetic materials, its were held by vises, vacuum chucks or some other fixture.

A straight wheel of abrasive is mounted on the horizontal spindle of the surface grinder. As the table reciprocates longitudinally, the traverse occurs and its fed laterlly after each stroke in the direction of the spindle axis. When grinding, heat generation cannot be avoided. Therefore, coolant usage can reduce the heat generation to the workpiece, thus increasing the tool life and life cycle production.

Surface grinder can be devide into 3 major types, which is tranverse grinding, plunge grinding, and Blanchard type. Blanchard type is a vertical spindle and rotary table grinder.

There are several considerations in selecting grinding wheel for grinding process. One of them is the compatibility with the workpice. For Aluminum Oxide, it is recomended to grind steels, ferrous alloys and other high tensile materials. Silicon Carbide extensively used for grinding hard and dense material such as non-ferrous metals, non-metallic elements, and cast iron.

1.3 PROBLEMS STATEMENT

Grinding is a major surface finishing in most application in industry. Therefore, lots of studies of optimization parameters for grinding were done by many researcher to improve the surface integrity of grinding surface. In surface grinding, abrasive will effect the surfae integrity of the workpice. As well known, the force from grinding will cause crack on the surface of workpice as the depth of cut increase, thus generate heat. This condition also called heat checking. Other than that, grinding also can cause sparks, tempering and softening from excessive temperature rise, burning on the workpice surface, and residual stress.

The selection of abrasive and workpiece also important to increase the life cycle production, as well as increasing the tool life and grinding efficiency. Besides that, the abrasive will wear due to the rapid collision with the workpiece and need to be dressing. Aluminum Oxide wheel grinder have a small grain size particles, therefore it is a good abrasive in order to get smooth surface. But it tend to wear when cycle production is conducted and dressing is a compulsory. Meanwhile, the Silicon Carbide wheel grinder have a larger grain size particles, thus generate a rough surface finishing.

Stainless steels, one of alloy steel group, consist a minimum of 10.5% or 11% chromium and more than 50% iron content by mass. Its a corrosion resistance steel and have the antibacterial properties. The chromium content in stainless steel alloy is what generally prevents corrosion. Altough it is a corrosion ressistance steel, the temperature during grinding will cause the oxidation on the surface layer. Oxidation will cause corrosion on the surface of the stainless steel. The corrosion on the surface layer need to be avoided when the application of steel used in medical equipments, cookwares or food storages.

The significant of this study will increase the efficientcy of grinding process for the stainless steels products. The optimization of grinding parameters will generate better surface roughness.

1.4 PROJECT OBJECTIVES

There are several objectives in conducting this project. The lists of project's objectives are:

(i) To determine the effect of Aluminum Oxide and Silicon Carbide abrasives on the stainless steel surface integrity.

(ii) To determine the optimum grinding parameter process by manipulating depth of cut of the grinding and coolant usage with two type of wheels

(iii) To investigate the relation of surface crack on the workpiece with the depth cut of the grinding using SEM or microscope.

1.5 PROJECT SCOPES

The project scopes were determined based on the following specifications:

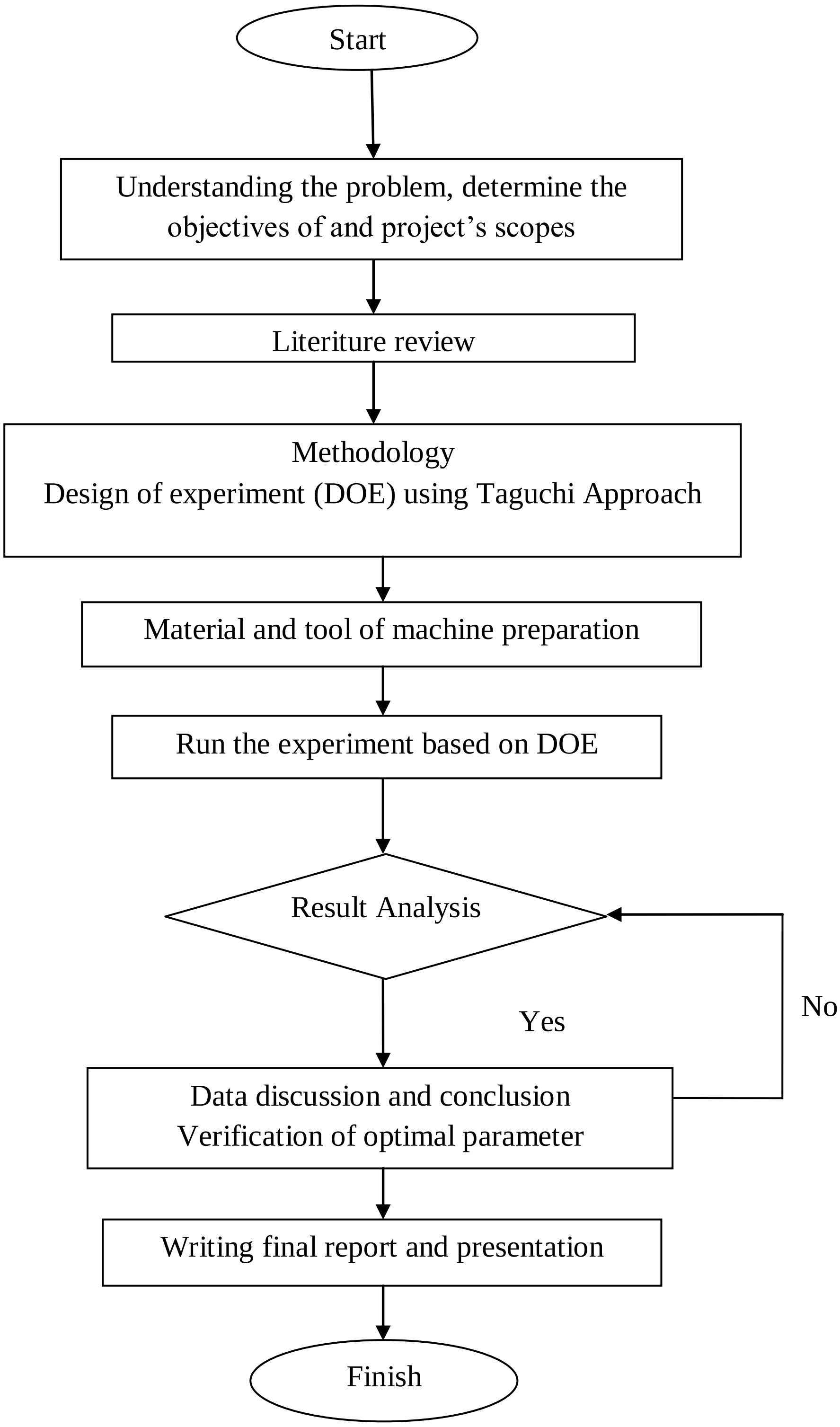
(i) The experimental will conduct based on DOE – Taguchi Approach

(ii) Identifying the parameter that should be considered in this experiment such as cutting fluid, feed rate, depth of cut, and spindle speed.

(iii) Selecting the abrasive usage based on the abrasive workpiece-material compatibility

(iv) The materials used are stainless steels

1.6 PROJECT FLOW CHART



CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

To produce a part that requires high dimensional accuracy and surface finishing, or the workpiece material that too hard or to brittle to process is using abrasive machining. Such characteristic can be obtained using grinding machine. Grinding machining is a process of removing small chips or particle from material using the mechanical action of abrasive particle. Fathallah et al. (2009) stated that the shapes of particle are in irregular shape, size, and hardness. This process can be either rough or precise operation, depending on the requirement of the product. For both internal and external grinding process, the medium required is the grinding wheels.

2.2 GRINDING MACHINE

2.2.1 Historical Perspective

According to American Society of Mechanical Engineers (ASME), grinding machine was first developed around 1830 – 1859. Surface-grinding machine was patented by J W Stone at Washington DC on 1831. And on 1834, grinding machine was developed and perhaps it was the first ever machine was developed. The developer of the grinding machine is Wheaton of Providence. The developments of grinding machines continued after that, and the revolution of grinding machine based on the purpose of the process. Figure 2.1 showed the time line of the development of the grinding machine.

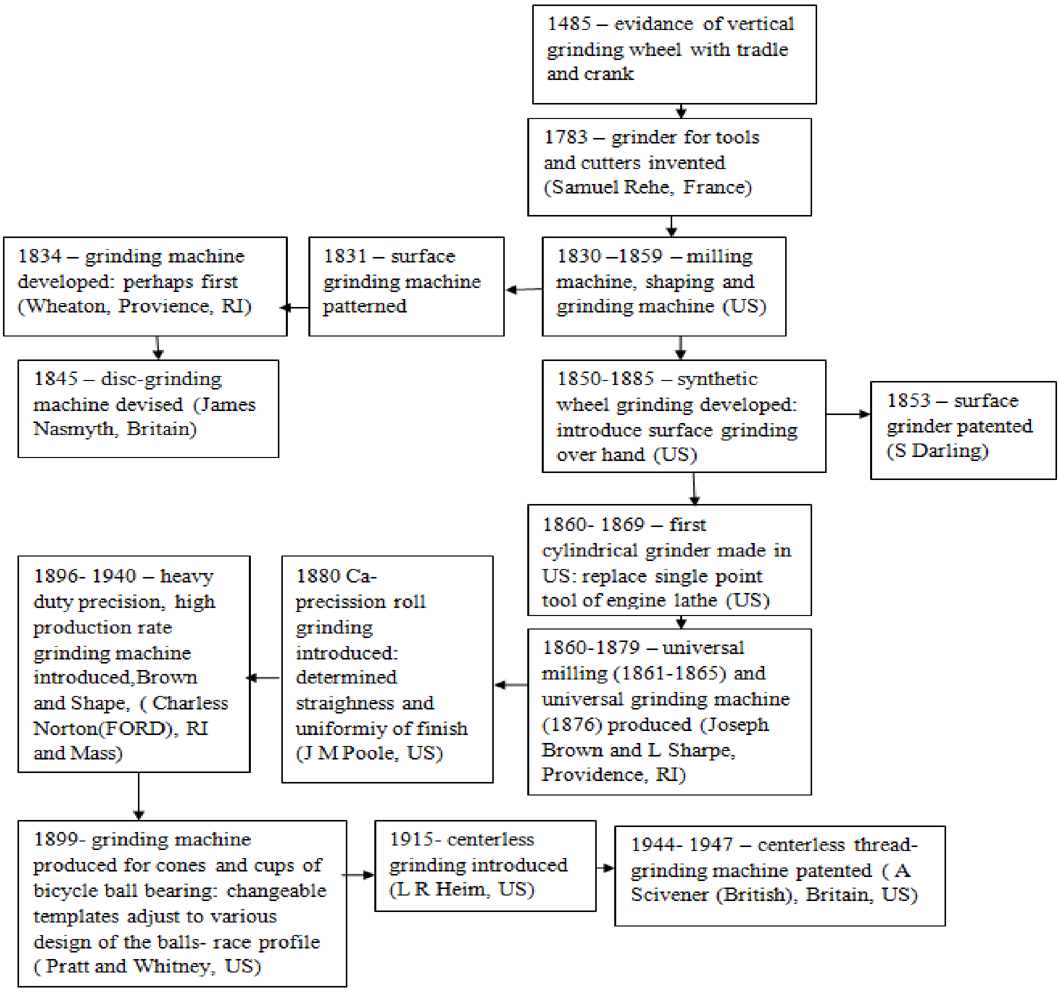


Figure 2.1: Schematic diagram of timeline of the developments of grinding machine

Adapted from: ASME

After the industrial revolution and World War II, many researchers did the development of grinding machine and the study to increase the efficiency and effectiveness because grinding process is a major surface finishing in industry.

