EFFECT OF ABRASIVE TOOLS ON SURFACE FINISHING WHEN GRINDING MILD STEEL

ABD FAIZ BIN MUHAMMAD

BACHELOR OF ENGINEERING
UNIVERSITI MALAYSIA PAHANG

2010

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

JUDUL: **EFFECT OF ABRASIVE TOOLS ON SURFACE FINISHING WHEN GRINDING MILD STEEL**

SESI PENGAJIAN: 2010/2011

Saya **ABD FAIZ BIN MUHAMMAD (880217- 11- 5617)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)
√	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:
LOT 3993, KG SUNGAI SERAI,
BINJAI RENDAH, 21400 MARANG,
TERENGGANU DARUL IMAN.

MR. KUMARAN A/L KADIRGAMA
(Nama Penyelia)

Tarikh: 6 DISEMBER 2010

Tarikh: 6 DISEMBER 2010

CATATAN:
* Potong yang tidak berkenaan
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atauTERHAD.
♦ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Effect of abrasive tools on surface finishing when grinding mild steel*" *is written by Abd Faiz bin Muhammad*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

Mr. Idris bin Mat Sahat

Examiner Signature

Dedicated to my parents

Muhammad bin Omar & Hasmah binti Safi

EFFECT OF ABRASIVE TOOLS ON SURFACE FINISHING WHEN GRINDING MILD STEEL

ABD FAIZ BIN MUHAMMAD

A project report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITY MALAYSIA PAHANG

DECEMBER 2010

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 with Manufacturing Engineering.

Signature:	
Name of Supervisor:	MR. KUMARAN A/L KADIRGAMA
Position:	LECTURER
Date:	6 DECEMBER 2010

STUDENT'S DECLARATION

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

Signature:

Name: ABD FAIZ BIN MUHAMMAD

ID Number: ME 07014

Date: 6 DECEMBER 2010

ACKNOWLEDGEMENT

By the name of ALLAH, the Most Gracious and Most Merciful

Due to completion of this thesis, I am deeply indebted to my respected supervisor, Mr Kumaran A/L Kadirgama from the Department of Mechanical Engineering for his encouragement, motivation, constructive criticism and beneficial guidance which led me through this project.

In carrying out experiment, I'm indebted to Universiti Malaysia Pahang (UMP) Mechanical Lab and Material Lab's assistants. Mr. Rusli Bin Ghani and Mr. Aziha Bin Abdul Aziz in helping and assist me in utilization of lab equipment and machine. I'm are also grateful for my presentation panels, Dr. Mahadzir Ishak @ Muhamad, Mr Hadi Abdul Salaam and Ms. Nurul Shahida Mohd Shalahim who offer valuable recommendations and guides during the presentation of my project.

Deep gratitude goes to multitude of my friends who have contributed their aid in some manner, especially Muhamad Afiq Razali and Mohd Hizam Mohd Noor.

Lastly, I would like to take this opportunity to thank everyone who involved directly or indirectly during this process on completing this research. Only ALLAH S.W.T could bestow all of you with His bless and kindness, handsomely reward for your contributions.

ABSTRACT

The main purpose of this study is to study the effects of abrasive tools on mild steel surface by using three parameters (depth of cut, table speed, and mode of dressing). This study was conducted by using surface grinding machine. Taguchi method was employed as an analysis tool for this study. Total series of experiments performed was 9 set for each grinding wheels (Silicon Carbide and Aluminium Oxide). Statistical software was used to predict the surface roughness. To validate the prediction result, experimental values compared. Result showed that lower depth of cut, lower table speed and lower mode of dressing produced better surface finish. For the abrasive tools used, the Aluminium Oxide wheel produced lower value of surface roughness compared with the Silicon Carbide wheel. The predicted result showed that depth of cut, table speed and dressing mode are significant parameter in influencing of surface roughness.

ABSTRAK

Tujuan utama kajian ini adalah untuk mempelajari pengaruh alat 'abrasive' terhadap permukaan mild steel dengan menggunakan tiga parameter (kedalaman potongan, kelajuan meja, dan cara 'dressing'). Kajian ini dilakukan dengan menggunakan 'surface grinding machine'. Kaedah Taguchi digunakan sebagai alat analisis untuk kajian ini. Jumlah siri percubaan yang dijalankan adalah 9 siri untuk setiap jenis 'grinding wheels' (Silicon Carbide and Aluminium Oxide). Perisian statistik digunakan untuk meramal nilai kekasaran permukaan. Untuk mengesahkan hasil ramalan, keputusan daripada eksperimental dibandingkan. Dari keputusan yang diperoleh, dapat disimpulkan bahawa kedalaman pemotongan yang rendah, kelajuan meja rendah, dan 'dressing mode' yang rendah menghasilkan permukaan akhir yang lebih baik. Untuk alat 'abrasive' yang digunakan, roda 'Aluminium Okside' menghasilkan nilai kekasaran permukaan yang lebih rendah berbanding dengan roda 'Silicon Carbide'. Hasil ramalan menunjukkan bahawa kedalaman pemotongan, kelajuan meja dan cara 'dressing' adalah parameter yang signifikan dalam mempengaruhi kekasaran permukaan bahan.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Steel is an alloy that consists mostly of iron and has carbon content between 0.2% and 2.1% by weight, depending on the grade. Carbon is the most common alloying material for steel, but various other alloying elements are used, such as manganese, chromium, vanadium, and tungsten. Carbon and other elements act as a hardening agent, preventing dislocations in the iron atom crystal lattice from sliding past one another. Varying the amount of alloying elements and the form of their presence in the steel (solute elements, precipitated phase) controls qualities such as the hardness, ductility, and tensile strength of the resulting steel. Steel with increased carbon content can be made harder and stronger than iron, but such steel is also less ductile than iron. Today, steel is one of the most common materials in the world, with more than 1.3 billion tons produced annually. It is a major component in buildings, infrastructure, tools, ships, automobiles, machines, appliances, and weapons.

Surface grinding processes are industrial processes in which removal of unwanted material to get good quality of surface finish. It is one of the most important and widely used manufacturing processes in engineering industries. In the study of surface grinding process, the output quality is rather important. A significant improvement in output quality may be obtained by optimizing the cutting parameters. Optimization of parameters not only improves output quality, but also can reduce cost manufacturing. Grinding parameters include mode of dressing, table speed, depth of cut, cutting fluids and so on.

Nowadays, roughness plays a significant role in determining and evaluating the surface quality of a product as it affects the functional characteristic. The product quality depends very much on surface roughness. Decrease of surface roughness quality also leads to decrease of product quality. In field of manufacture, especially in engineering, the surface finish quality can be a considerable importance that can affects the functioning of a component, and possibly its cost.

Generally, the type of wheels plays a very important role, as it is responsible to obtain the quality of surface finish. This paper presents an experimental study of surface grinding with two type of wheel to investigate the relationship between abrasive tools with surface finish of workpiece in different table speed, depth of cut, and mode of dressing.

1.2 PROBLEM STATEMENT

The quality of surface finish is an important requirement for many grinded workpieces. Thus, the choice of optimized cutting parameters is very important for controlling the required surface quality. In grinding operation, there are many parameters such as table speed, depth of cut and dressing mode that have great impact on the surface finish. A smooth surface finish reduces the risk of system contamination, and increases the speed of cleaning and sterilization. All these while, there are numbers of studies are done to investigate the effects of table speed, mode of dressing and depth of cut on the surface roughness with two types of grinding wheel used which is silicon carbide and aluminum oxide. In this research, grinding operations will be carried out to generate the optimum surface finish by using table speed, dressing mode and depth of cut as parameters. The material that will be used is mild steel.

1.3 PROJECT OBJECTIVES

1) To investigate the influence of wheels types on surface finishing via experimental in term of surface roughness analysis.
2) Study the effect of cutting parameters on the surface quality of the machined surfaces.

1.4 SCOPE OF PROJECT

In order to achieve the objectives notified earlier, the following scopes have been identified:

1) Performed surface grinding operation. Grinding operation will be done on mild steel based on three machining parameters.
2) Determine the major grinding parameters that influence the surface finishing.
3) Investigate the surface roughness using the Perthometer machine.
4) Obtain optimal level of parameters for each performance using graph of S/N ratio.
5) Use the Analysis of variance (ANOVA) to get the relationship between the roughness and variables parameters machining.
6) Compared the data and decide which the most significant parameter that affect surface roughness by using Response surface method (RSM) modeling.

1.5 SUMMARY

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project on the effects of abrasive tools on surface finish when grinding mild steel with different parameters which is table speed, mode of dressing and depth of cut. This chapter is as a fundamental for the project and act as a guidelines for project research completion.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

From the early stage of the project, various literature studies have been done. Research journal, reference books, printed or online conference article were the main source in the project guides as they contain the current knowledge on particular research. The reference sources emphasize on effect of abrasive tools on surface finish when grinding mild steel. Then, the effects of abrasive tools on surface finish of mild steel will be justified using surface roughness value.

2.2 SURFACE GRINDING MACHINE

Grinding machines are used for finishing process. When greater accuracy than that obtainable on the milling machine or the lathe is required, recourse is had to grinding. This operation depends upon the abrasive or cutting qualities of emery, corundum, and carborundum. With workpiece properly held to a solid grinding wheel, it is not difficult to attain great accuracy. Surface grinding is used to produce a smooth finish on flat surfaces. It is a widely used abrasive machining process in which a spinning wheel covered in rough particles (grinding wheel) cuts chips of metallic or non metallic substance from a workpiece, making a face of it flat or smooth.

2.2.1 Process of Surface Grinding

Surface grinding is the most common of the grinding operations. It is a finishing process that uses a rotating abrasive wheel to smooth the flat surface of metallic or nonmetallic materials to give them a more refined look or to attain a desired surface for a functional purpose.

The surface grinder is composed of an abrasive wheel, a workholding device known as a chuck, and a reciprocating table. The chuck holds the material in place while it is being worked on. It can do this one of two ways: metallic pieces are held in place by a magnetic chuck, while nonmetallic pieces are vacuumed in place.

Factors to consider in surface grinding are the material of the grinding wheel and the material of the piece being worked on. The grinding wheel is not limited to just a cylindrical shape, but can have a myriad of options that are useful in transferring different designs to the object being worked on. When surface grinding an object, one must keep in mind that the shape of the wheel will be transferred to the material of the object like a mirror image.

2.2.2 Equipment

Figure 2.1: Surface Grinder with electromagnetic chuck, inset shows a Manual magnetic chuck

A surface grinder is a machine tool used to provide precision ground surfaces, either to a critical size or for the surface finish. The typical precision of a surface grinder depends on the type and usage, however +/- 0.002 mm (+/- 0.0001") should be achievable on most surface grinders.

The machine consists of a table that traverses both longitudinally and across the face of the wheel. The longitudinal feed is usually powered by hydraulics, as may the cross feed, however any mixture of hand, electrical or hydraulic may be used depending on the ultimate usage of the machine (i.e. : production, workshop, cost). The grinding wheel rotates in the spindle head and is also adjustable for height, by any of the methods described previously. Modern surface grinders are semi-automated, depth of cut and spark-out may be preset as to the number of passes and once setup the machining process requires very little operator intervention.

Depending on the workpiece material, the work is generally held by the use of a magnetic chuck. This may be either an electromagnetic chuck, or a manually operated, permanent magnet type chuck; both types are shown in the first image. The machine has provision for the application of coolant as well as the extraction of metal dust (metal and grinding particles).

2.2.3 Types of Surface Grinders

1) Horizontal-spindle (peripheral) surface grinders - The periphery (flat edge) of the wheel is in contact with the workpiece, producing the flat surface. Peripheral grinding is used in high-precision work on simple flat surfaces; tapers or angled surfaces; slots; flat surfaces next to shoulders; recessed surfaces; and profiles.
2) Vertical-spindle (wheel-face) grinders - The face of a wheel (cup, cylinder, disc, or segmental wheel) is used on the flat surface. Wheel-face grinding is often used for fast material removal, but some machines can accomplish high-precision work. The workpiece is held on a reciprocating table, which can be varied according to the task, or a rotary-table machine, with continuous or indexed rotation. Indexing allows loading or unloading one station while grinding operations are being performed on another.
3) Disc grinders and double-disc grinders - Disc grinding is similar to surface grinding, but with a larger contact area between disc and workpiece. Disc

grinders are available in both vertical and horizontal spindle types. Double disc grinders work both sides of a workpiece simultaneously. Disc grinders are capable of achieving especially fine tolerances.

2.2.4 Grinding Wheels for Surface Grinders

Aluminum oxide, silicon carbide, diamond, and cubic boron nitride (CBN) are four commonly used abrasive materials for the surface of the grinding wheels. Of these materials, aluminum oxide is the most common. Because of cost, diamond and CBN grinding wheels are generally made with a core of less expensive material surrounded by a layer of diamond or CBN. Diamond and CBN wheels are very hard and are capable of economically grinding materials, such as ceramics and carbides, which cannot be ground by aluminum oxide or silicon carbide wheels.