2.2.2 Types of Grinding Process

Grinding process were selected based on the purpose of the grinding itself. There are several operation of grinding machine. Table 2.1 show the variety of grinding machine process.

Table 2.1: Variety of grinding process

Process	**Characteristics**	**Typical maximum dimensions,length and diameter, (m)**
Surface	Flats surfaces on most materials;production rate depends on the table size and level of automation;labor skill depends on part complexity;production rate is high on vertical – spindle rotary – table machines	Reciprocating table length: 6 Rotary table diameter: 3
Cylindrical	Round workpieces with stepped diameter ; low production rate unless automated; low to medium labor skill	Workpiece diameter: 0.8 Roll grinder diameter: 1.8 Universal grinder diameter: 2.5
Centerless	Round and slender workpieces; high production rate; low to medium labor skill	Workpiece diameter: 0.8
Internal	Holes in workpiece; low production rates; low to medium labor skill	Hole diameter: 2
Honing	Holes in workpiece; low production rates; low labor skill	Spindle diameter: 2
Lapping	Flat, cylindrical or curved; high production rate; low labor skill	Table diameter: 1.2
Ultrasonic machining	Holes and cavities with various shapes; suitable for hard and brittle materials; medium labor skill	-

Adapted from: Kalpakjian and Schimid (2006)

2.3 SURFACE GRINDING

Surface grinding involve of placing the workpiece material on the bed, and clamp with magnetic chuck. The grinding occurs when the longitudinal bed tranverse, then the grinding wheel make the contact with the workpiece. The abrasive removes the chips on the material when the contact occurs.

Chati'opadhyay and Paul (1995) stated that the grinding process has some basic characteristics, such as high specific energy and high grinding zone temperature which are identified as the main cause of several related problems in grinding process. Its generate the cracks on surface integrity and increase the roughness of the surface.

Figure 2.2: Surface grinding machine

To reduce these problems, previous researchers did many studies (Fathallah et al., 2009; Choi et al., 2001; Chaitopadhyaya and Paul, 1995). Cutting speed, the stock removal rates and cutting fluid have got much attention in recent years (Chaitopadhyaya and Paul, 1995).This multitude of process parameters has made the selection of the adequate grinding conditions more and more difficult and gives rise to the need to conduct comparative studies to help finding the appropriate parameters depending on the ground material and selection criteria.

2.4 CUTTING FLUIDS

As Kalpakjian and Schimid (2006) claimed, the cutting fluid is an important in grinding process. Depending on the type of grinding, the cutting fluid used can be coolant, lubricant or both. The extensively usage of cutting fluid mainly to achieve the following results:

(i) Reduce friction and wear, therefore can improving tool life and the surface finish of the workpiece
(ii) Cooling the cutting zone, thus improving tool life and reducing the temperature and thermal distortion of the workpiece
(iii) Reduces force and energy consumption
(iv) Flush the cutting chips away from cutting zone
(v) Protect the machined surface from environmental corrosion

The mechanism of cutting fluids can penetrate the important rake face of the tool and influence the cutting process. Cutting fluid gains access to the tool-chip interface by seeping from the side of the chips by the capillary action of the interlocking network of surface asperities in the interface (Malkin and Guo, 2008; Chaitopadhyaya and Paul, 1995). Commonly, four basic cutting fluids used widely in machining operation as stated by Kalpakjian S.and Schimid S. (2006). There are:

(i) Oils: also called straight oil, including mineral, animal, vegetables, compounded, and synthetic oil typically are used for low-speed operation which temperature rise is not significant
(ii) Emulsion: also called soluble oils, mixture of oil and water and additives
(iii) Semi-synthetics
(iv) Synthetics

2.4.1 Oil-Based As Coolant and Lubricant

The effectiveness of certain cutting fluids depend on the machining process parameter itself such as type of machining operation, tools and workpiece materials, cutting speed and the method application as carried out Brinksmeier et al., (1999). The coolant usage, which contains chlorine, sulfur and phosphorus improve the grinding efficiency. Chaitopadhyaya and Paul, (1995) found that the surface roughness with coolant usage was better compared with dry grinding.

The usage of grooved wheels and soluble oil as coolants reduce the temperature. Besides that, coolant also produce lubricants reduce the heat generation at workpiece material and reduce the specific energy. In addition, because of its cooling effect is inferior to that of water, oil generally used where the primary aim is to reduce friction (Choi et al., 2001; Klocke et al., 2000; Chaitopadhyaya and Paul, 1995).

Nevertheless, nowadays, the concerning about cutting fluid usage that causes the environmental pollution considered. One of the ways is by replacing the oil-based with cyro-cooling and use dry grinding with compressed air as studied by Choi et al. (2001); and Chaitopadhyaya and Paul, (1995). Studies conducted to observe the effects of cyro-cooling on the surface integrity of workpiece.

Choi et al. (2001) stated that the result of wet grinding with the coolant and dry grinding with compressed cold air showed that surface roughness of the grinding surface had a similar tendency. Nevertheless, the change of residual stress with compressed cold air less compared with the coolant. Fredj et al., (2006) state that the usages of cyro-cooling in grinding not only reduce the grinding force and temperature but also improves the surface integrity supported this.

The alternative usage of coolant and lubricant was considered because it shown that the maintenance cost increase when the usage of oil-based and it also cause pollution to environment (da Silva et al., 2007).

2.5 ABRASIVE

In recent years, brazing superabrasive grits to a steel substrate in a monolayer configuration with a suitable material has found application in manufacturing high performance wheels which can outperform their conventional galvanically bonded single layer counterpart (Webster and Tricard , undated).

Better grit retention, better bond uniformity and higher crystal exposure are claimed to be advantageous features of such wheels. Claims are made that such types of superabrasive tools can efficiently solve abrasive machining problems involving loading and heat generation by da Silva et al, (2007) and Webster and Tricard, (undated).

Aluminum Oxide or called corundum was made in 1983, generally produced by fusing bauxite, iron filling and choke. Silicon Carbide was first introduced in 1981 and made with silica sand and petroleum choke (Tata-McGrawhill, 1986).

The performance of any abrasive product depends on the abrasive properties and grinding conditions (forces, chip thickness, etc.) to which it is subjected. One abrasive that is an excellent performer in high force per grit applications may be less than optimal in low force per grit applications. The selection of wheel grinding of superabrasive were determined in Table 2.2.

Table 2.2: Standard marking system for Aluminum Oxide and Silicon Carbide bonded abrasive

51	**A**	**36**	**L**	**5**	**V**	**23**
Prefix Type	Abrasive	Abrasive Grain Size	Grade	Structure	Bond Type	Manufacturer's Code

Adapted from: Kalpakjian and Schimid (2006)

Figure 2.3: Aluminum oxide wheel abrasive

Figure 2.3 showed the Aluminum Oxide grinder 1A1-straight wheel type. It contains more than 98% of aluminum oxide and use to machine steel and alloys that contain more than 0.5% carbon. It works well on tool steels such as stainless steels and cast iron. Usually, the material's hardness that was machined by this type of wheel grinder is above 62 HRC. The other name of this grinder wheel is 25A-Pink. The diameter is 1.8 mm and the thickness is 13 mm (Saint-Gobain).

Figure 2.4: Silicon Carbide wheel abrasive

Figure 2.4 showed the Silicon Carbide grinder wheel. The specifications of Silicon Carbide listed in Table 2.4.

Table 2.4: Specification of Silicon Carbide grinder wheels

Name	Colouration	SiC contents	Machined materials
39C (green Silicon Carbide)	dark green	99,66%	cemented carbides, titanium, metal matrix composites and plasma sprayed materials
37C (black Silicon Carbide)	black	98,26%	300 series stainless steels, irons, nonferrous metals (aluminum, brass, bronze and copper) and non-metallic materials (stone, marble, rubber, ceramics and glass).

Adapted from: Saint-Gobain

2.5.1 Abrasive - Workpiece Material Compatibility

It claimed that the less the reactivity of the two materials, the less wear, and dulling of the grains occurs during grinding. Both of these factors will make the grinding process less efficient as stated by Kalpakjian and Schimid (2006), and Malkin and Guo (2008). Therefore, it will create damage on the surface integrity of the workpiece.

Generally, the following recommendations considered before selecting an abrasive for certain process (Kalpakjian and Schimid, 2006).

(i) Aluminum oxide: carbon steels, ferrous alloys, and alloys steels.
(ii) Silicon Carbide: nonferrous metals, cast irons, carbides, ceramics, glass, and marble.
(iii) Cubic boron nitride: steels and cast iron above 50 HRC hardness and high temperature alloys.
(iv) Diamond: ceramics, cemented carbides, and some hardened steels.

Stainless steel is a steel alloy that does not stain, corrode, or rust as easily as ordinary steel, but it is not stain-proof. It contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure.

To perform grinding on stainless steels, it is affordable to use Aluminum Oxide or Silicon Carbide abrasive type since the cost is less compared to diamond abrasive and efficent fo industry application.

2.6 PARAMETERS

Parameters involve in grinding must be controlled properly. Each parameter in the grinding contributes to the surface integrity of the workpiece. The interaction of them will discuss later in the result.

2.6.1 Depth of Cuts

The depth of cut defined as the depth of the chip taken by the cutting tool. It typically measured in millimeters or inches. It significantly influences the tool life. Increasing in the depth of cut is proportional to the cracks and heat generated.

2.6.2 Cutting speed

Cutting speed in this experiment was fixed. It defined as the speed of the wheel at which the work moves with respect to the material workpiece. Usually, cutting speed is measured in revolution per second. It is also proportional to the diameter of the wheel speed. Lager diameter means less velocity, therefore, less cutting speed produced.

2.6.3 Feed Rate

The speed of cutting tools movement relatives to the workpiece as the tool make cut. The feed rates measured in millimeters per minutes and it is products of the cutting feed and the spindle speed.

2.7 SURFACE INTEGRITY

2.7.1 Cracks

All abrasive finishing systems are intended to ‘‘generate surfaces’’. The value or benefit may be described in terms of the functions served by the surface and how fast that surface can be generated (Oliveira et al., 2006).

Types of cracking and fracture ground surface layers generally known to be formed by a combination of grinding force and grinding temperature. Studies (da Silva et al., 2006; Eda et al., 1983; and Kalpakjian and Schimid, 2006) determined that such high surface temperature usually results in thermal damage such as burning, oxidation, formation of untempered martensitic layer, induction of tensile residual stresses and cracks at the surface.

As Barbacki et al., (2003) carried out the study, the surface layer is usually composed of a superficial white layer and a dark layer. The latter is formed when heat produced by the machining process can overtemper the transitional zone between the white layer and the unaffected material. This will generate cracks on the surface of the workpiece.

2.7.2 Residual stress

The tensile residual stresses detrimentally reduce the static strength and fatigue life, enhance chemical corrosion, propagate cracks in brittle materials and lead to distortion while grinding and during service life of the product (Eda et al., 1983).

The principal stress directions for the stresses generated in the grinding process were found aligned approximately parallel and perpendicular to the grinding direction. Balart et al., (2004) stated that it is important to know the magnitude and location of the maximum residual stress.

Residual stress profiles were measured to be either compressive or tensile, with the maximum stress magnitude always situated at the sample surface. Previously, Barbacki et al., (2003) carried out the study that the onset of tensile surface residual stresses is caused by exceeding a critical transition temperature. The grinding parameters are only contributory in as much as they cause the transition temperature to be exceeded.

Temperatures for the threshold of softening were higher than the corresponding critical transition temperature for the onset of tensile residual stress. The onset of tensile residual stresses is primarily activated by a combination of mechanical deformation and thermally-induced plastic deformation effects (Balart et al., 2004).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In order to achieve the objectives of this study, sequences of works have been planned as shown in Figure 3.1. This process involved in achieving notified objectives are including determining apparatus, methods, and parameters, conducting machining experiments, results analysis and data discussion. The result obtained from this project then will be applied in identifying the major factor and the relations of this parameters and the influences to the surface integrity of the grinding stainless steel.

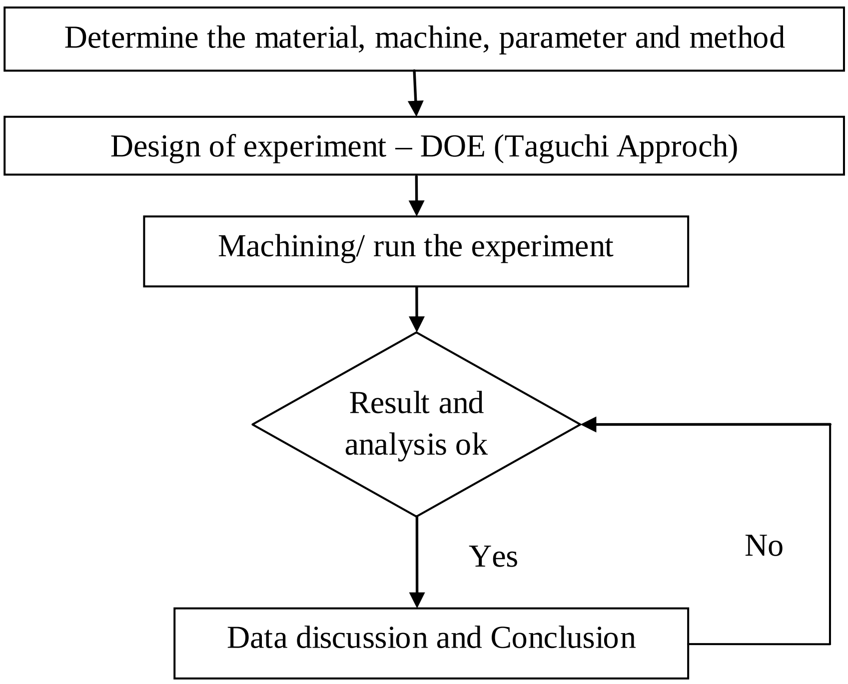


Figure 3.1: Schematic diagram of procedure flow chart

3.2 EXPERIMENTAL SETUP

3.2.1 Workpiece Material

Material for workpiece used in this experiment is stainless steel as showed in Figure 3.2. The properties of the stainless steel are stated as in Table 3.1. The properties listed are common properties.

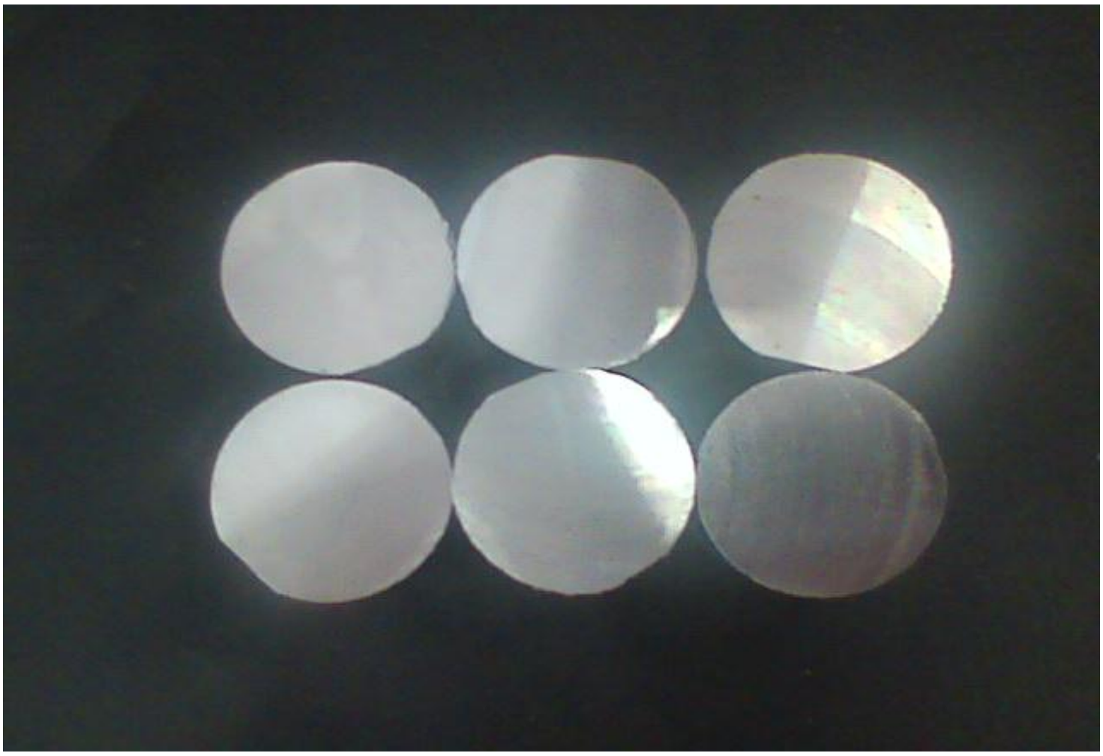


Figure 3.2: Stainless steel

Table 3.1: Common properties of stainless steel

Density, ρ	**Hardness, Rockwell B**	**Tensile Strength, Ultimate**	**Tensile Strength, Yield**	**Thermal Conductivity**	**Melt temperature**
8.03 g/cc	82	621 Mpa	290 Mpa	21.4 W/m-K	1371- 1399 °C

Adapted from: ASTM

3.2.2 Size of Workpiece Material

The size of workpiece material that will be used in this project is 30 mm in diameter times 20 mm length. From the experiment design, there are 36 times of experiment run. Therefore, the total workpiece that will be used in this experiment is 36. 18 workpieces used for grinding with Aluminum Oxide wheel and the others 18 workpieces used for grinding with Silicon Carbide wheel.

3.3 MACHINE TOOL

Material of tool in this experiment is Aluminum Oxide and Silicon Carbide wheel abrasive. The selection wheel is based on the abrasive-workpiece compatibility. Tata-McGrawhill, (1986) stated that Aluminum Oxide are used for grinding steels, ferrous alloys and other high tensile materials. Silicon Carbide extensively used for grinding hard and dense material such as non-ferrous metals, non-metallic elements, and cast iron.

The other consideration is the cost. Kalpakjian and Schimid (2006) stated in the Manufacturing Engineering and Technology, 2006 that the cost of Aluminum Oxide and Silicon Carbide is approximately about $2-$10 for small wheel (about 25 mm in diameter), and about $500 for large wheel (about 500 mm in diameter and 250 mm width) respesctively. The common properties of Aluminum Oxide and Silicon Carbide wheel are listed as in Table 3.2.

Table 3.2: Properties of Aluminum Oxide and Silicon Carbide abrasive

Wheel Type	**Tensile Strength [kp mm^{-2}]**	**Hardness as per Moh's Scale**	**Mass Density [g cm^{-3}]**
Aluminum Oxide	53	9	4.00
Silicon Carbide	50 - 60	9.13	3.20

Adapted from: ASTM

3.4 MACHINING PROCESS

The machining process were conducted using surface grinding. This process involving the grinding of flat surface of the workpiece. The workpiece is attached on a magnetic chuck to the work table of the grinder. Figure 3.3 show the position of workpiece and grinding wheel when machining process conducted.

Grinding is a surface finishing process. Therefore, the workpiece materials were first face milled with the vertical milling in order to reduce the surface roughness. The figure of the machine in machining process shown in Appendix C and Appendix D.

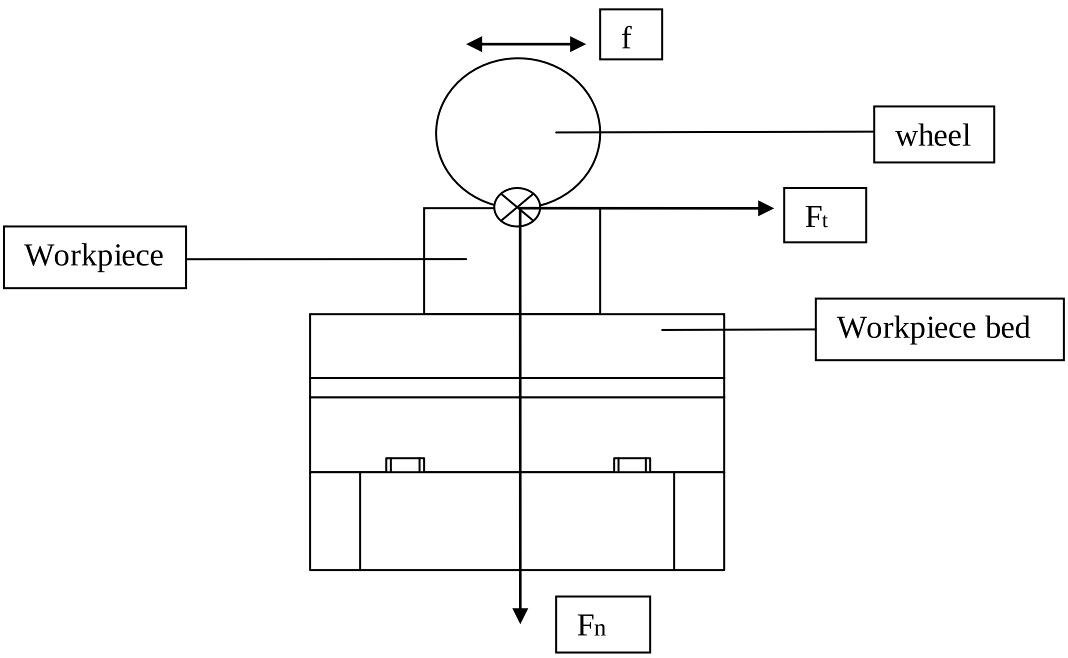


Figure 3.3: Illustration of mechanisme of machining process of surface grinding

The tranverse surface grinding machine which used in this experiment was shown in Figure 3.4.