2.2.5 Lubrication

Lubricants are sometimes used to cool the workpiece and wheel, lubricate the interface, and remove swarf (chips). It must be applied directly to the cutting area to ensure that the fluid is not carried away by the grinding wheel. Common lubricants include water-soluble chemical fluids, water soluble oils, synthetic oils, and petroleum-based oils.

2.2.6 Grinding Machine Safety

Grinding machines are used daily in a industry process. To avoid injuries follow the safety precautions listed below.

1) Wear goggles for all grinding machine operations.
2) Check grinding wheels for cracks before mounting.
3) Never operate grinding wheels at speeds in excess of the recommended speed.
4) Never adjust the workpiece or work mounting devices when the machine is operating
5) Do not exceed recommended depth of cut for the grinding wheel or machine.

6) Remove workpiece from grinding wheel before turning machine off.
7) Use proper wheel guards on all grinding machines.
8) On bench grinders, adjust tool rest 1/16 to 1/8 inch from the wheel.

2.3 WHEEL STRUCTURE

A grinding wheel (more specifically, the rim, or the abrasive segments, of the grinding wheel) consists of abrasive grains (a.k.a. abrasive grits), bond material, and pores, as shown in Figure 2.2 (Jackson et. al., 2003). Grinding wheels can be manufactured in a variety of grades or structures determined by the relative volume percentage of abrasive grains, bond, and porosity (Bright and Wu, 2004). Grinding wheels and abrasive segments fall under the general category of 'bonded abrasive tools'. The properties and performance of bonded abrasive tools depend on the type of abrasive grain material, the size of the grit, the bond material, the properties of abrasive and bond, and the porosity (Z.J. Pei et al., 2006).

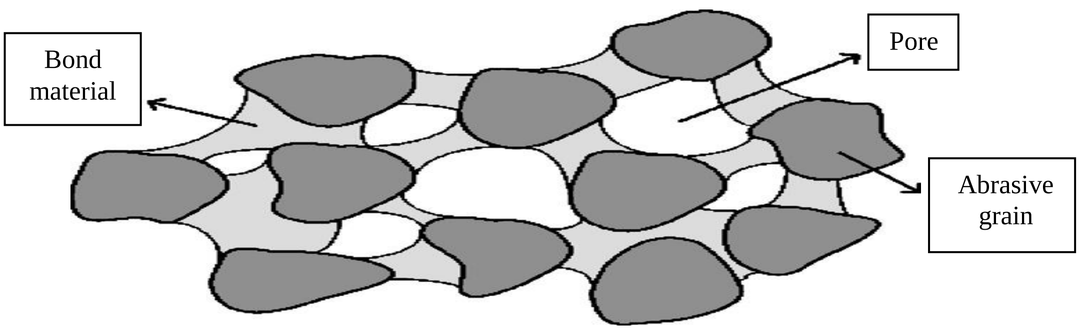


Figure 2.2: Compositions of a grinding wheel (Z.J. Pei et al., 2006).

Figure 2.3 illustrates the open/closed structures of grinding wheels. When a great deal of abrasive grains are mixed with very strong bond material and pressed under high pressure, a dense, low porosity grinding wheel will produced. This closed-structure wheel is typically used for holding the form. When a small amount of grains are mixed with a small amount of bond material and pore inducers, a very open, highly porous structure grinding wheel will result once the pore inducers are removed. This open structure wheel is used to remove a great amount of materials from workpieces when chip clearance is a limiting factor (Salmon S.C., 1992). The wheel grade, frequently referred as the wheel hardness, indicates the resistance of the abrasive grains from breaking out of the wheel's bonding system. It indicates the bond strength - the holding power of the bond to hold the abrasive grains in position under grinding forces (Drozda and Wick, 1983). With hard wheels, relatively more fracture occurs within the grain than at the bond. With soft wheels, the wheels wear faster (C. Karpac et. al., 2004).

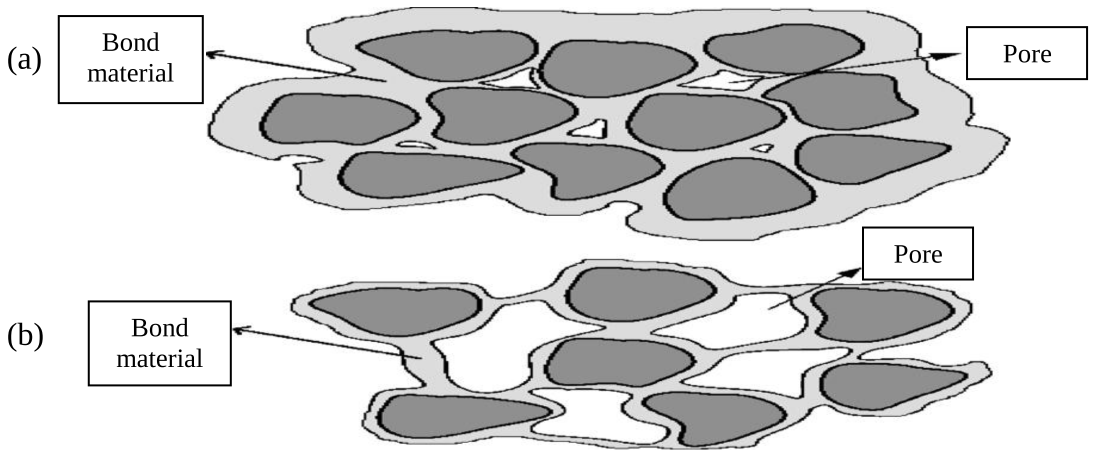


Figure 2.3: Illustration of wheels structure (a) Closed structure (b) Open structure (Z.J. Pei et al., 2006).

2.3.1 Grain Size

Grain size is determined mainly by the surface-finish requirement which the smaller the grain, the smoother the surface obtained. Conventionally, the grain size of abrasive particles is expressed in term of mesh sizes. The mesh size corresponds to the number of openings per linear inch in the wire gauze. Generally, small grain sizes can produce better finishes on ground surfaces, while larger grain sizes allow higher material removal rates. Furthermore, wheels with smaller grain sizes generally produce smoother surfaces. As the grain size becomes smaller, the roughness of the ground surfaces decreases (Z.J. Pei et al., 2006).

2.3.2 Bonds

The bond in a grinding wheel cements the abrasive grains together. Among other factors, the bond plays a predominant part in the diamond wheel performances and on the quality of grinding results. There are mainly three distinct wheel wear mechanisms, namely attritions wear, grain fracture, and bond fracture. Generally, the bond plays a very important role, as it is responsible for retaining the rigid inclusions against pull-out mechanisms (Malkin, 1989).

Surface finish performances and the obtained flow are linked with nature (Desmars and Margerand, 1994). In grinding, many differences in surface characteristics were underlined between the resin bond and the metallic bond. Resin is a soft bond that offers better quality of surface finish. However, wear of resin-bonded stones generally appears faster. This can decrease efficiency of the wheel as mentioned by Tong et al., (2006). To optimize wheel life and grinding performance, the bond wear rate should be equal to or slightly higher than the wear rate of the abrasive grain during grinding operations. The bond material must allow the diamond grains to fracture or pull out after they become worn to expose new cutting surfaces. It was found that ductile streaks at ground surface are found more when resin bond used than when metal bond is used (Venkatesh et al., 2005; Desmars and Margerand, 1994).

2.4 PARAMETERS THAT AFFECTING SURFACE FINISH IN SURFACE GRINDING OPERATION

2.4.1 Grinding Forces

As is well known, grinding force is one of the most important parameters in evaluating the whole process of grinding. Generally, the grinding force is resolved into three component forces, namely, normal grinding force F_n, tangential grinding force F_t and a component force acting along the direction of longitudinal feed which is usually neglected because of its insignificance. The normal grinding force F_n has an influence upon the surface deformation and roughness of the workpiece, while the tangential grinding force F_t mainly affects the power consumption and service life of the grinding wheel.

The force plays an important role in grinding process since it is an important quantitative indicator to characterize the mode of material removal (the specific grinding energy and the surface damage are strongly dependent on the grinding force) (Agarwal and Rao, 2007).

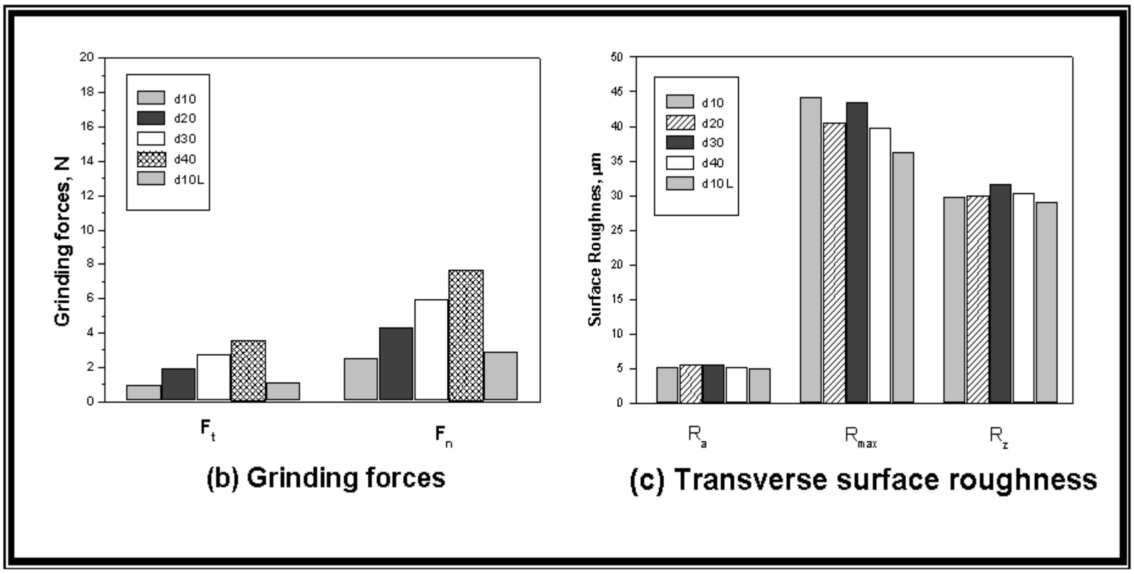


Figure 2.4: Grinding force versus Depth of Cut Graph
(Agarwal and Rao, 2007).

Grinding parameters like grinding velocity, traverse speed or wheel depth of cut affects the grinding force which in turn can cause fracture, rounding or flattening on few overlying grits thus, bringing more number of underlying grits into action. This change in topographical feature of single layer wheel, in various levels, affects the surface roughness of the workpiece. Grinding force increases with decrease in grinding velocity while the same increases with increase in table speed and depth of cut. Accordingly a trend is observed on decrease of surface roughness with decrease in grinding velocity and increase of both traverse speed and wheel depth of cut.

2.4.2 Dressing Mode

The surface profile of the wheel formed by dressing is determined by the relative motion between the diamond and the wheel, the characteristics of the wheel and the shape of the diamond. In early research, the dressing process was described as a wheel cutting process. Pahlitzsch and Brunswick (1954), suggested that the diamond cuts through the abrasive grains to produce cutting points. The dressing tool moves across the wheel surface with a dressing lead per wheel revolution while removing a dressing depth. Generally a fine dressing operation refers to the combination of a small dressing lead and a small dressing depth. Conversely, the combination of a large dressing lead and a large dressing depth is described as a coarse dressing operation. When the wheel is used for grinding, a pattern based on the distribution of abrasive grains transfers to the workpiece surface. This "grain cutting" theory has been assumed by many researchers since the surface profile of the ground workpiece can often be directly attributed to the dressing process. For a dressing diamond with a tip angle ¢, the theoretical peak-to-valley height of the thread profile generated on the wheel can be written as

$$Rp_{\mathrm{v}} = \frac{fd}{2tan\,(\frac{\emptyset}{2})} \qquad (2.1)$$

According to this equation, the dressing traverse rate and the shape of the single-point diamond are particularly important. Bhateja et al. (1972), recorded wheel and workpiece profiles by stylus measurement. Dressing features clearly appeared on the workpiece surface, but could not be detected on the surface of the wheel. It was suggested that this was probably because any grooves produced in the wheel by the dressing process were very small compared to the roughness of the wheel.

2.4.3 Cutting Fluid

In general, the functions of the fluid include: mechanical lubrication of the abrasive contacts, chemo-physical lubrication of the abrasive contacts, cooling in the contact area particularly in creep grinding, bulk cooling outside the contact area, flushing or the transport of the debris away from the abrasive process, transport of abrasive to a loose abrasive process, entrapment of abrasive dust and metal process vapors (Tawakoli et. al., 2007). In spite of many advantages of the use of cutting fluids in the machining processes, they have serious disadvantages, such as ecological and economical problems, which have guided research works in the last decades to reduce or even eliminate the use of metal fluids (Tawakoli et. al., 2007).