Figure 3.4: Tranverse surface grinding

The process of machining started with the cutting process of Stainless Steels bar into 36 pieces. Then, its were undergo the facing proces, a proces required to reduce the surface roughness in order to save the grinding time. It is because the grinding machine that used in this study can only grind up to 0.003 mm per depth of cut. The flow of grinding process shown in the flowchart in Figure 3.5.

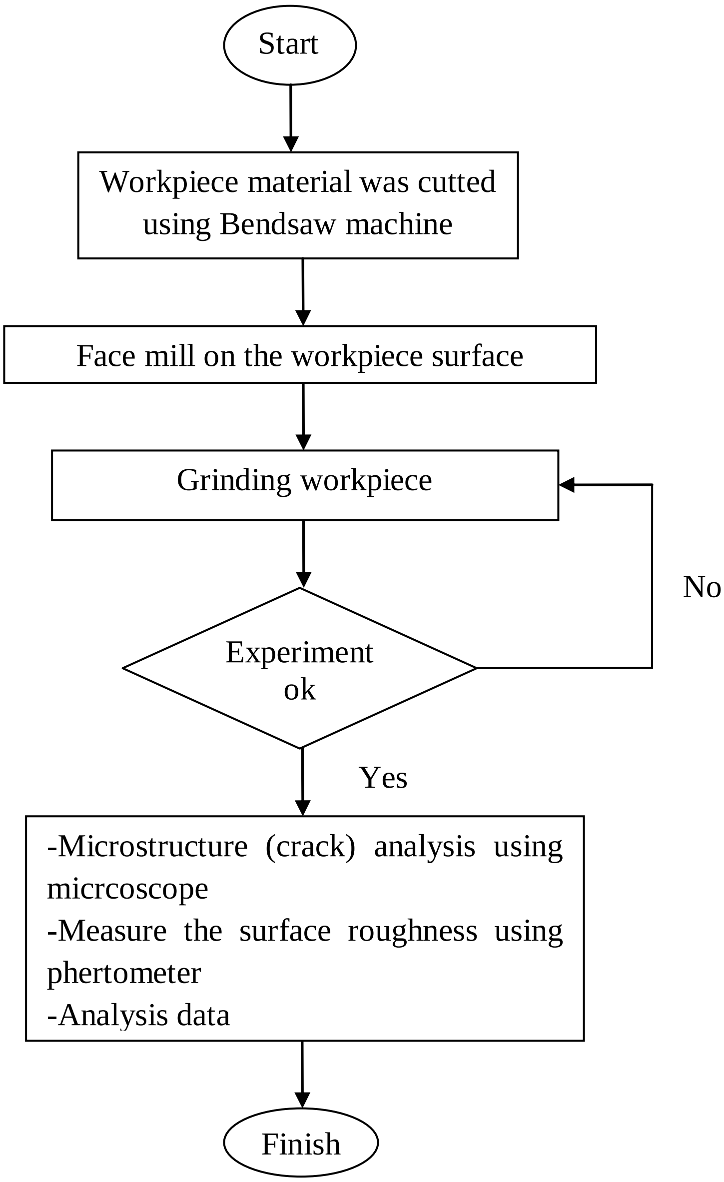


Figure 3.5: Flowchart of machining mechanisme

3.4.1 Machining Parameters

The parameters that considered in this experiment are depth of cut, different wheel types and cutting fluid. The range of the depth of cut are listed in Table 3.3. As mentioned before, the different wheels are Silicon Carbide and Aluminum Oxide.

Table 3.3: Machining parameters

Variables	Unit	Level		
		1	**2**	**3**
Wheel Types	-	Aluminum Oxide	Silicon Carbide	-
Cutting Fluid	-	Use Coolant	Not Use Coolant	-
Depth of cut	µm	20 (low)	40 (medium)	60 (high)

3.5 DESIGN OF EXPERIMENT

In order to identify the effect of selected machining parametrs in grinding machine, the design of experiment (DOE) were used. Therefore, the correlation of the variable parameters and interaction of them can be determine to select the optimum parameter.

Using MiniTab software, the mixed level of Taguchi design were selected to determine the number of experiment that need to conduct for this project. The mixed level of Taguchi design allows to design factors that each have a different number of levels. It will create an experiment that includes all possible combinations of factor levels. All factors should be categoric (i.e. batch type, tool type, process method) rather than numeric.

In this experimental study, there are one factor of experimental design with three levels and one factor of experiment with two level experiment. The number of experiment should be carried out is 36. The table of mixed level factorials experiment is shown in table below. Surface roughness and crack is the result that need to obtain from this experiment.

3.5.1 Taguchi Orthogonal Array Design

L36(2**2 3**1)

Factors: 3

Runs: 36

Columns of L36(2**11 3**12)

Array 1 2 12

Table 3.4: Mixed Taguchi experimental design

Experiment No.	Wheel Type	Coolant	Depth of Cut
1	Aluminum Oxide	Use	0.02
2	Aluminum Oxide	Use	0.04
3	Aluminum Oxide	Use	0.06
...	...	...	...
10	Aluminum Oxide	Not Use	0.02
11	Aluminum Oxide	Not Use	0.04
12	Aluminum Oxide	Not Use	0.06
...	...	...	...
28	Silicon Carbide	Not Use	0.02
29	Silicon Carbide	Not Use	0.04
30	Silicon Carbide	Not Use	0.06
...	...	...	...
34	Silicon Carbide	Not Use	0.02
35	Silicon Carbide	Not Use	0.04
36	Silicon Carbide	Not Use	0.06

3.6 SURFACE ROUGHNESS AND CRACKS

To determine the surface roughness, perthometer will be used. The figure of perthometer shown as in Figure 3.6. Perthometer will measure the roughness in the stright line on the workpiece surface layer and compute the average of roughness, Ra.

Figure 3.6: Perthometer to measure surface roughness

The cracks measured using microscope. The circumference length of crack obtained by drawing line within the crack. Figure 3.7 show the microscope that used to observe the crack circumference.

Figure 3.7: Microscope to analyze surface crack

3.7 ANOVA

The ANOVA was carried out to find the dependent variable that effects the machining parameters and machining characteristic. Analysis of varience (ANOVA) is the statistical treatment most commonly applied to the results of experiment to determine the percentage contribution of each factors. The software then will calculate the relations of the parameters involves in this study.

The ANOVA compares group means by analyzing comparisons of variance estimates. The ANOVA is based on the fact that two independent estimates of the population variance can be obtained from the sample data. Consider all of the possible outcomes that could occur in the experiments. This will help to better understand the effects involved in general and the concept of an interaction in particular. There are eight possibilities for what could occur. In other words, there are eight possibilities of what could be significant in the analysis. The possibilities of outcome from this experiments listed as:

(i) Nothing
(ii) Main effect of factor A
(iii) Main effect of factor B
(iv) Both main effects (factors A and B)
(v) A x B interaction
(vi) A x B interaction and main effect of factor A
(vii) A x B interaction and main effect of factor B
(viii) A x B interaction and both main effects (factors A and B)

Hypothesis has been made based on the research questions. The questions came up from the need of the study and the objectives of the study. The objective of this ANOVA is to determine the interaction of the usage of coolant and different level of depth of cut with the the main effects. The main effects in this experiments are crack length and surface roughness. The questions are:

Research questions (main effect is crack):

(i) Does the depth of cut effect the crack length?
(ii) Does the crack length change with the coolant usage?
(iii) Does effect of depth of cut change with coolant usage?

Research questions (main effect is surface roughness):

(i) Does the depth of cut effect the surface roughness?
(ii) Does the surface roughness change with the coolant usage?
(iii) Does effect of depth of cut change with coolant usage?

Hypothesis was made for each of the three questions. To make its clear and easy to understand, tables of the hyphothesis were constructed. Both of the hypothesis and the questions used for both grinder wheels.

Table 3.5: Hyphothesis for factor A

	In symbol	In words
H_O	$A_1 = A_{2=} = A_3 = 0$	Depth of cut not effect the crack length
H_A	Not H_O	Depth of cut effect the crack length

Table 3.6: Hyphothesis for factor B

	In symbol	In words
H_O	$B_1 = B_{2=} = 0$	Crack not change with coolant usage
H_A	Not H_O	Crack change with coolant usage

Table 3.7: Hyphothesis for interaction of factor A X B

	In symbol	In words
H_O	$AB_{11} = AB_{21}\ AB_{21} = AB_{22} = AB_{31} = AB_{31} = 0$	Effect of depth of cut not depend on the coolant usage
H_A	Not H_O	Effect of depth of cut depend on the coolant usage

The computation of the interaction then carried out by Minitab software. Table 3.8. show the factors that will be computed by the software based on the tabulated statistics. The same step repeated for Silicon Carbide wheel grinder. After that, the main effect changed to surface roughness, or in other words, main effect is surface roughness.

Table 3.8: Interaction of factors A and B that effect to the main effect

		Factor B (coolant)		Margin A
		Yes (B_1)	**No (B_2)**	
Factor A	20	1-	1-	$MEAN_{20}$=
(depth of	(A_1)	2-	2-	
cut)		3-	3-	
		MEAN=	MEAN=	
	40	1-	1-	$MEAN_{40}$=
	(A_2)	2-	2-	
		3-	3-	
		MEAN=	MEAN=	
	60	1-	1-	$MEAN_{60}$=
	(A_3)	2-	2-	
		3-	3-	
		MEAN=	MEAN=	
Margin B		$MEAN_{YES}$=	$MEAN_{NO}$=	GRAND MEAN=

Margin is the mean of effect for each factors. It is the mean of mean or mean square of each factors. The values of margins are subsitiuted into the equation and the interactions of the mean are what Minitab software calculated.