During grinding many of the abrasive grits are in contact with the work piece each second, but just a portion of these grits have the cutting role in the real process and the others do not perform real cutting, but instead generate heat by rubbing and ploughing the work piece surface in the grinding contact zone. High heat generation and temperature in the grinding contact zone is associated with a high negative rake angle and with a great contact length in grinding process (Tawakoli and Azarhoushang, 2008).

Silva et al. (2005) investigated the effects of grinding parameters on ABNT 4340 steel using Minimum Quantity Lubricant (MQL) technique. They found that the surface roughness, diametric wear, grinding forces and residual stress improved with the use of the MQL system in grinding process due to better lubrication of grinding zone and providing better slipping of grain at the contact zone (Silva et. al., 2005).

2.4.4 Depth of Cut

Apart from the influence factors above, the surface structure produced in the surface grinding also affected by depth of cut. Based on W. H. Tuan* and J. C. Kuo (1997), the amount of the smooth area is decreased with the increased of depth of cut. For the ground specimen, the strength also decreased with the increased of the depth of cut.

Based on Agarwal and Rao (2007), the tangential grinding forces increase with the increase in depth of cut. This increase in grinding force is expected because of increased chip thickness at higher depth of cut. If the cutting depth is large enough to cause cracks, a chip removal will be due to the fracture of material surface. So, the surface finish of workpiece becomes rough.

2.5 INTERACTION OF THE ABRASIVE GRAINS AND THE WORKPIECE SURFACE

Depending on the grinding condition, only a small number of the abrasive grains on the grinding wheel will contact the workpiece surface. Among this small number of active grains, only a small portion will cut and form chips while the other will only plough or rub the workpiece surface. Therefore, an algorithm is first proposed to identify the active grain. Then, the attack angle of the active grain is estimated, based on which the grain will be determined cut, or plough, rub the workpiece surface.

2.5.1 Attack Angle of the Abrasive Grain

In grinding metals three distinct phases can be distinguished at the interface of the abrasive grain and the workpiece: rubbing, ploughing and cutting (R.S. Hahn and R.P. Lindsay, 1982). When the depth of cut is shallow, the grain only slides on the work causing elastic deformation in the work material with essentially no material removal. This is rubbing phase. Ploughing occurs as the grain causes more plastic flow of the work material in the direction of sliding with material being thrown up and broken off the sides of the groove.

Komanduri (1971), carrying out single point turning with negative rake angle tools, found that the value of the rake angle decided whether the tool cut, ploughed or rubbed. Takenaka (1966) observed that there was a critical depth of cut when the grain stopped cutting. Xie and Williams (1996) studied abrasive wear by repeating sliding of a hard asperity on the workpiece surface. They established that the deformation modes of the material depended essentially on the following factors: lubrication, the mechanical properties of the softer material and the distance between adjacent tracks in repeated pass situation. Kato (1992) conducted a scratch test in SEM apparatus, and observed that the material removal mode was affected by the degree of penetration, lubrication, and the hardness ratio of the abrading tip and the wear surface. Butler et al., (2002) showed that the grinding performance was correlated with the arithmetic sum of the curvature of the grinding wheel surface.

2.6 DRY GRINDING

In spite of many advantages of the use of cutting fluids in the machining processes, they have serious disadvantages, such as ecological and economical problems, which have guided research works in the last decades to reduce or even eliminate the use of metal fluids (Tawakoli et al., 2007). Besides that, many of industries try to reduce the using of grinding fluids because the cost of these fluids very high (T.D. Howes et al., 1991). In order to solve the ecological and economical problems, Tawakoli et al. (2007) have investigated the strategies for minimizing the quantity of grinding fluid by using special conditioning on grinding wheel or change in the characteristics of the grinding wheel such as grit size, bonding and porosity, and changing in the grinding parameters such as depth of cut, feed rate or grinding speed and mode of dressing.

2.7 SURFACE ROUGHNESS

Surface roughness is described by parameters predicating about longitudinal or cross-surface profile. Parameters of surface roughness are simplification of real profile, are simply determinable and have sufficient ability to give account of surface. Surface roughness should be arranged as an optimal value for function execution of a part surface. It is usually set up by the design engineer optionally after an agreement with the process engineer. In general, certain roughness is possible to reach by a few technologies but the difference by the same roughness values is in surface profile. Increasing the depth of cut changed the maximum height of the surface roughness more than the centerline average height (Jae-Seob Kwak et al., 2005).

Surface finish influences not only the dimensional accuracy of machined parts but also their properties and their performance in service. The term ‘surface finish’ describes the geometric features of a surface, and surface integrity pertains to material properties such as fatigue life and corrosion resistance, in which are strongly influenced by the nature of the surface produced (Kalpakjian, 2006).

1) Tool influence: Grain size affects number and dimension of chips, width of plastic deformed zone and ratio of plastic and elastic deformations. Kind of grinding material influences the surface roughness particularly by mechanical properties of itself and grain geometry. Factor of the heat conductivity of grain and quality of the grain-binder bond cannot be neglected as well. Strength of bond is given not only by binder properties but also by morphology and chemical composition of grain.

2) Workpiece influence: Properties of workpiece material effect on the surface creation by strength, hardness and heat conductivity of material and workpiece itself by dimensions of it. Structure and previous heat treatment are very significant as well.

3) Cutting environment influence: Environment by grinding is formed by process liquid of various types. Most of these liquids represent water solutions of chemical substances and emulsions. In the last years, producers of coolants endeavour after producing of quality cooling fluid being ecologically desirable. Coolant carried out a few very important functions. Except already mention edit is chip creation support, chip removal, preclusion of pore blinding of grinding wheels, preclusion of corrosion etc.

2.8 PARAMETERS AND THEIR SELECTION STRATEGIES

Grinding is a complex manufacturing process with a large number of interacting variables, which depend on the type of grinding employed. The geometry produced in the surface grinding is influenced by many variables given as follows:

1) Wheel characteristic - wheel diameter, grit type and size, wheel grade, structure, bond, dressing method, degree of wheel balance, etc.;
2) Work characteristic - workpiece hardness, structure, chemistry, etc.;
3) Machine characteristic - spindle and table stiffness, damping, dynamic characteristic, etc.;

4) Operating conditions - wheel speed, feed, infeed (depth of cut), grinding fluid, etc.

Many investigations have been carried out to understand relationship between grinding conditions and their influence on machining. Existing techniques employed to deal with the selection of grinding conditions can be classified as follows:

1) Data retrieval methods;
2) Process model methods;
3) Artificial Intelligence (AI) methods.

The data retrieval method uses a database of cutting conditions either as suggested in the hand book or gathered from the industrial field. Though computerized machine ability database systems are available for turning, drilling and milling, only few covers grinding. The process models for grinding, both physical and empirical models, contribute significantly to the understanding of the process.

However, as many uncontrolled parameters are involved in the grinding process, physical models cannot have a comprehensive definition and empirical models have restricted range of validity. So the process models are not reliable in practice. AI methods include rule based reasoning; care based reasoning, artificial neural networks, hybrid systems, etc. Each of these methods has its own limitations in giving a comprehensive and precise relationship between the grinding variables and the grinding behavior in a specific situation.

To achieve the required quality requirements in a specific situation, operating parameters are often determined with the aid of grinding tests. If more number of parameters are there the conventional testing methods are time consuming and expensive. Here lies the importance of the Taguchi methods for the design of experiments (V. Radhakrishnan et al., 2002).

2.9 APPLICATION OF TAGUCHI METHOD

Taguchi methods of experimental design provide a simple, efficient and systematic approach for the optimization of experimental designs for performance quality and cost. It has been proved successful to many manufacturing situations. The traditional experimental design procedures focus on the average product or process performance characteristics. But the Taguchi method concentrates on the effect of variation on the product or process quality characteristics rather than on its averages. That is, the Taguchi's approach makes the product or process performance insensitive (robust) to variation to uncontrolled or noise factors. Taguchi recommends that this can be done by the proper design of parameters during the 'parameter design' phase of off-line quality control. He designed certain standard orthogonal arrays (OAs) by which simultaneous and independent evaluation of two or more parameters for their ability to affect the variability of a particular product or process characteristic can be done in a minimum number of tests. Subsequently, decision is made for the optimum combination of these parameters (V. Radhakrishnan et al., 2002).

The parameter design phase of the Taguchi method generally includes the following steps:

1) identify the objective of the experiment
2) identify the quality characteristic (performance measure) and its measurement systems
3) identify the factors that may influence the quality characteristic, their levels and possible interactions
4) select the appropriate OA and assign the factors at their levels to the OA
5) conduct the test described by the trials in the OA
6) analysis of the experimental data using the signal-to-noise (S/N) ratio, factor effects and the ANOVA (analysis of variance) to see which factors are statistically significant and find the optimum levels of factors
7) verification of the optimal design parameters through confirmation experiment

2.9.1 Selection of OA and Assignment of Factors

For the experiment having three factors at three levels the associated degree of freedom is 9 (including the degree of freedom for the mean). So the selected OA should have a minimum of nine rows (representing nine trials) and three columns to accommodate three factors having three levels. The L9 OA which meets this requirement was selected. If traditional experimental procedure had been followed 27 trials would have been required to yield the same information.

2.9.2 Evaluation of S/N Ratios

Taguchi suggests the transformation of the repetition data in a trial into a consolidated single value called the S/N ratio. Here, the term ‘signal’ represents the desirable value (mean) and the ‘noise’ represents the undesirable value (standard deviation). So the S/N ratio represents the amount of variation present in the quality characteristic. Depending upon the objective of quality characteristic there can be various types of S/N ratios. Here the desirable objectives are lower values of surface roughness and force components. So the lower-the-better type S/N ratio, as given below was applied for transforming the observed data:

$$\eta = -10\log\frac{1}{n}\left[\sum_{i=1}^{n} yi2\right] \tag{2.2}$$

Where η is the S/N ratio for the lower-the-better case, yi the measured quality characteristic for the ith repetition, and n the number of repetitions in a trial (Ross P.J, 1996).

2.10 RESPONSE SURFACE METHODOLOGY

The surface finish of machined surface is important in engineering Applications which have considerable effect on wear resistance, light reflection, heat transmission, coating and resisting fatigue of the material. While machining, quality of the parts can be achieved only through proper cutting conditions. In order to know the surface quality and dimensional properties in advance, it is necessary to employ theoretical models making it feasible to do predict the response as a function of operating conditions. Response surface methodology (RSM) is a mixture of mathematical and statistical technique which is useful for modelling and analysing the problems in which a response of interest is influenced by several variables and the objective is to optimize that response (Montgomery D.C, 2005).

In many engineering fields, there is a relationship between an output variable of interest ‘y’ and a set of controllable variables $\{x_1, x_2 \ldots x_n\}$. In some systems, the nature of the relationship between y and x values might be known. Then, a model can be written in the form

$$\gamma = f(x_1, x_2 \ldots x_n) + \boldsymbol{\varepsilon} \tag{2.3}$$

Where ε represents noise or error observed in the response y. If we denote the expected response be

$$E(\gamma) = f(x_1, x_2 \ldots x_n) = \bar{Y} \tag{2.4}$$

Then the response surface represented by

$$\bar{Y} = f(x_1, x_2 \ldots x_n) \tag{2.5}$$

In most of the RSM problems, the form of relationship between the response and the independent variable is unknown. Thus the first step in RSM is to find a suitable approximation for the true functional relationship between y and set of independent variables employed (Kwak J.S, 2005).

2.11 PERTHOMETR S2

The evaluation unit Perthometer S2 is featured by:

- Roughness and waviness measurements according to current standards (DIN EN ISO 3274, e.g. band-pass filter)
- A large high resolution graphics display to indicate results and profiles
- Easy operation based on the automatic teller principle and large operation buttons
- Storage facility on PCMCIA memory card for measuring programs, results and profiles
- Add-On program S2Prog for easy creation of measuring programs
- Extensive, easily applicable software functions, such as:
    1) Automatic function for setting standardized filters and tracing lengths

2) Monitoring of calibration and maintenance intervals
3) ARC function for arc elimination
4) Dynamic and static calibration routines
5) Tolerance monitoring with sound and optical signals
6) Blocking of instrument settings to prevent unintentional modifications plus possibility of password protection
7) Integrated statistical functions
8) Easy call-up and printout of measuring records and individual functions

Figure 2.5: Perthometer S2

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The experiment methods and procedures used in order to get the experiment results are discussed clearly step by step in this chapter. This systematic planning of methodology very important to keep the experiment is running smoothly.

Machining work started by preparing 18 pieces of workpiece by using band saw machine, determining the grade of mild steel, then facing the workpiece surface by using conventional milling machine and the last step of machining work is doing the grinding process using surface grinding machine. After finish the machining process, the surface roughness of workpiece is determine using Perthometer S2. The result obtained from the experiment will be applied using Response Surface Method (RSM) in identifying significant and insignificant parameters to the surface finishing process.

3.2 LITERATURE STUDY

Literature studies on various sources such as research journal, online conference article and reference books are done in order to get better understanding about this thesis. Main focus would be on effects of abrasive tools on the surface finish of mild steel.

3.3 MATERIAL PREPARATION

After finished gathering all the information, the project starts by preparing the materials which is mild steel that available at FKM Laboratory. In this phase, band saw machine (Figure 3.1) have been used for this purposed to cut Mild steel into 18 pieces with dimension 50 x 50 x 6 mm each. Then, all the ground surface of workpiece is facing using conventional milling machine (figure 3.2) to remove rust on surface in order to get fine surface for grinding process.

Figure 3.1: Band saw machine

Figure 3.2: Milling machine

3.4 SELECTION OF PARAMETERS

Based on research journal, parameters which commonly used for surface grinding process are table speed, depth of cut and mode of dressing. The spindle speed and coolant condition are set as constant parameters.

3.5 SURFACE GRINDING PROCESS

A series of experiments have been conducted to evaluate which grinding parameters affect the quality of surface finish in surface grinding. Three grinding parameters which is mode of dressing, depth of cut and table speed were selected for experimentation. All the grinding experiments of mild steel were performed on (STP1022ADCΠ, SUPERTEC) surface grinding machine (Figure 3.3).

Figure 3.3: Surface Grinding Machine

In this project, surface grinding process will be executed on mild steel by using different type of wheels. The influence of the wheel structure on surface ground of workpiece will be predicted using surface roughness value. Figure 3.4 below show a design layout on how this experiment will be carried out.

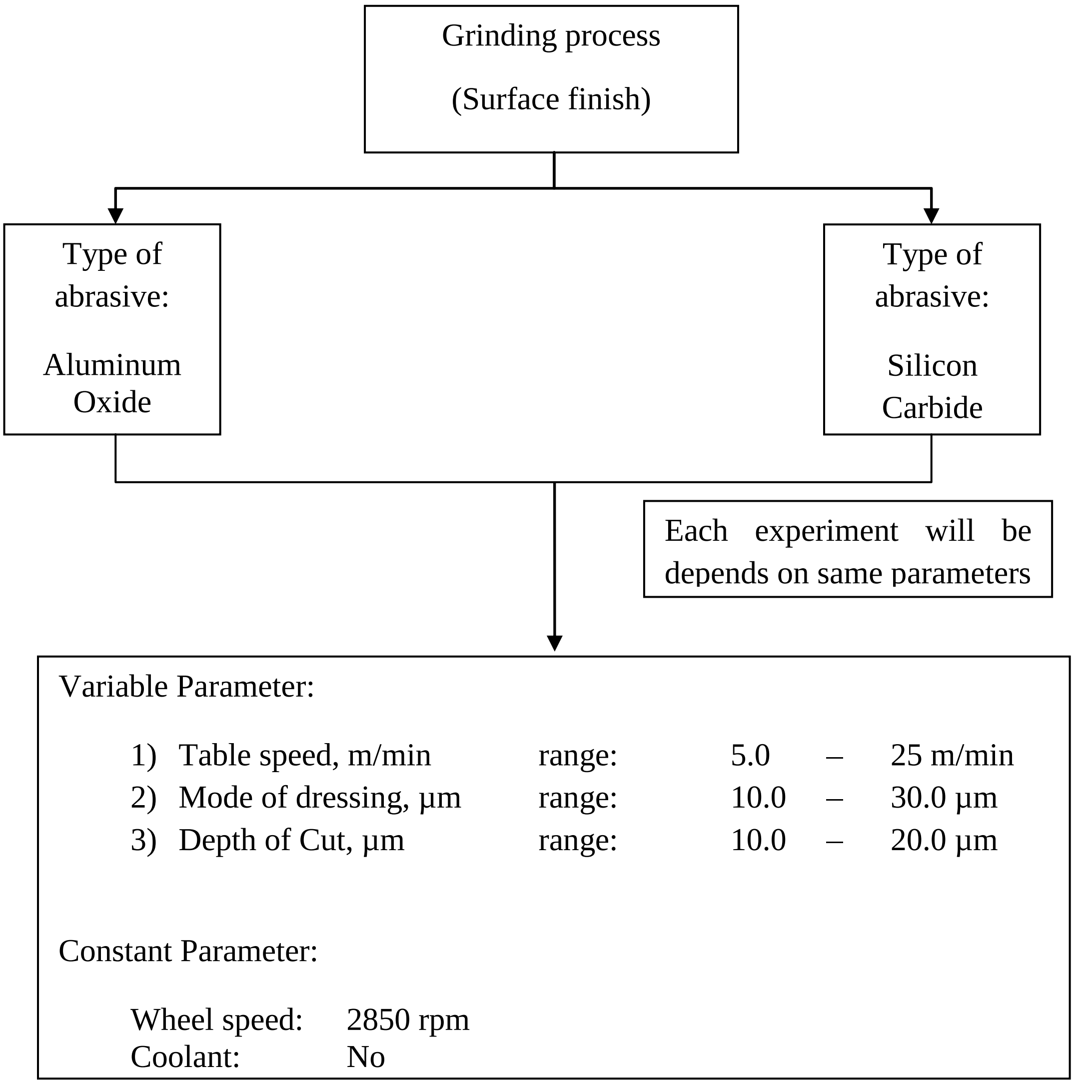


Figure 3.4: Design layout

3.6 RECORDING DATA

The data will be recorded in Table 3.1 and Table 3.2 as shown below based on three parameters used for grinding process. Each table separated based on different types of wheel which is Silicon Carbide and Aluminium Oxide. The difference types of wheel will be applied on workpiece and the values of surface roughness will measure using perthometer S2.

Table 3.1: Silicon Carbide wheel

Trial no.	Level of factors			Surface Roughness, R_a (μm)				S/N Ratio (dB)
	Table speed (m/min)	Depth of cut (μm)	Dressing mode (μm)	1st trial	2nd trial	3rd trial	Average of Ra	
1	5	10	10					
2	5	15	20					
3	5	20	30					
4	15	10	20					
5	15	15	30					
6	15	20	10					
7	25	10	30					
8	25	15	10					
9	25	20	20					

Table 3.2: Aluminium Oxide wheel

Trial no.	Level of factors			Surface Roughness, R_a (μm)				S/N Ratio (dB)
	Table speed (m/min)	Depth of cut (μm)	Dressing mode (μm)	1st trial	2nd trial	3rd trial	Average of Ra	
1	5	10	10					
2	5	15	20					
3	5	20	30					
4	15	10	20					
5	15	15	30					
6	15	20	10					
7	25	10	30					
8	25	15	10					
9	25	20	20					

3.7 SURFACE ROUGHNESS TEST

Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of surface quality. The surface roughness was measured by using Perthometer (Figure 3.5). The values of surface roughness of the specimens in each level of parameter for different wheels are stated down for further analysis. Surface roughness value is taken three times to get better accuracy.

Figure 3.5: Perthometer

3.8 DATA DISCUSSION

With regard to prior result analysis, a final discussion will be carried on. In this discussion, parameters with greatest tendency to onset the surface roughness and type of abrasive which give the highest quality surface when grinding mild steel will be determined. Response surface method (RSM) modeling will be used to decide which the most significant parameter that affects surface roughness. The analysis concluded from experiment will be used for surface finish prediction.

3.9 WHEEL TYPE

3.9.1 Aluminium Oxide

Aluminium oxide is the most common industrial mineral in use today. Fused aluminium oxide is produced synthetically by melting bauxite and additive in an arc furnace to form a fused aluminium oxide ingots, which are later crushed and sized. Fused aluminium oxide is also produced synthetically by chemically purifying. The various types of fused aluminium oxides are distinguished by the levels of chemical impurities remaining in the fused mineral. Titanium and chromium oxides are typical additives. Fused aluminium oxide is available in several variations depending on composition and processing such as white (high purity), brown or regular (titanium oxide modified) and pink (chromium oxide additions). Titanium oxide additions can toughen the abrasive and enable heat treating process, which changes brown aluminium oxide to a blue colored grain as TiO_2 precipitates form. Aluminium oxide abrasives are also produced with chemical precursors and precipitation, calcinations and/or sintering processes. Calcined or platelet aluminas as used in fine grit or polishing applications. Sol-gel aluminium oxide is produced in using chemical ceramic technology, but this abrasive has very high performance and is usually referred to as Ceramic abrasive grain to distinguish the grain from lower performing fused aluminium oxide. Aluminium oxide occurs naturally in the form of the mineral corundum, but the mineral is not used as a commercial abrasive except as a component of emery.

3.9.2 Silicon Carbide

Silicon carbide is a synthetic abrasive first developed in the late 1800s. SiC is harder than aluminium oxide, but more friable than fused aluminium oxide grains. Silicon carbide is typically applied to nonferrous applications (brass, aluminium, titanium). The high solubility of carbon and silicon in iron would result in a reaction of silicon carbide with the iron base alloy and poor grinding performance. Levels and types of impurities distinguish the green and black forms of silicon carbide. The sharp and easily fractured abrasive grains for abrading other non-metals such as the stone, glass, wood, and leather. SiC, like diamond, is susceptible to oxidation at higher temperatures.

3.9.3 Grinding Wheel Specifications

Wheel specifications	Explanations
Grit type and colour	Aluminium oxide (white, pink, ruby red, brown, grey, etc.) and silicon carbide (black or green).
Grit size	Coarse (16 -24 grit), medium (36 - 60 grit) and fine (80-120 grit). Superfine grits run from 150 and higher.
Hardness	'A' is being the weakest bond and 'Z' being the strongest.
Structures	An open structure would be 12 or higher while a closer structure would be 6 or so.
Bond types	'B' is resin, 'M' is metal and 'V' is vitrified
Wheel types	'A' is aluminium oxide, 'C' is silicon carbide, 'D' is diamond and 'CBN' is cubic boron nitride

Grinding wheel specification for silicon carbide is 'GC 80 K V'. 'GC' is the grit type which is green silicon carbide, '80' is the grit size, 'K' is the relative hardness, and 'V' is the type bond which means vitrified bond. For the aluminium oxide wheel, it specification is 'A 46 P 7 V'. In this case, 'A' is aluminium oxide, '46' is grit size and it typically at medium grit size. 'P' is the grade of wheel (the relative hardness), '7' is structure or grain spacing, and 'V' is the vitrified bond.

3.10 PROCEDURE OF EXPERIMENTAL

First of all, check all equipments were used in this experiment whether ok or not especially surface grinding machine. If surface grinding machine in good condition, clean the machine from all things that can affect the process flow. Make sure all guards in its position and safe to use. Before start the grinding process, the grinding wheel (silicon carbide) must going through the dressing process to remove impurities that stuck on the wheel surface and this process also can rebuild the wheel surface become more flat. After that, clamp the workpiece on work table using magnetic power (make sure work table clean first). To avoid the workpiece move out from its place, hold the workpiece using two small thickness of flat steel plates. Each plate placed at the left and right side of workpiece. Then adjust the parameters of experiment based on table 3.1 and run the experiment. After finish, remove the workpiece from the work table and replace with other workpiece. Repeat the process for other workpiece using different levels of parameters. After finish all the experiments using silicon carbide wheel, repeat the whole process from starting for next grinding wheel which is aluminium oxide wheel based on parameters and its levels in table 3.2. When all experiment is done, check the surface roughness for all workpiece using perthometer S2. Then key in all data in the table provided.

3.11 DRESSING PROCESS

Firstly clean the work table surface from all things that can disturb the dressing process. After that, clamp the diamond cutting tool on work table using magnetic power. Set the depth of cut based on level of parameters that used in the experiment. Speed of work table at z-axis and spindle speed was set as constant. For first dressing process, depth of cut used is 10mm. Then, turn ON the spindle and dress the wheel smoothly. The dressing tool moves across the wheel surface one revolution per process to get the required surface which means the work table for z-axis moves forward across the wheel surface and return back at it origin position. After finish one revolution of process, turn OFF the spindle and work table. Repeat the process from start until the end for the next depth of cut.

3.12 PROCESS TO MEASURE THE SURFACE ROUGHNESS

Firstly, make sure the perthometer in good condition and turn ON the device if it is in good condition. Next, set the measuring conditions based on standard of device. After that, put the workpiece on the small X/Y table. Make sure the drive unit is higher than workpiece to prevent the surface roughness sensor from damaged. Then adjust the angle of drive unit at good position to get better reading. After finish set the surface roughness sensor at the best position on workpiece surface, press the START button. Then, the values of surface roughness are shows on the monitor device and print the recorded data from that device. Repeat the measurement process three times for each workpieces.