CHAPTER 4

RESULTS AND DISCUSSION

4.0 INTRODUCTION

In this chapter, the result obtained from the experiments was shown. This chapter presents about the final results of relation of length of crack and surface roughness with the depth of cut and the optimization of grinding parameters were discussed throughly based on the data that collected during experiments. The main objective of this chapter is to determine the significant factor and non-significant factor among the machining parameters with the main effects using the analysis of variance (ANOVA). From that, the relation of lenght of crack and surface roughness with the depth of cut was elaborated.

4.1 EXPECTED RESULT FROM EXPERIMENTS

From the literiture reviews, claim was made that the length of crack or crack circumference and surface roughness depend on the depth of cut. Since table-speed and wheel-speed of grinding machine was fixed, the crack's length is proportional with the depth of cut, as well as the heat generation. In other word, the length of crack will increase with the depth of cut.

Surface roughness of workpiece material depend on the type and grit size of wheels. For Silicon Carbide wheel, the surface roughness of the workpiece will be rougher compared to Aluminum Oxide wheel. It is because the particles shape of Silicon Carbide is rougher than Aluminum Oxide.

Coolant usage will reduce the roughness of the workpiece material. It is because coolant act as heat reducer on the surface contact between the wheel and the workpiece. It also reduce the friction between the wheel and the workpiece. The usage of cutting fluid that act as lubricant and coolant is good for achieving better surface finish of workpiece material, but it will effect the tool life.

4.2 RESULT OF EXPERIMENTS

Based on the DOE that designed earlier, a table to collect the experimental data was constructed. Using phertometer, the roughness of each materials was took for three reading. The average of the reading then calculated. Further analysis was done to the collected data using ANOVA.

Table 4.1: Results of Aluminum Oxide (Al_2O_3) wheel

Exp. No.	Wheel Type	Coolant	Depth of Cut, (µm)	Average Surface Roughness, Ra (µm)	Circumference Crack length, (µm)
1	Al_2O_3	Use	20	0.506	105.2
2	Al_2O_3	Use	40	0.595	220.2
3	Al_2O_3	Use	60	0.601	357.6
4	Al_2O_3	Use	20	0.504	100.4
5	Al_2O_3	Use	40	0.589	219.3
6	Al_2O_3	Use	60	0.611	308.4
7	Al_2O_3	Use	20	0.507	110.8
8	Al_2O_3	Use	40	0.613	246.3
9	Al_2O_3	Use	60	0.705	340.1
10	Al_2O_3	Not Use	20	0.959	224.3
11	Al_2O_3	Not Use	40	1.074	755.9
12	Al_2O_3	Not Use	60	1.167	953.6
13	Al_2O_3	Not Use	20	0.934	207.5
14	Al_2O_3	Not Use	40	1.082	719.0
15	Al_2O_3	Not Use	60	1.157	801.9
16	Al_2O_3	Not Use	20	0.941	237.5
17	Al_2O_3	Not Use	40	1.068	700.2
18	Al_2O_3	Not Use	60	1.165	857.1

Table 4.2: Results of Silicon Carbide (SiC) wheel

Exp. No.	Wheel Type	Coolant	Depth of Cut, (μm)	Average Surface Roughness, Ra (μm)	Circumference Crack length, (μm)
19	SiC	Use	20	0.537	215.7
20	SiC	Use	40	0.617	352.8
21	SiC	Use	60	0.639	592.0
22	SiC	Use	20	0.509	249.4
23	SiC	Use	40	0.611	337.9
24	SiC	Use	60	0.646	571.3
25	SiC	Use	20	0.518	209.6
26	SiC	Use	40	0.605	314.6
27	SiC	Use	60	0.635	588.3
28	SiC	Not Use	20	1.246	526.1
29	SiC	Not Use	40	1.401	765.3
30	SiC	Not Use	60	1.458	965.2
31	SiC	Not Use	20	1.298	468.3
32	SiC	Not Use	40	1.379	764.8
33	SiC	Not Use	60	1.449	988.6
34	SiC	Not Use	20	1.237	507.7
35	SiC	Not Use	40	1.381	891.0
36	SiC	Not Use	60	1.435	975.3

4.3 DISCUSSION OF RESULT

From data that collected, analysis was done in order to determine the most signifcant parameters for optimizing grinding machining. The analysis was done to each of the parameters that stated earlier. The relationship among them was eleborated.

4.3.1 Main Effect of Surface Roughness

The effect of parameters that contribute the most to the surface roughness was determined. A graph of surface roughness versus depth of cut was constructed. Considered all others parameters that involve in this experiments, comparison was made among this parameters. Then, analysis was done regarding to the graph.

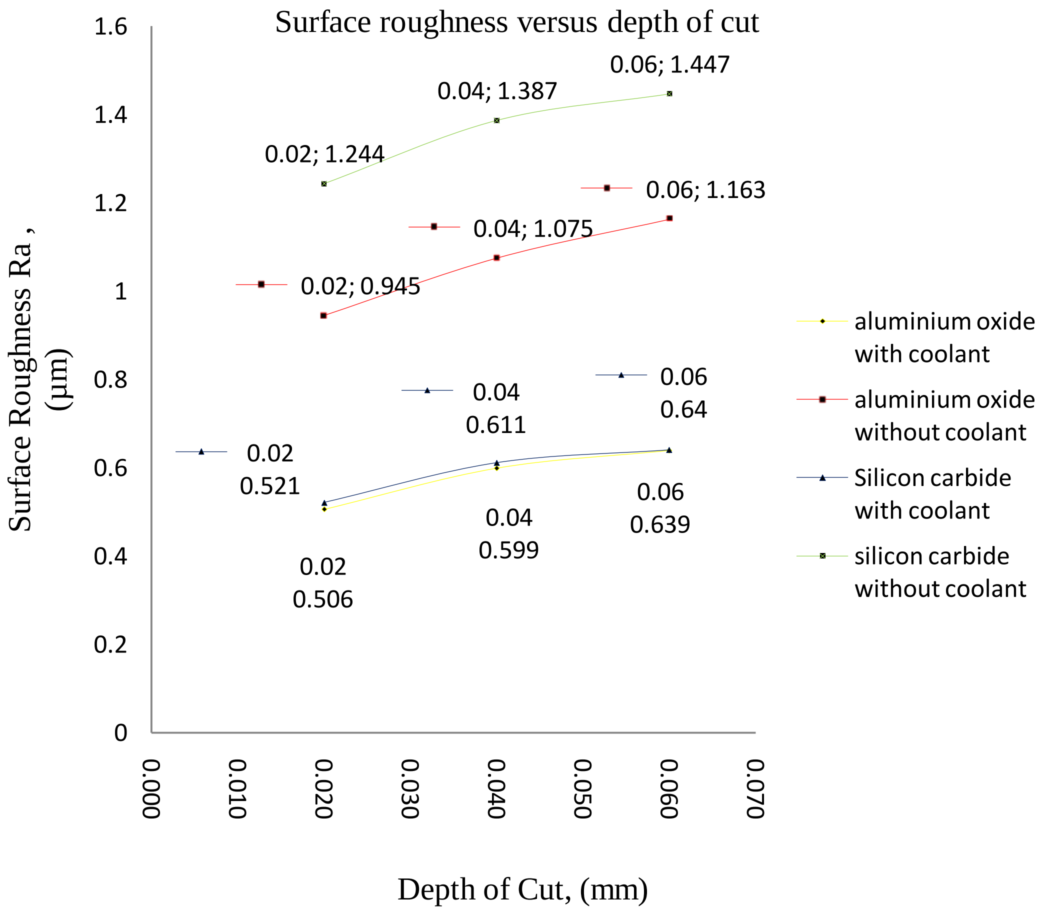


Figure 4.1: Graph of surface roughness versus depth of cut

From the graph in Figure 4.1 and as claimed in the literiture reviews, it shown that the surface roughness was increased with the increasing of the depth of cut. It also shown that the average surface roughness is finer with the used of coolant since the heat generation is reduced. To compare the compatibility of wheels, the surface roughness of workpiece material that grinded using Aluminum Oxide is finer compared with the Silicon Carbide. Grinding stainless steel with Silicon Carbide wheel grinder without the usage of coolant were not recomanded for products of Stainless Steel that required fine surface finishing because the surface roughness that generated even with 0.02 mm depth of cut was rougher compared to grinding using . The same goes for the Aluminum Oxide grinder wheel. But, for both wheels, there are only slightly different of surface roughness when coolant was used. Even though the surface roughness generated by Aluminum Oxide were finer.

4.3.2 Main Effect of Crack Circumference

A graph of crack circumference versus depth of cut was constructed, and comparison between all others parameters was done.The effect of parameters that contribute the most to the crack circumference was determined. This is to determine the most optimum parameter that can be used in optimizing the machine's parameter.

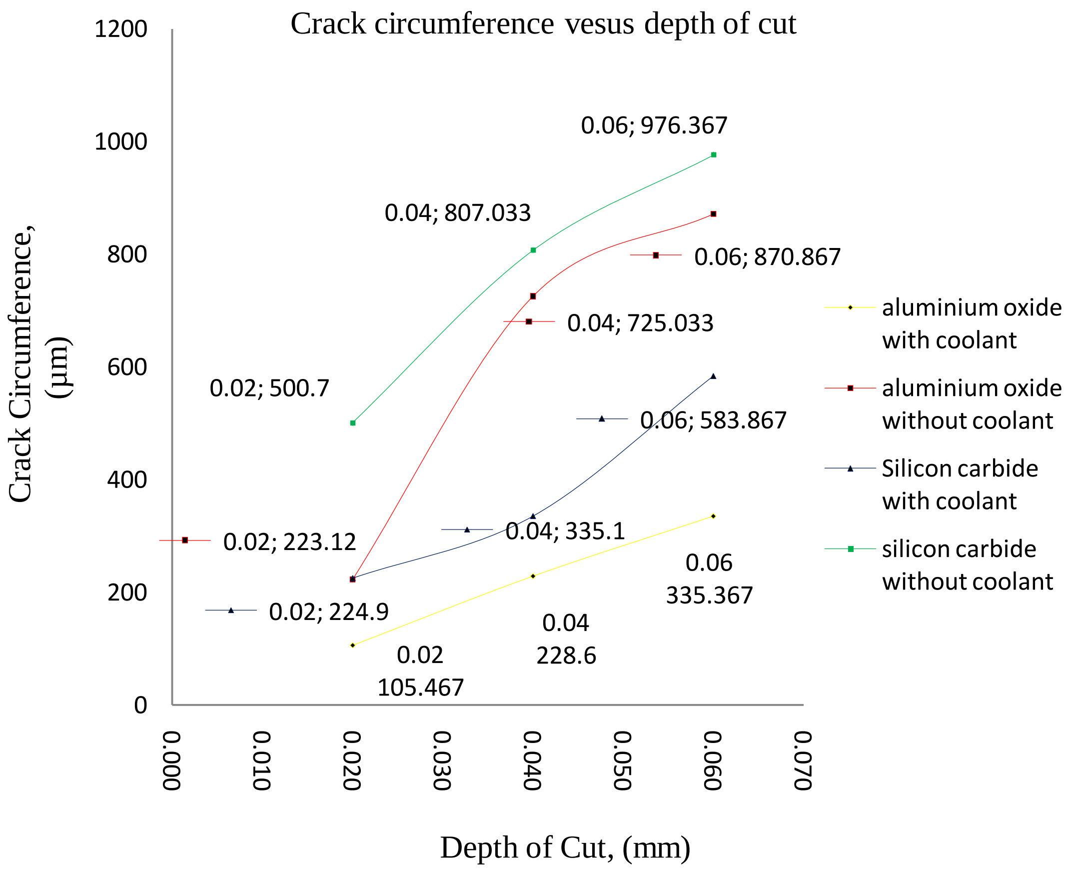


Figure 4.2: Graph of crack circumference versus depth of cut

The crack length or crack circumference, which is observed using microscope were determined for each samples. Using 200 magnificient, it was observed that the crack length tencedy to occur is proportional to the increasing of the depth of cut. From the result, it also found that the elongation tendency of the crack length is higher when Silicon Carbide wheel was used. The coolant usage shown the reduction of tendecy of crack to occur and the crack length also decreased.