3.13 SUMMARY

This experiment is about carrying out surface grinding process using different type of wheels with different set of parameters. Then, values of surface roughness are measured by using Perthometer. The effect of abrasive tools on surface finish based on different parameters for mild steel is analyzing base on surface roughness value. All data are comparing to decide which category of parameter level and type of wheels will produce lowest surface roughness value.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter describes the results and discussion based on the experiment conducted. The experimental results will be presented in the table to facilitate the process of analyzing those results. Then the experimental results will be compared to each other. Recommendation will be given for future improvements. Surface roughness is the measure if the finer surface irregularities in the surface texture. The ability of manufacturing operation is base on many factors. The final surface depends on the table speed, depth of cut, and dressing mode. Beside, type of grinding wheels is one of important consideration that affects the surface finish when grinding mild steel.

4.2 EXPERIMENTAL RESULT

All experiment result had filled in to surface roughness table base on their machining parameters. Data in each table had been analyzed using graph surface roughness value in respond to depth of cut, table speed, and dressing mode.

4.2.1 Result of Chemical Composition Test of Mild Steel

As the grade of mild steel used is unknown, a chemical analysis test is carried on the specimen to identify the grade of specimen. The test is carried using an arc spectrometer. The test is run three times on the surface of mild steel to get more accurate result.

Table 4.1: Result from arc spectrometer tester

Composition	Ni	Al	Co	Cu	Nb	Ti	V	W
1st Run	0.0060	0.0010	0.0027	0.0335	0.0020	0.0020	0.0206	0.0150
2nd Run	0.0050	0.0015	0.0029	0.0344	0.0020	0.0020	0.0213	0.0150
3rd Run	0.0050	0.0011	0.0029	0.0349	0.0020	0.0020	0.0199	0.0150
Average	**0.0050**	**0.0012**	**0.0029**	**0.0343**	**0.0020**	**0.0020**	**0.0206**	**0.0150**

Composition	Pb	Sn	B	Ca	Zr	As	Bi	Pb
1st Run	0.0250	0.0020	0.0010	0.0003	0.0020	0.0050	0.0300	0.0250
2nd Run	0.0250	0.0020	0.0010	0.0003	0.0020	0.0050	0.0300	0.0250
3rd Run	0.0250	0.0020	0.0010	0.0002	0.0020	0.0050	0.0300	0.0250
Average	**0.0250**	**0.0020**	**0.0010**	**0.0003**	**0.0020**	**0.0050**	**0.0300**	**0.0250**

Composition	Fe	C	Mn	Si	P	S	Cr	Mo
1st Run	98.800	0.2210	0.5310	0.1470	0.1000	0.0794	0.0252	0.0050
2nd Run	98.700	0.2240	0.5360	0.1410	0.1000	0.0858	0.0238	0.0050
3rd Run	98.800	0.2260	0.5270	0.1370	0.1000	0.0873	0.0250	0.0050
Average	**98.800**	**0.2240**	**0.5310**	**0.1420**	**0.1000**	**0.0842**	**0.0247**	**0.0050**

Based on the result shown in Table 4.1 above, the grade of the mild steel is basically determined using the 3 main compositions. The specimen contains average 98.8 % of iron, 0.22 % of carbon and 0.53 % manganese. Since it contains high, nearly 100% iron, we can assume that the specimen has not undergone any treatment. The 0.22

% carbon content indicate that the specimen maybe from grade AISI 1022. The other composition result above contain very slight amount in the specimen. Therefore, there are no particular composition take significant effects on the mechanical properties of specimen. It can be conclude and assume that the specimen used is grade AISI 1022.

4.3 SURFACE ROUGHNESS

After all experiment had been conducted, surface roughness for AISI 1022 mild steel of each condition had measured using perthometer S2. All the data had filled in table 4.2(a) (silicon carbide wheel) and 4.2(b) (aluminium oxide wheel) based on their machining parameter which is table speed, depth of cut, and dressing mode. Each level of parameter takes average for three times reading to make sure it more accurate.

Table 4.2(a): Surface roughness for Silicon carbide wheel

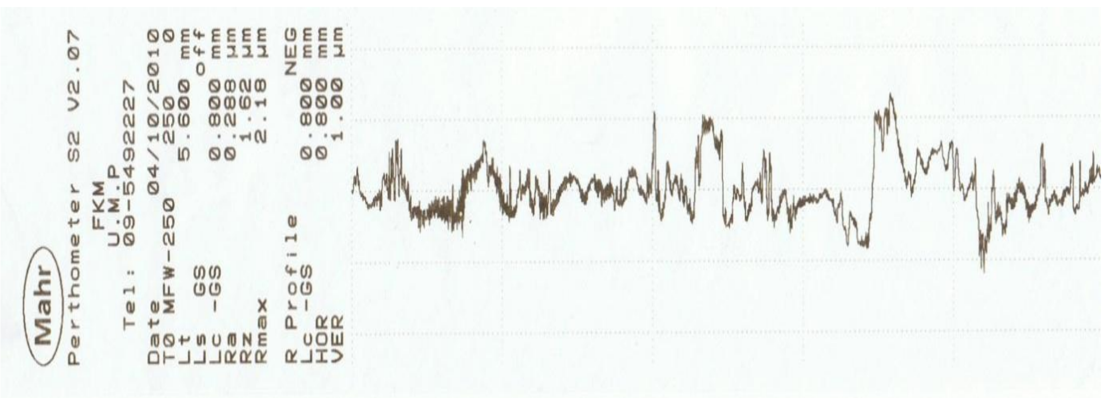
Trial no.	Level of factors			Measured values, Surface Roughness, R_a (µm)				S/N Ratio (dB)
	Table speed (m/min)	Depth of cut (µm)	Dressing mode (µm)	1st trial	2nd trial	3rd trial	Average of Ra	
1	5	10	10	0.288	0.297	0.300	0.295	10.6036
2	5	15	20	0.421	0.423	0.419	0.421	7.5144
3	5	20	30	0.451	0.449	0.459	0.453	6.8780
4	15	10	20	0.449	0.446	0.446	0.447	6.9938
5	15	15	30	0.551	0.549	0.556	0.552	5.1612
6	15	20	10	0.459	0.461	0.457	0.459	6.7637
7	25	10	30	0.625	0.629	0.627	0.627	4.0546
8	25	15	10	0.541	0.549	0.542	0.544	5.2880
9	25	20	20	0.620	0.616	0.618	0.618	4.1802

Table 4.2(b): Surface roughness for Aluminium oxide wheel

Trial no.	Level of factors			Measured values, Surface Roughness, R_a (µm)				S/N Ratio (dB)
	Table speed (m/min)	Depth of cut (µm)	Dressing mode (µm)	1st trial	2nd trial	3rd trial	Average of Ra	
1	5	10	10	0.219	0.215	0.214	0.216	13.3109
2	5	15	20	0.377	0.374	0.376	0.376	8.4962
3	5	20	30	0.403	0.403	0.397	0.401	7.9371
4	15	10	20	0.406	0.395	0.395	0.399	7.9805
5	15	15	30	0.518	0.483	0.490	0.497	6.0729
6	15	20	10	0.412	0.410	0.410	0.411	7.7232
7	25	10	30	0.581	0.574	0.575	0.577	4.7765
8	25	15	10	0.514	0.511	0.507	0.511	5.8316
9	25	20	20	0.584	0.584	0.583	0.584	4.6717

4.3.1 Figure of Surface Roughness

a) Silicon Carbide



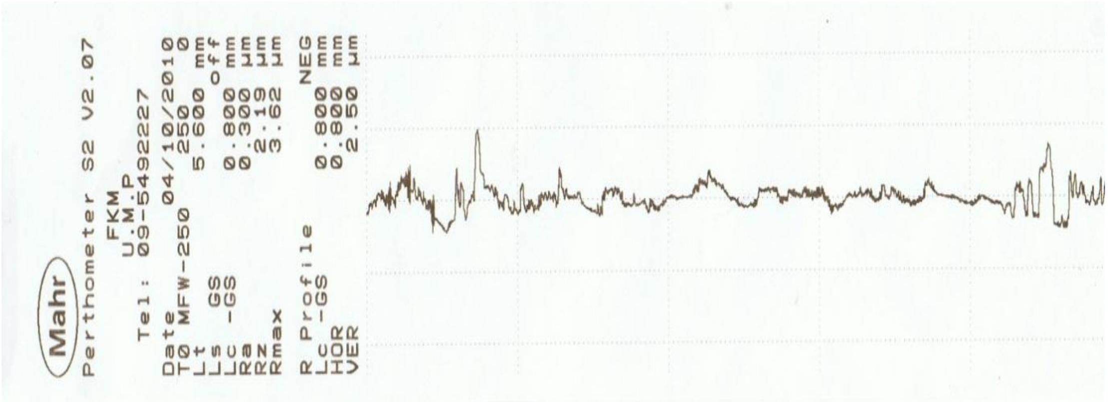


Figure 4.0(a): Example of Ra values for Silicon Carbide wheel

b) Aluminium Oxide

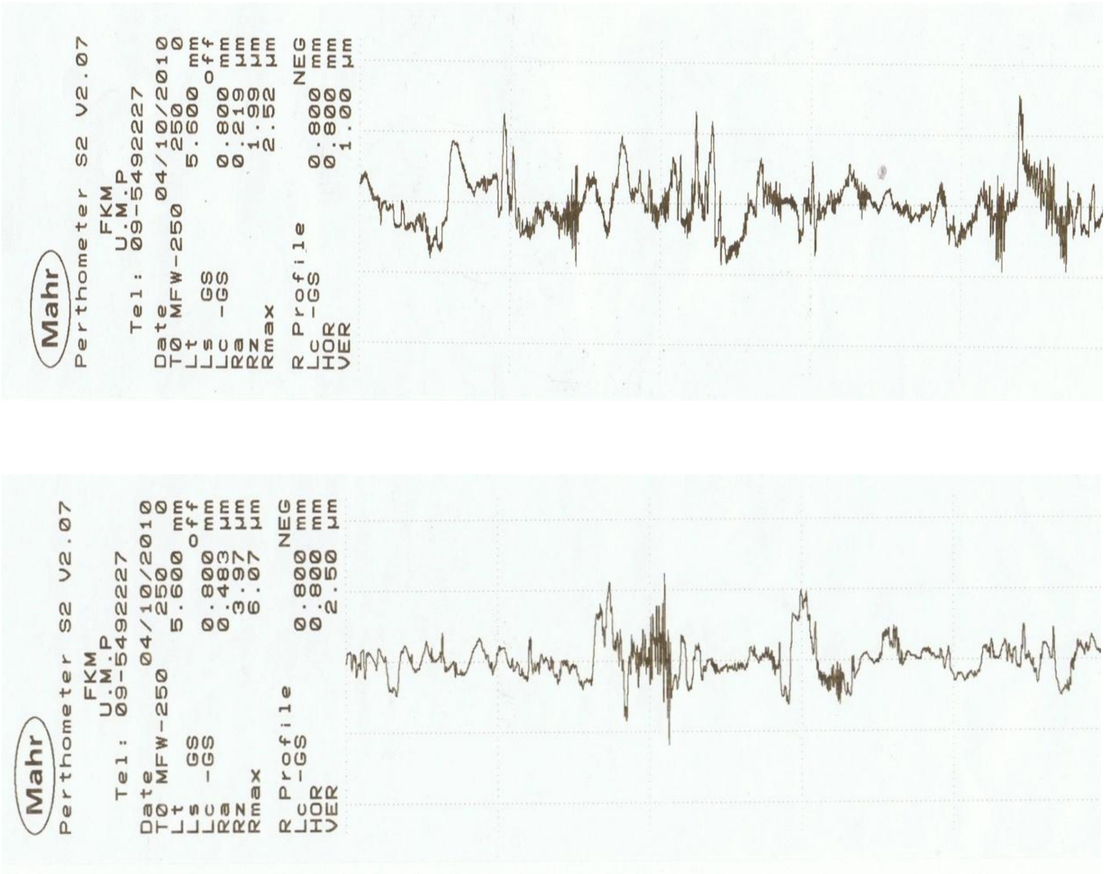


Figure 4.0(b): Example of Ra values for Aluminium Oxide wheel

4.3.2 Analysis of Surface Roughness Value in Response to Depth of Cut, Table Speed and Dressing Mode.

In the experiment, there are three factors which each factor had three levels (process ranges). Three different table speeds, depth of cut and dressing mode are applied for surface grinding process. The spindle speed was set as a constant. The three table speeds are 5 m/min, 15 m/min and 25 m/min. For the depth of cut (DOC) used are 10µm, 20µm, and 30µm. lastly, 3 different mode of dressing used are 10µm, 20µm, and 30µm.