From the graph, finest surface integrity i.e less crack circumference can be obtained by using the Aluminum Oxide wheel with the coolant usage. The depth of cut also must be equal or less than 0.02 mm per cut. The usage of Silicon Carbide with coolant is acceptable, but the crack generated is higher compared with Aluminum Oxide usage with coolant. For product of Stainless Steels that required tigh surface finishing and tolerence, it is cheaper and recommended to use the Aluminum Oxide wheel for grinding process.

The coolant usage provide lubricant that lubricate the surface contact of machining workpiece. It also regenerate heat which produced by the force of wheel. Therefore, from this experiments, the most optimum parameters in reducing crack on stainless steel workpiece surface are by grinding using Aluminum Oxide wheel with coolant usage. The crack circumferences also less when depth of cut was less.

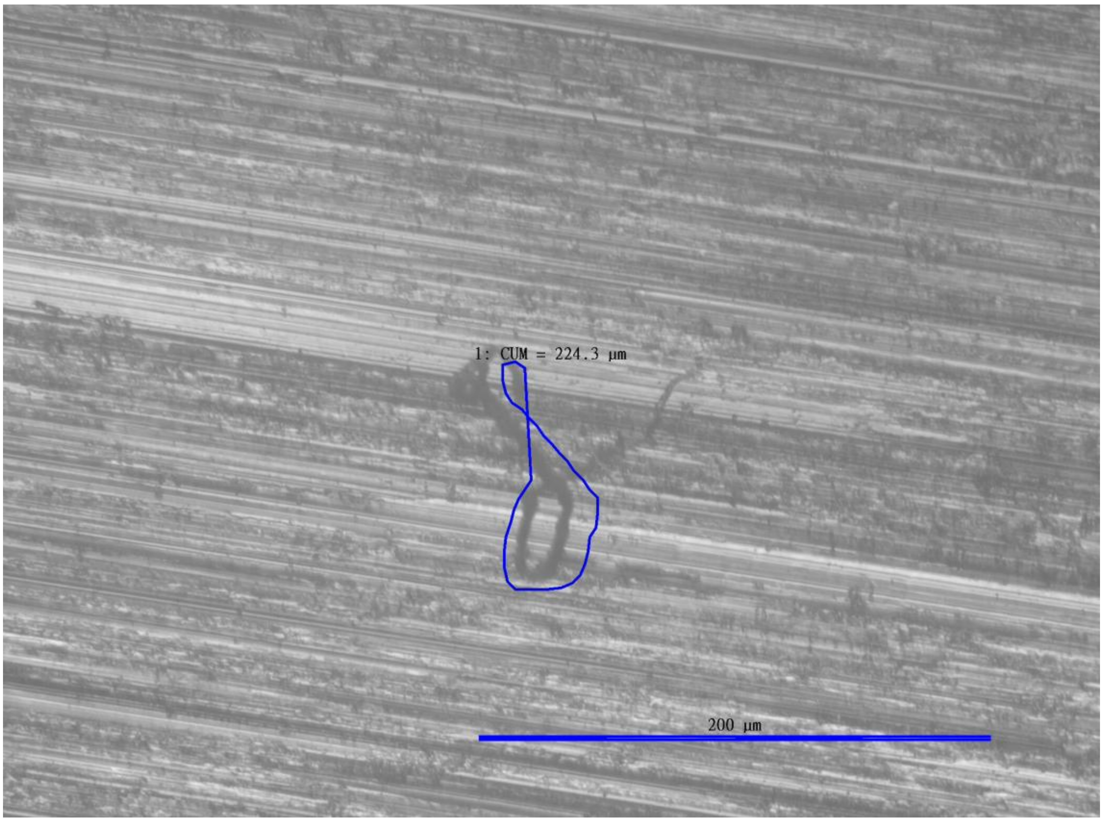


Figure 4.3 : Sample of crack on workpiece surface

4.4 ANOVA

The ANOVA evaluate the importance of one or more factors by comparing the response variable means at the different factor levels. The null hypothesis, H_o stated that all population means (factor level means) are equal while the alternative hypothesis states that at least one is different.

4.4.1 Anova for Aluminum Oxide grinder wheel

(i) Surface roughness, Ra computation for Aluminum Oxide wheel grinder. The computation base on the tabulated statistic as in Table 4.3. The ANOVA analysis then carried out to determine the interaction effect between the factor A and the factor B with the main effect which is surface roughness.

Table 4.3: Tabulated statistics for factor A (coolant) and factor B (depth of cut)

	1	**2**	**3**	**All**
1	0.5057	0.5990	0.6390	0.5812
	0.00153	0.01249	0.05738	0.06613
	3	3	3	9
2	0.9447	1.0747	1.1630	1.0608
	0.01290	0.00702	0.00529	0.09543
	3	3	3	9
All	0.7252	0.8368	0.9010	0.8210
	0.24059	0.26069	0.28931	0.25927
	6	6	6	18

Cell Contents: Ra : Mean — Rows: coolant
Ra : Standard deviation — Columns: depth of cut
Count

Table 4.4: Two-way anova; surface rougnhness versus depth of cut and coolant

Source	**DF**	**SS**	**MS**	**F**	**P**
coolant	1	1.03488	1.03488	1680.91	0.000
depth of cut	2	0.09501	0.04750	77.16	0.000
Interaction	2	0.00545	0.00273	4.43	**0.036**
Error	12	0.00739	0.00062		
Total	17	1.14273			

S = 0.02481 **R-Sq = 99.35%** R-Sq(adj) = 99.08%

From the ANOVA analysis, the P value of interaction between the main effect, surface roughness with depth of cut and coolant usage was determined. Since the P value is 0.036 and less then 0.05, or in other words, $P<0.05$, the value show that there is significant interaction of the two parameters which are coolant and depth of cut, with the main effect which is surface roughness. Therefore, the hyphotesis of the two parameters are not significant with the main effect was rejected.

To determine either the experiments was valid or not, the value of R-Sq or also called as R-Squared observed. The R-squared values used to find the point where adding more predictors is not worthwhile because it leads to a very small increase in R-squared. The value is 99.35%, which is exceed the minimum confidence level which is 95%. Therefore, the experiments conducted are valid.

(ii) Crack circumference computation for Aluminum Oxide wheel grinder. The computation base on the tabulated statistic in Table 4.5. The ANOVA analysis carried out to determine the interaction effect of the factor A and the factor B with the main effect which is crack circumference.

Table 4.5: Tabulated statistics for factor A (coolant) and factor B (depth of cut)

	1	**2**	**3**	**Margin A**
1	105.5	228.6	335.4	223.1
	5.21	15.34	24.94	100.74
	3	3	3	9
2	223.1	725.0	870.9	606.3
	15.04	28.34	76.78	297.21
	3	3	3	9
Margin B	164.3	476.8	603.1	414.7
	65.21	272.67	297.72	291.91
	6	6	6	18

Cell Contents: Crack : Mean Rows: coolant

Crack : Standard deviation Columns: depth of cut

Count

Table 4.6: Two-way anova; crack circumference versus depth of cut and coolant

Source	**DF**	**SS**	**MS**	**F**	**P**
coolant	1	660752	660752	507.71	0.000
depth of cut	2	612407	306203	235.28	0.0000
Interaction	2	159814	79907	61.40	**0.000**
Error	12	15617	1301		
Total	17	1448590			

S = 36.08 **R-Sq = 98.92%** R-Sq(adj) = 98.47%

The P value of interaction between the main effect with depth of cut and coolant usage was determined. Since the P value is 0.000, the value show that there is no significant interaction of the two parameters which are coolant and depth of cut, with the main effect which is crack. Therefore, the hyphotesis of the two parameters are not significant with the main effect was accepted.

To determine either the experiments was valid or not, the value of R-Sq or also called as R-Squared observed. The R-squared values used to find the point where adding more predictors is not worthwhile because it leads to a very small increase in R-squared. The value is 98.92%, which is exceed the minimum confidence level which is 95%. Therefore, the experiments conducted are valid.

The normal probability graph is plotted as in Figure 4.4 for surface roughness and Figure 4.5 for crack circumference fro the Aluminum Oxide grinding wheel. Residual values are especially useful in ANOVA procedures because its indicate the extent to which a model accounts for the variation in the observed data.