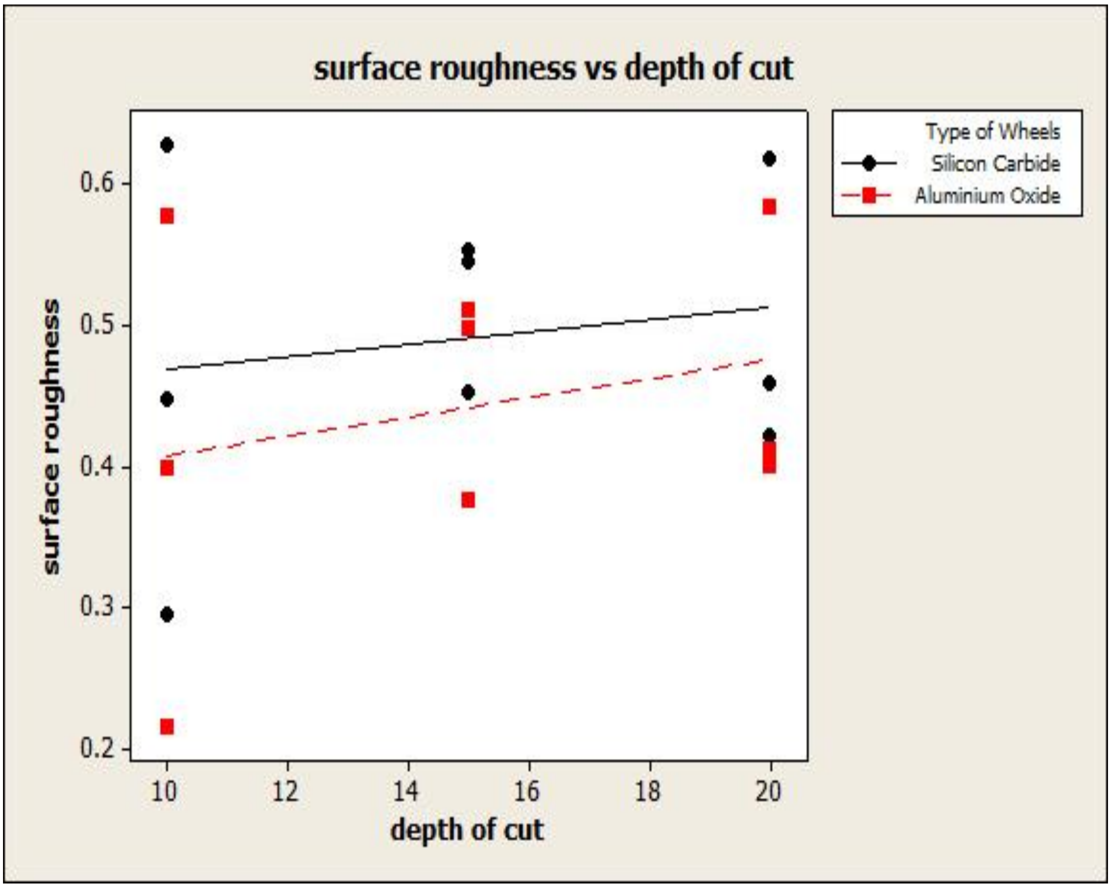


Figure 4.1: Graph of surface roughness VS depth of cut for different wheels

Figure 4.1 above is the graph of surface roughness value of different DOC under different grinding wheels. Accordingly the surface roughness increased as the depth of cut increased. The surface roughness increased as the DOC increases, which are from 0.4692 µm to 0.5122 µm for silicon carbide wheel and from 0.4073 µm to 0.4753 µm for aluminium oxide wheel. In other words, it means that the surface finish is better at smaller value of DOC. And in comparison of the two grinding wheels, the surface roughness for aluminium oxide wheel produced lower value of surface roughness. This also indicates that grinding wheel produced finer surface finish. Theoretically, the smallest DOC value yields better surface finish; and the aluminium oxide also yields better surface finish. Shaji S. and Radhakrishnan V. (2002) state that the surface roughness increases with the increase of depth of cut.

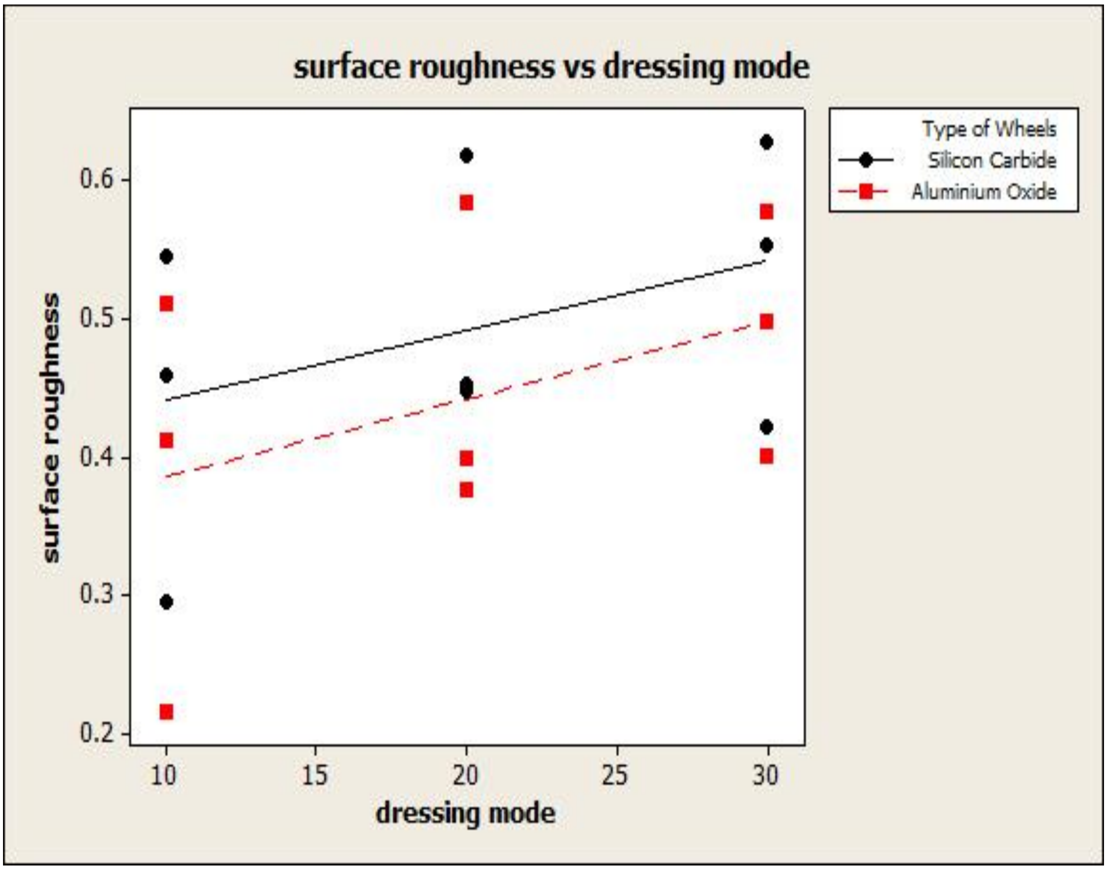


Figure 4.2: Graph of surface roughness VS mode of dressing for different wheels

The Figure 4.2 above shows graph for the comparison of all three different mode of dressing used for the two different type of grinding wheels which is silicon carbide wheel and aluminium oxide wheel. From this graph, it can be concluded that the surface roughness value are increasing when the mode of dressing increasing. This also indicates that the surface finish will improve when using lower dressing mode value which is 10µm. For the silicon carbide wheel, the value of surface roughness is higher compare to aluminium oxide wheel because the temperature is high. This occurs because the temperature also influences the surface roughness of materials. When grinding the workpiece, as the temperature increases, the surface roughness value also increased. In other words, different wheels also affect the surface roughness. The dressing condition of the wheel has a profound influence on the parameters under study. Dressing controls the distribution of active grits, their initial sharpness or bluntness and the chip accommodation space. The force components, specific energy, temperature and surface finish generally decrease with the coarser dressing modes in all the environments under study (Shaji S. and Radhakrishnan V., 2002).

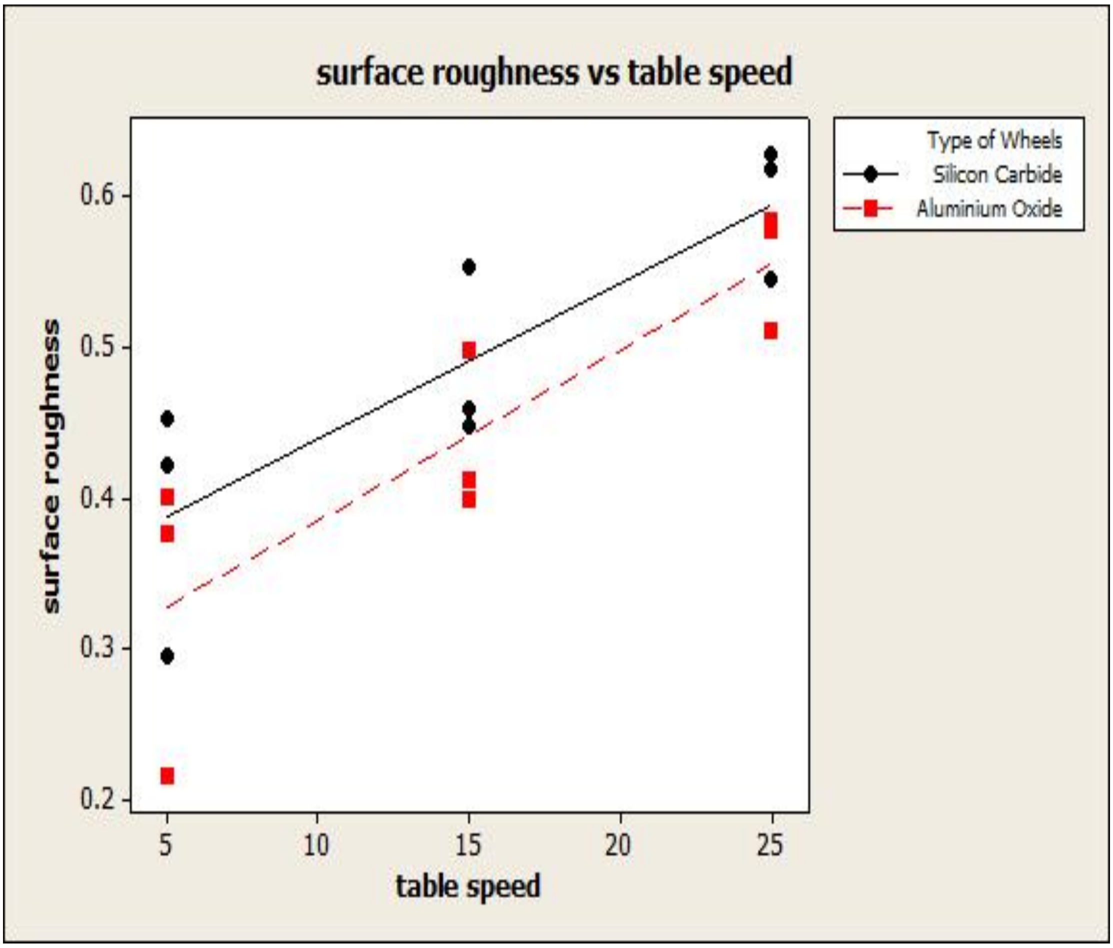


Figure 4.3: Graph of surface roughness VS table speed for different wheels

Figure 4.3 above displays the surface roughness values for different table speed which is 5 m/min, 15 m/min, and 25 m/min respectively. The surface roughness is measured using a Perthometer, and three measurements are taken for each level of table speed. The average surface roughness value for aluminium oxide wheel in term of table speed 5 m/min is 0.3282 µm, 15 m/min is 0.0.4414 µm and 25 m/min is 0.5546 µm. For silicon carbide wheel, the value surface roughness for table speed 5 m/min is 0.3874 µm, 15 m/min is 0.4907 µm and 25 m/min is 0.5940 µm. The surface roughness increases as the table speed increases. In other words, it means that the surface finish is better at smaller value of table speed.

4.4 ANALYSIS OF CONTROL FACTOR

4.4.1 Signal to Noise Ratio

Analysis of the influence of each control factor which is table speed, depth of cut and mode of dressing on the surface roughness Ra has been performed with a so-called signal to noise ratio response table. Response tables of S/N ratio for surface roughness are shown in Table 4.3 (a) for silicon carbide wheel and Table 4.4 (a) for aluminium oxide wheel respectively. It shows the S/N ratio at each level of control factor and how it is changed when settings of each control factor are changed from one level to other.

The influence of each control factor can be more clearly presented with response graphs. Response graphs for all control factors are shown in Fig. 4.4(a) for silicon carbide wheel and Fig. 4.5(a) for aluminium oxide wheel, the slope of the line which connects between the levels can clearly show the power of the influence of each control factor.

This control factors which present the value of means for each level also show in Table 4.3 (b) for silicon carbide and Table 4.4 (b) for aluminium oxide. The impact of the means for each control factors are shown in Fig. 4.4 (b) and Fig. 4.5 (b). Based on main effect plot for means graph, factors with steeper slopes have larger effects and thus larger impacts on the results.

In addition, the analysis of interactions gives more accurate and additional information about optimal cutting parameter. Figure 4.6(a) and Fig. 4.6(b) present interaction plot for S/N ratios for surface roughness Ra under silicon carbide and surface roughness aluminium oxide wheel respectively.

Table 4.3 (a): Response table for S/N ratios (smaller is better) for Silicon carbide wheel

Level	Table speed	Depth of cut	Dressing mode
1	8.332	7.217	7.552
2	6.306	5.988	6.229
3	4.508	5.941	5.365
Delta	3.824	1.277	2.187
Rank	1	3	2

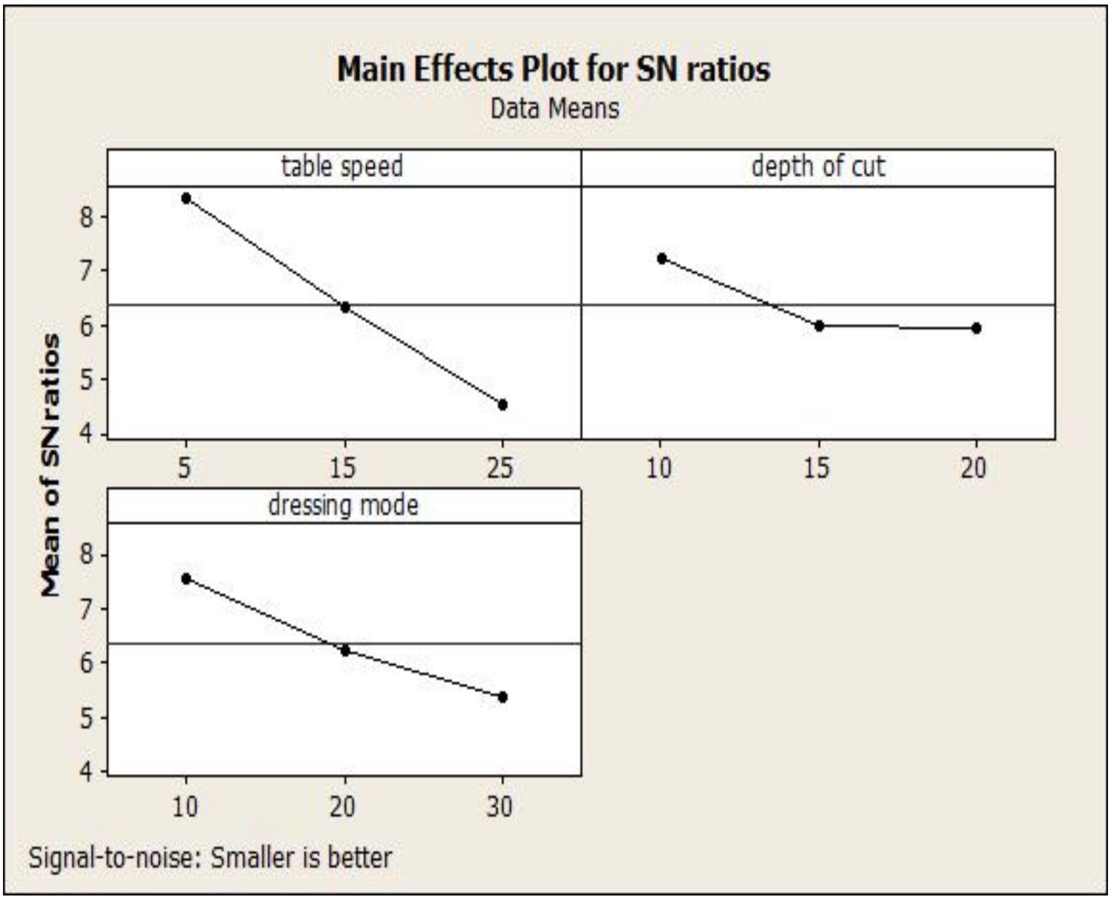


Figure 4.4(a): Main effect plots for S/N ratio for surface Roughness (Ra) by using Silicon Carbide wheel

Figure 4.4(a) presented the calculated S/N ratios of three factors that give effect on the surface roughness according to the each level when grinding mild steel using silicon carbide wheel. The higher the difference between the minimum and the maximum S/N ratios in each factor is, the higher the effect on the surface roughness is. As shown in Figure 4.4(a), the table speed is dominant parameter for the surface roughness and the next was the mode of dressing. The depth of cut had lower effects on the surface roughness value.

And also because of the-lower-the better characteristics, the highest S/N ratio in the each factor was desirable to obtain the minimum value of surface roughness. In the case of the dressing mode when the lowest dressing mode as a value of 10 μm was applied, the surface roughness value could be decreased. It was due to a low level of mode of dressing being profitable to the surface structure aspect. A low level of the depth of cut, which reduced heat generation during grinding process, could reduce the value of surface roughness.

The minimum value of surface roughness will be achieved at the low levels of the table speed, depth of cut and the dressing mode. So, the optimum conditions for the surface roughness for silicon carbide wheel can be established at:

- Table speed : 5 m/min
- Depth of cut : 10 μm
- Mode of dressing : 10 μm

Table 4.3 (b): Response table for Means for Silicon carbide wheel

Level	Table speed	Depth of cut	Dressing mode
1	0.3897	0.4563	0.4327
2	0.4860	0.5057	0.4953
3	0.5963	0.5100	0.5440
Delta	0.2067	0.0537	0.1113
Rank	1	3	2

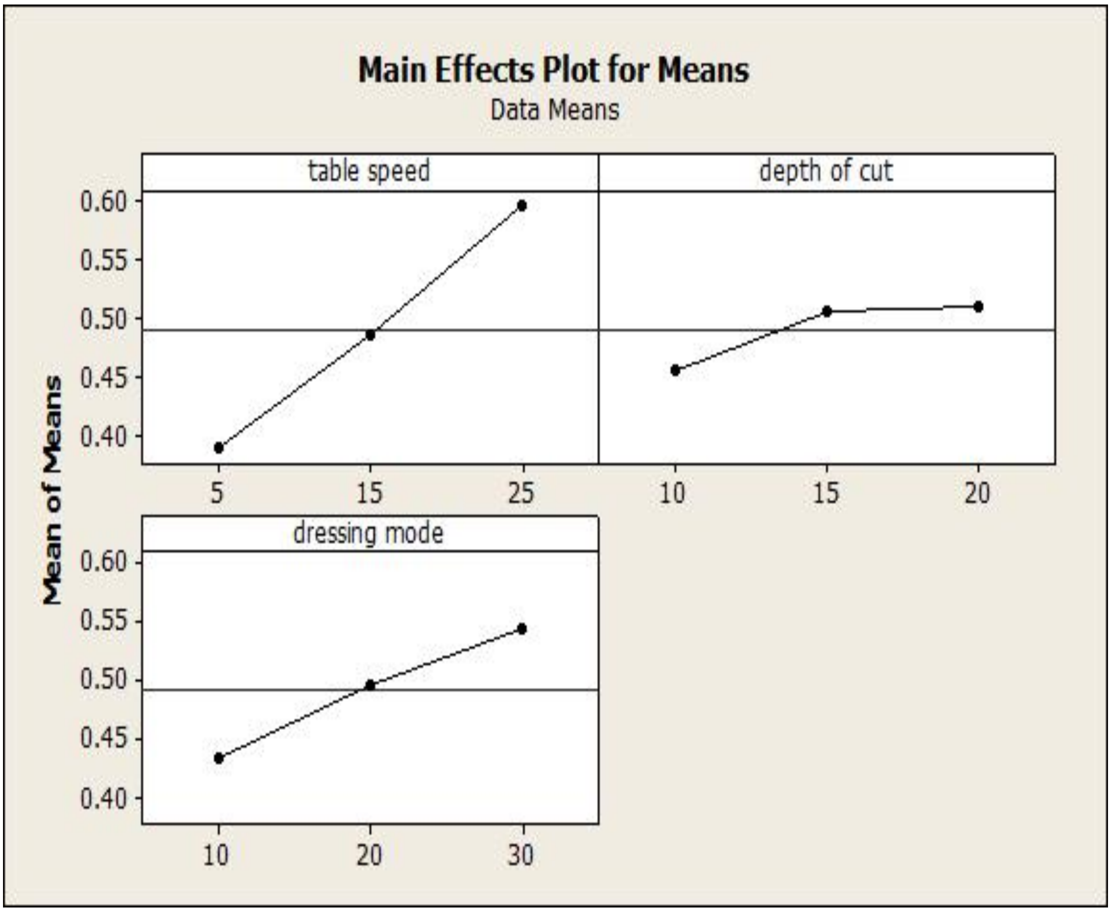


Figure 4.4(b): Main effect plots for Means for surface Roughness (Ra) by using Silicon Carbide wheel

Table 4.4 (a): Response table for S/N ratios (smaller is better) for Aluminium oxide

Level	Table speed	Depth of cut	Dressing mode
1	9.915	8.689	8.955
2	7.259	6.800	7.050
3	5.093	6.777	6.262
Delta	4.821	1.912	2.693
Rank	1	3	2

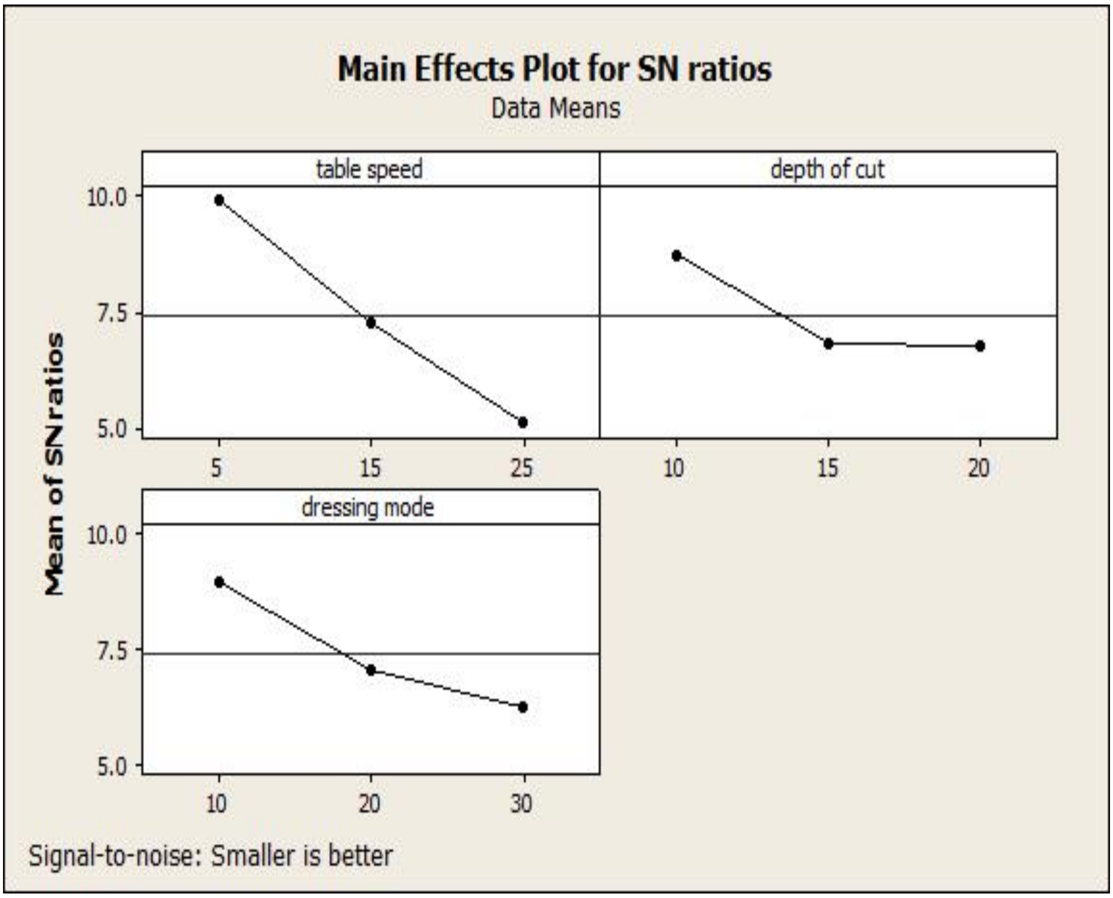


Figure 4.5(a): Main effect plots for S/N ratio for surface Roughness (Ra) by using Aluminium Oxide wheel

Then, Figure 4.4(b) also presented the calculated S/N ratios of three factors that affect the surface roughness value according to the each level but the process of grinding mild steel conducted by using aluminium oxide wheel. As shown in Figure 4.4(b), the table speed was a dominant parameter for the surface roughness as same as grinding process using silicon carbide wheel and the next was the dressing mode. The depth of cut had lower effects on the surface roughness.