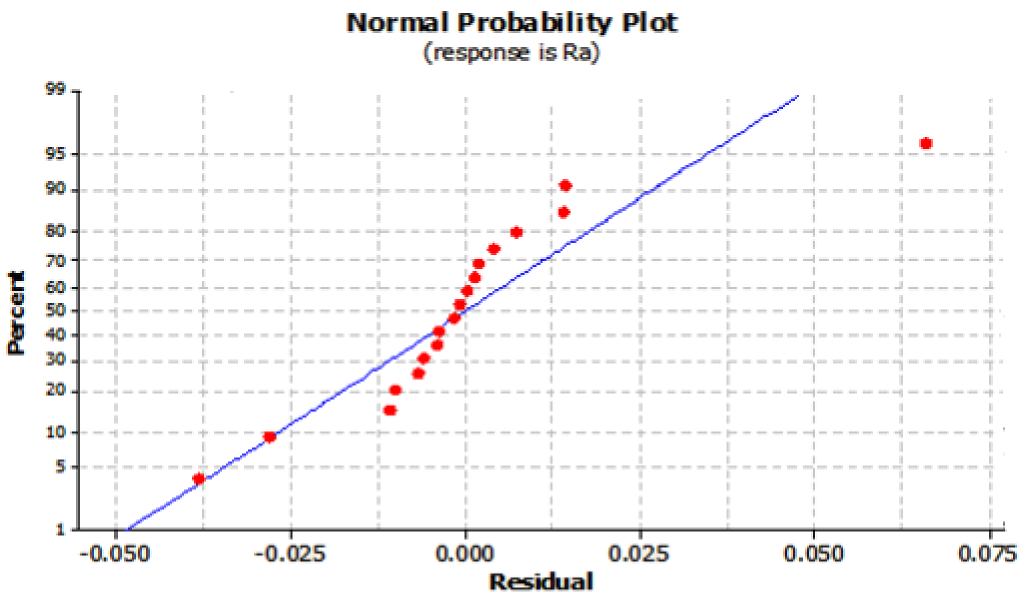


Figure 4.4: Normal probability graph of surface roughness in grinding using Aluminum Oxide wheel

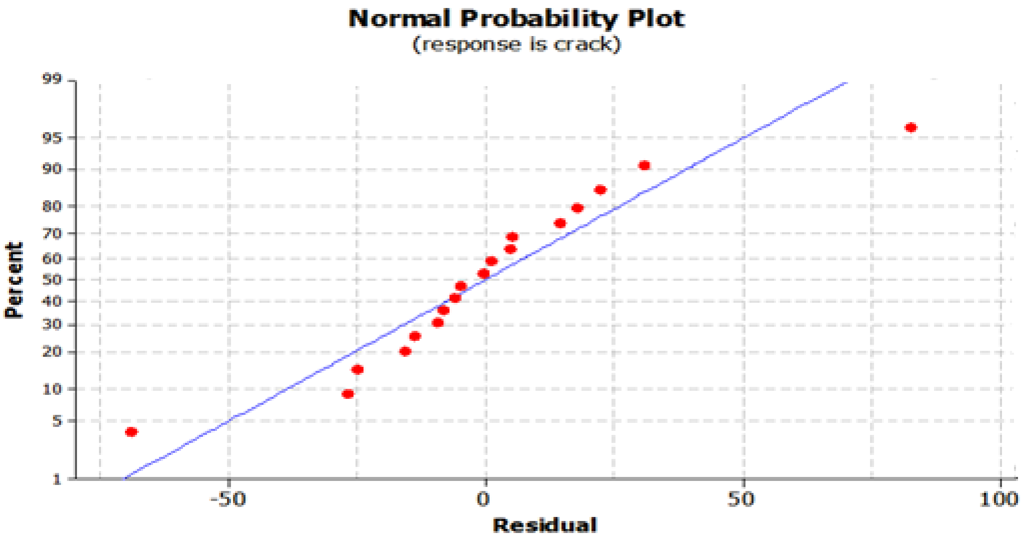


Figure 4.5: Normal probability of residual on surface crack circumference in grinding using Aluminum Oxide wheel

4.4.2 Anova for Silicon Carbide grinder wheel

(iii) Surface roughness, Ra computation for Silicon Carbide wheel grinder. The computation base on the tabulated statistic as in Table 4.7. The ANOVA analysis then carried out to determine the interaction effect between the factor A and the factor B with the main effect which is surface roughness.

Table 4.7: Tabulated statistics for factor A (coolant) and factor B (depth of cut)

	1	**2**	**3**	**All**
1	0.5213	0.6110	0.6400	0.5908
	0.01429	0.00600	0.00557	0.05421
	3	3	3	9
2	1.2603	1.3870	1.4473	1.3649
	0.03293	0.01217	0.01159	0.08470
	3	3	3	9
All	0.8908	0.9990	1.0437	0.8210
	0.40540	0.42512	0.44227	0.40421
	6	6	6	18

Cell Contents: Ra : Mean Rows: coolant

Ra : Standard deviation Columns: depth of cut

Count

Table 4.8: Two-way anova; surface rougnhness versus depth of cut and coolant

Source	**DF**	**SS**	**MS**	**F**	**P**
coolant	1	2.69662	2.69662	9877.71	0.000
depth of cut	2	0.07411	0.03705	135.73	0.000
Interaction	2	0.00351	0.00176	6.43	**0.013**
Error	12	0.00328	0.00027		
Total	17	2.77751			

S = 0.01652 **R-Sq = 99.88%** R-Sq(adj) = 99.83%

From the ANOVA analysis, the P value of interaction between the main effect, surface roughness with depth of cut and coolant usage was determined. The P value is 0.013 and less then 0.05, i.e $P<0.05$. The value indicate that there is significant interaction of the two parameters which are coolant and depth of cut, with the main effect which is surface roughness. Therefore, the hyphotesis of the two parameters which is coolant usage and depth of cut are not significant with the main effect was rejected.

To determine either the experiments was valid or not, the value of R-Sq or also called as R-Squared observed. The R-squared values used to find the point where adding more predictors is not worthwhile because it leads to a very small increase in R-squared. The value is 99.88%, which is exceed the minimum confidence level which is 95%. Therefore, the experiments conducted are valid.

(iv) Crack circumference computation for Aluminum Oxide wheel grinder. The computation base on the tabulated statistic in Table 4.9. The ANOVA analysis carried out to determine the interaction effect of the factor A and the factor B with the main effect which is crack circumference.

Table 4.9: Tabulated statistics for factor A (coolant) and factor B (depth of cut)

	1	**2**	**3**	**Margin A**
1	224.9	335.1	583.9	381.3
	21.44	19.25	11.04	160.00
	3	3	3	9
2	500.7	807.0	976.4	761.4
	29.53	72.72	11.74	212.53
	3	3	3	9
Margin B	362.8	571.1	780.1	571.3
	152.81	262.83	215.22	267.47
	6	6	6	18

Cell Contents: Crack : Mean — Rows: coolant
Crack : Standard deviation — Columns: depth of cut
Count

Table 4.10: Two-way anova; crack circumference versus depth of cut and coolant

Source	**DF**	**SS**	**MS**	**F**	**P**
coolant	1	650066	650066	538.01	0.000
depth of cut	2	522460	261230	216.20	0.000
Interaction	2	29198	14599	12.08	**0.001**
Error	12	14499	1208		
Total	17	1216224			

S = 34.76 **R-Sq = 98.81%** R-Sq(adj) = 98.31%

The P value of interaction between the main effect with depth of cut and coolant usage was determined as in Table 4.10. Since the P value is 0.001, the value show that there is small significant interaction of the two parameters which are coolant and depth of cut, with the main effect which is crack. Although it is very small, the interaction must be taken into account because the grinding process dealing with the tight tolerence. Therefore, the hyphotesis of the two parameters are not significant with the main effect was rejected.

To determine either the experiments was valid or not, the value of R-Sq was observed. The R-squared values used to find the point where adding more predictors is not worthwhile because it leads to a very small increase in R-squared. The value is 98.81%, which is exceed the minimum confidence level which is 95%. Therefore, the experiments conducted are valid.

The normal probability graph is plotted as in Figure 4.6 for surface roughness and Figure 4.7 for crack circumference fro the Silicon Carbide grinding wheel. Residual values are especially useful in ANOVA procedures because its indicate the extent to which a model accounts for the variation in the observed data.

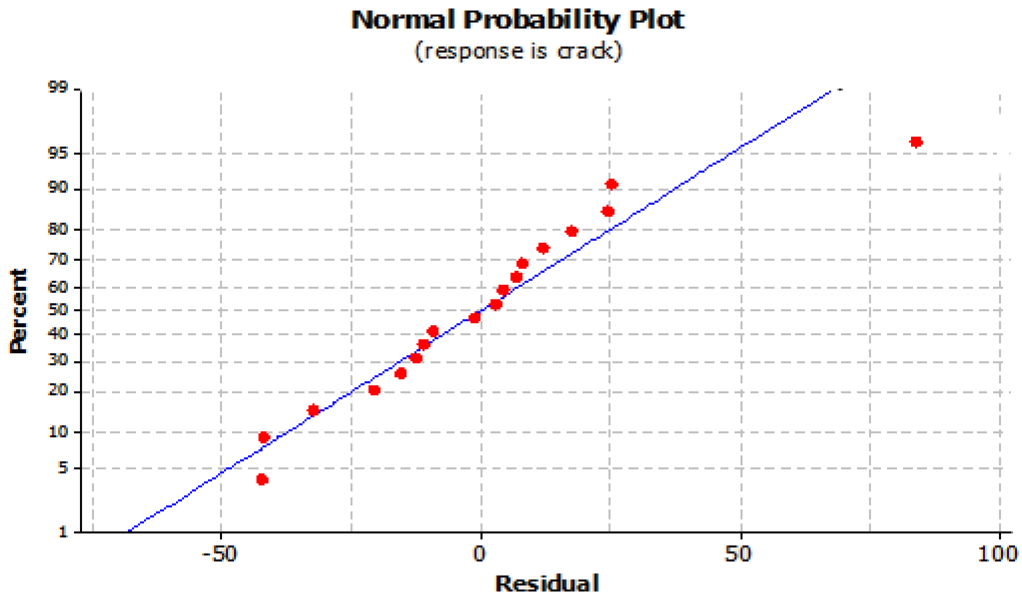
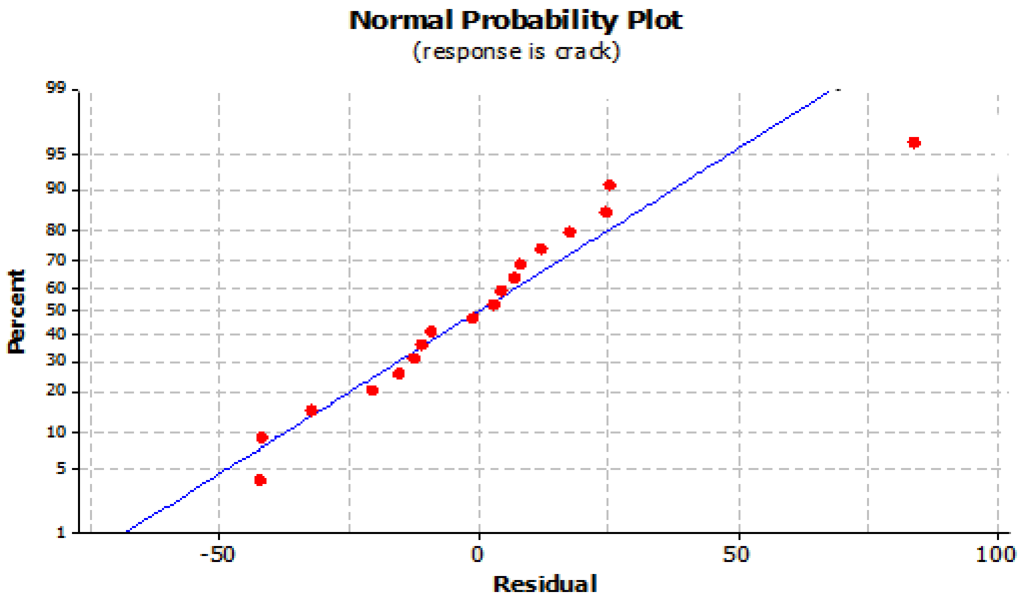


Figure 4.6: Normal probability of residual on surface roughness in grinding using Silicon Carbide wheel



x

Figure 4.7: Normal probability of residual on surface crack circumference in grinding using Silicon Carbide wheel

4.5 OPTIMIZATION OF PARAMETERS

From the analysis of the results and ANOVA on both wheels grinder, there are several optimum parameters that can be concluded. The results showed that most significant coolant usage are in achieving finer surface roughness.

Coolant usage reduce the roughness of stainless steel workpieces by reducing the heat generated on the surface layer when the contact of wheel grinder and workpiece occur. In addition, coolant also contain lubricant. Both of this elements contribute to the improvements of the surface integrity. Thus, the coolant is an important medium in grinding and the effect of coolant usage gave great impact in obtaining better surface roughness.

As shown in graph in Figure 4.1, the most optimum parameters are grinding the stainless steel with the usage of coolant. Although the depth of cut increased, both Aluminum Oxide grinder wheel and Silicon Carbide grinder wheel shown reduction of surface roughness when coolant used. The percentage of reduction is about 80% for the Silicon Carbide wheel and 60% for the Aluminum Oxide grinder wheel. The finest surface roughness obtained from grinding the stainless steel workpiece using Aluminum Oxide grinder wheel with the use of the coolant.

There is only small interaction of coolant usage with the crack length. This shown that the coolant usage also reduced the crack length and the tendecy of cracks to occurs, but the effects are not much as the effects of coolant usage to the surface roughness. Therefore, coolant usage optimum in reducing the surface roughness.

The graph from results also shown that the crack length and the tendecy of the crack to occurs increase with the increasing of the depth of cut. The longest crack circumference shown when the Silicon Carbide grinder wheel used to grinding the stainless steels materials without coolant usage at the higest level of depth of cut which is 30 µm. The value of the crack circumference is 976.367 µm. But, when the depth of cut is low, the crack length also less.

The usage of coolant contribute to reducing the crack length. But, from this experiments, it shown that the optimum parameter that reduce the crack length is depth of cut. Less crack obtained from grinding the stainless steels workpiece with Aluminum Oxide grinder wheel and with the coolant usage.

The crack length, crack tendecy to occurs and surface roughness show similar trend of increasing when the stainless steel workpiece was grinded by the Silicon Carbide grinder wheel. It is because the particles shapes of Silicon Carbide are bigger and rougher compared to the Aluminum Oxide grinder wheel. Therefore, Aluminum Oxide grinder wheel optimum to grind the stainless steel workpiece.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

In this chapter, the outcome from the experiments that conducted in this study was concluded. And for a better research in future, some recommendation was suggested.

5.2 CONCLUSION

This project is successfully completed and all of the notified objectives has been achieved. In this study, the effects of the abrasive grain type, the coolant usage and the grinding depth of cut on the ground surface integrity of the stainless steel were investigated**.** From the experiments, there are several thing that can be concluded.

(i) The grindability of stainless steel workpiece materials was found to increase substaintially by using the Aluminum Oxide grinder wheels. The coolant usage contribute in improving the surface integrity of grinding stainless steel. These grinding conditions reduce the grinding forces, reduce the surface damage, lower the level of heat generated and extend the surface integrity improvement which is less crack and better surface roughness can be obtained comparatively to grinding conditions using the Silicon Carbide grinding wheel. It is wise to use Aluminum Oxide wheel grinder because it cheaper, the surface roughness “generated” by it particles are smoother, and compatible with the stainless steel.

(ii) Surface roughness of the grinded stainless steels are propotianal with the depth of cut and coolant usage of the grinding machine. Higher the depth of cut, rougher the surface roughness. The relations of the coolant usage with the depth of cut indicate that coolant usage can extend the depth of cut to several times. The coolant itself prooved as important medium in order to reduce the surface roughness. The coolant usage optimum to reduce the surface roughness of stainless steel that has been grinded by both Aluminum Oxide and Silicon Carbide grinder wheel.

5.3 RECOMMENDATIONS

Several recommendations suggested for future studies. First, all the parameters that involve in grinding machine should be considered such as depth of cut, heat generated, tensile residual stress, wheel speed, table speed, and properties of the materials. All of the effects must be determine properly, and the relation with the other parameters must be observe and determine. The parameters interactions are simultaneously, therefore observation of their interaction must be determine properly.

Second, the conditions while conducting the experiments must be constant. In other word, environments also affect the experiments. All possibilities that affect the experiments must be considered. If can, eliminate the variables of environments that affect the experiments. The usage of various grinder types also will increase the significant of each parameter. It is because not all the parameters that contribute to one type of grinder will contribute to the other types of grinder.

The properties different types of wheels are different. As the result, the effects of the grinding process also will be different. Therefore, the compatibility with the materials that needs to be grinded must confirmed earlier. If possible, the properties of the materials also first studied. With the help of better equipments, the outcome of the study will be more precise.

Advance technologies of grinding machine such as CNC grinding machine will help to reduce the error while conducting experiments. The computerized numerical control features are big advantage and much better in order to reduce the errors that might occurs from human while handling the grinding machine. Conventional grinding machine has less performance in term of accuracy and stability compared with the CNC grinding machine.

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APPENDIX A

Table A-1: Gantt chart for final year project 1

Task \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Obtain project title	■															
Identify problems statements		■	■													
Determine the objectives and scopes				■	■											
Find journals and articles					■	■	■									
Literature reviews							■	■	■	■						
Methodology												■	■			
Survey equipment		■								■		■				
Presentation															■	
Submit proposal																■

APPENDIX B

Table B-1: Gantt chart for final year project 2

Task \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Workpiece and Machine Setup	■															
Learn Machining		■	■													
Machining Process				■	■											
Measure Crack & Roughness					■	■	■									
Analysis the data							■	■	■	■						
Thesis Writing												■	■			
Slide presentation		■								■		■				
Presentation															■	
Submit Thesis																■

APPENDIX C

Figure C-1: Bendsaw Machine

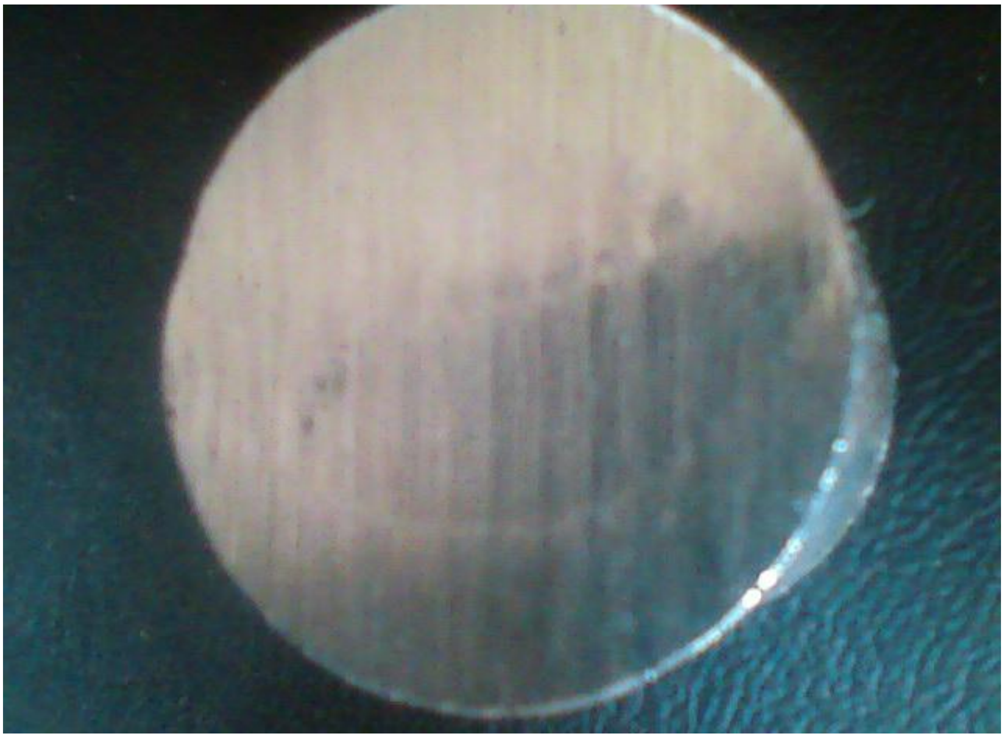

Figure C-2: Surface condition of stainless steel after has been cutted with bendsaw machine

APPENDIX D

Figure D-1: Vertical milling machine doing surface milling

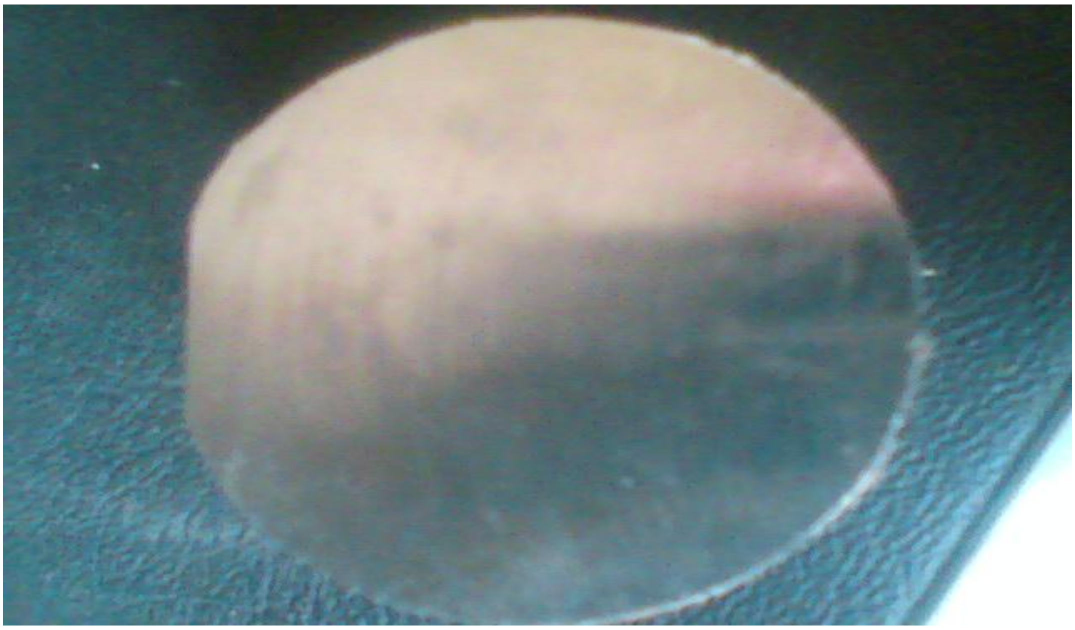

Figure D-2: Surface condition of stainless steel after undergo surface milling process