The minimum value of surface roughness when grinding mild steel using aluminium oxide wheel will be achieved at the low levels of the table speed and depth of cut and the dressing mode. So, the optimum conditions for the surface roughness for aluminium oxide wheel can be established at:

- Table speed : 5 m/min
- Depth of cut : 10 µm
- Mode of dressing : 10 µm

Table 4.4 (b): Response table for Mean for Aluminium oxide

Level	Table speed	Depth of cut	Dressing mode
1	0.3310	0.3973	0.3793
2	0.4357	0.4613	0.4530
3	0.5573	0.4653	0.4917
Delta	0.2263	0.0680	0.1123
Rank	1	3	2

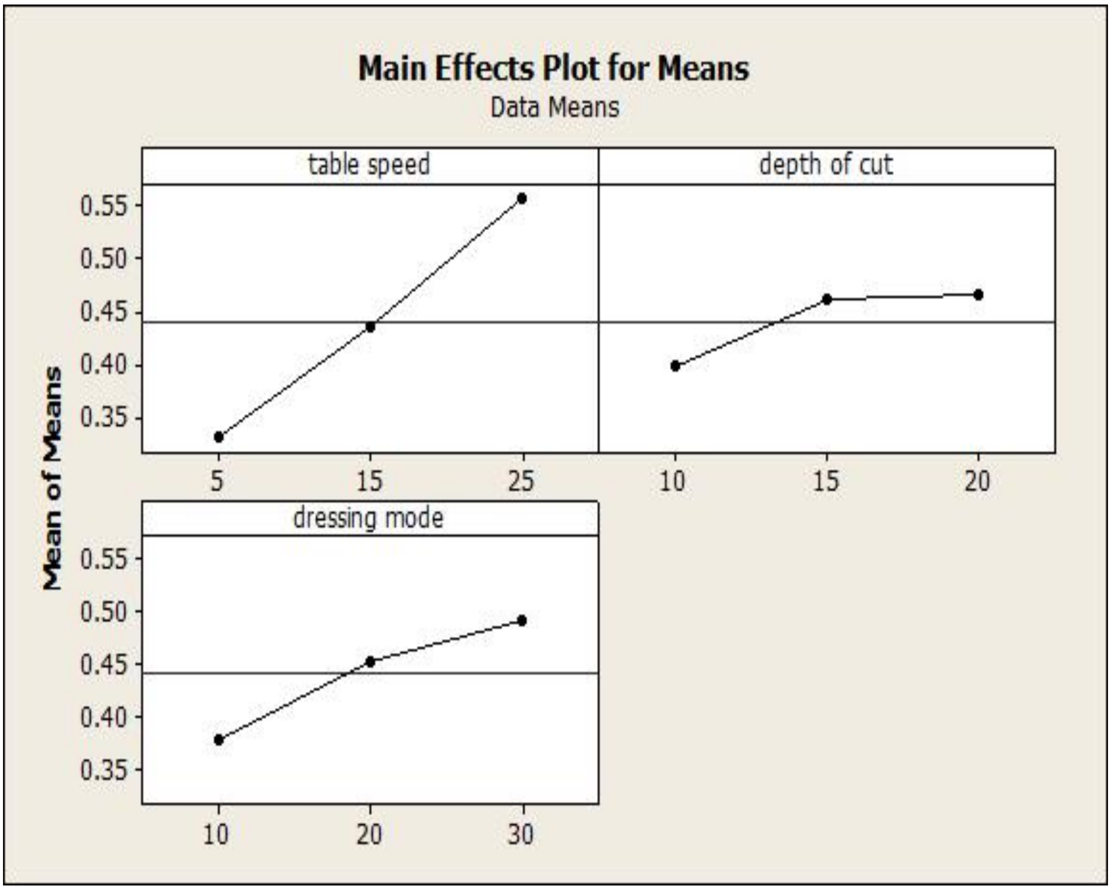


Figure 4.5(b): Main effect plots for Means for surface Roughness (Ra) by using Aluminium oxide wheel

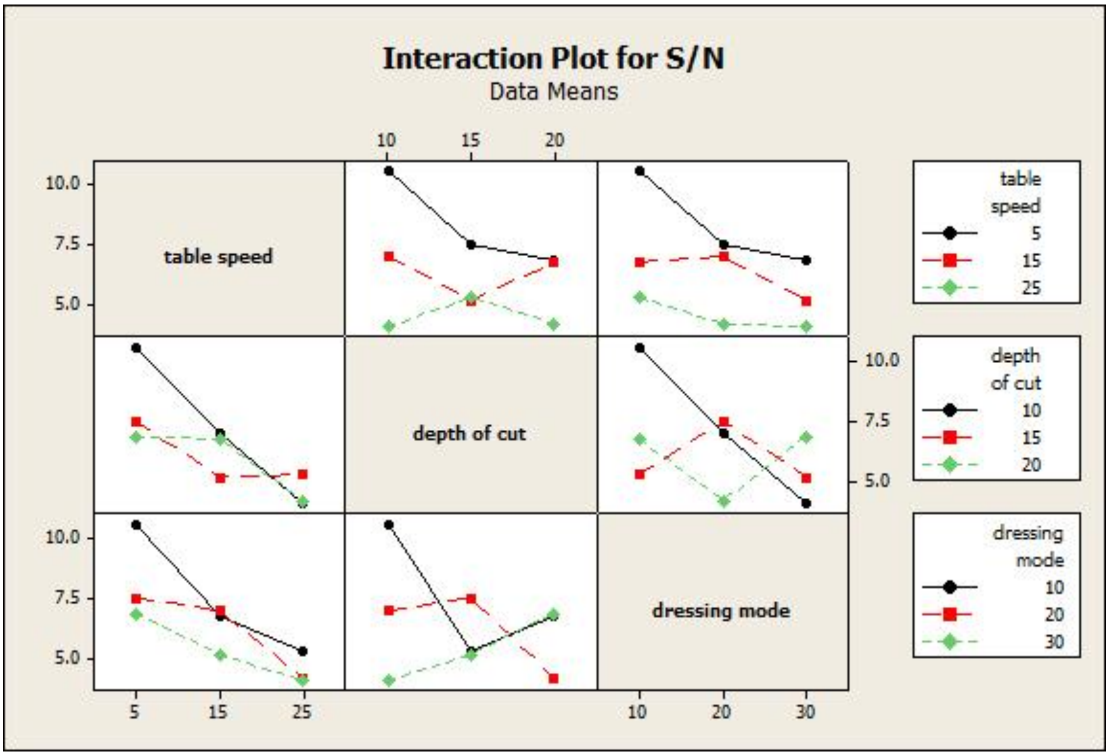


Figure 4.6(a): Interaction plot for S/N ratio for surface Roughness (Ra) by using Silicon Carbide Wheel

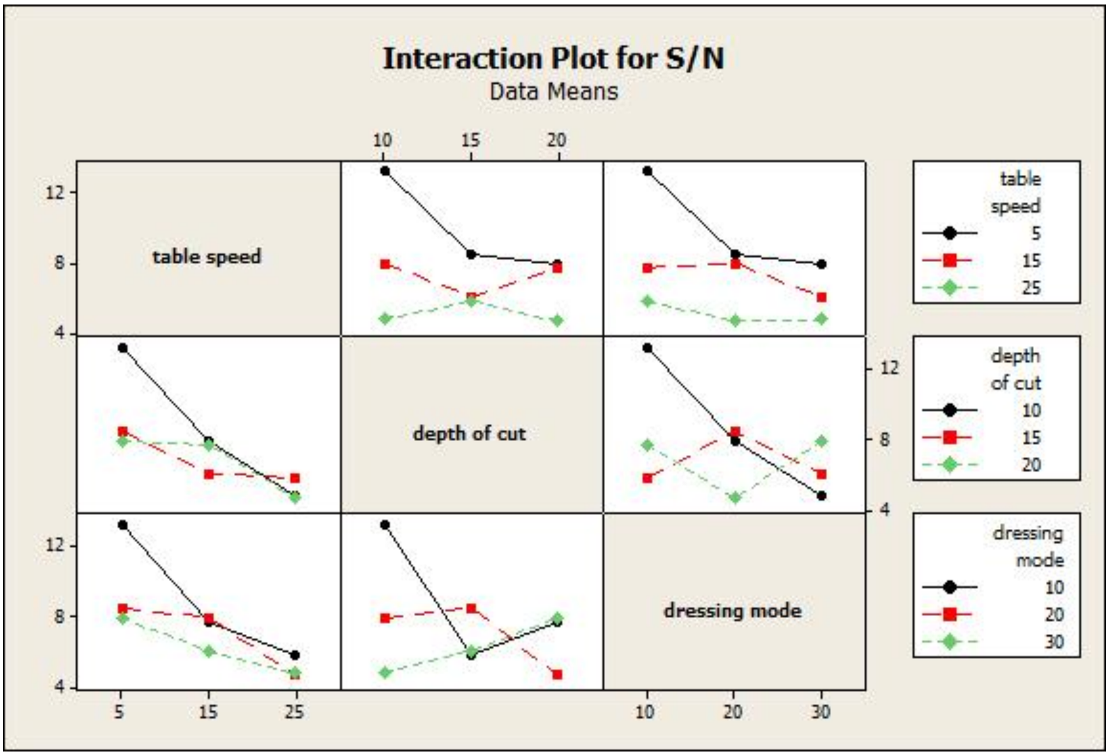


Figure 4.6(a): Interaction plot for S/N ratio for surface Roughness (Ra) by using Aluminium oxide wheel

To determine the main effects for each factor, it is crucial to identify how multiple factors interact in affecting the results. An interaction occurs when one factor affects the results differently depending on a second factor. Interaction plots are used to determine the effect size of interactions. Figure above 4.6(a) and 4.6(b) shown interaction between each control factors based on S/N ratio. For interaction between depth of cut and table speed in figure 4.6(a), the interaction plot shows that the effect of depth of cut is larger when table speed is 25 m/min. Interaction between dressing mode and table speed shows that the effect of dressing mode also larger at same table speed. Then, the interaction plot between depth of cut and dressing mode with table speed as shown in figure 4.6(b) shows not much difference compared to interaction plot in figure 4.6(a). The effect of depth of cut also larger when table speed is 25m/min.

4.5 PREDICTION RESULTT OF SURFACE ROUGHNESS USING MINITAB15

4.5.1 Response Surface Regression: Ra versus Depth of Cut, RPM (Linear Regression) for Silicon Carbide Wheel

Table 4.5: Estimated Regression Coefficients for surface roughness

Term	SE	Coef	T	P
Constant	0.49067	0.006488	75.622	0.000
table speed	0.10333	0.007947	13.003	0.000
depth of cut	0.02683	0.007947	3.377	0.020
dressing mode	0.05567	0.007947	7.005	0.001

S = 0.0194654 PRESS = 0.00556168

R-Sq = 97.87% R-Sq(pred) = 93.74% R-Sq(adj) = 96.59%

Table 4.6: Analysis of Variance for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	0.086980	0.086980	0.028993	76.52	0.000
Linear	3	0.086980	0.086980	0.028993	76.52	0.000
Residual Error	5	0.001895	0.001895	0.000379		
Total	8	0.088874				

Table 4.7: Unusual observations for Ra

Obs	StdOrder	Surface roughness	Fit	SE Fit	Residual	St Resid
2	2	0.421	0.387	0.010	0.034	2.04 R

R denotes an observation with a large standardized residual.

Table 4.8: Estimated linear regression equation

Term	Coef
Constant	0.143833
table speed	0.0103333
depth of cut	0.00536667
dressing mode	0.00556667

Table 4.9: Predicted Response for New Design Points Using Model for surface roughness

Point	Fit	SE Fit	95% CI	95% PI
1	0.304833	0.0152168	(0.265717, 0.343949)	(0.241321, 0.368345)
2	0.387333	0.0102591	(0.360961, 0.413705)	(0.330772, 0.443895)
3	0.469833	0.0152168	(0.430717, 0.508949)	(0.406321, 0.533345)
4	0.463833	0.0102591	(0.437461, 0.490205)	(0.407272, 0.520395)
5	0.546333	0.0102591	(0.519961, 0.572705)	(0.489772, 0.602895)
6	0.461833	0.0129769	(0.428475, 0.495192)	(0.401696, 0.521971)
7	0.622833	0.0152168	(0.583717, 0.661949)	(0.559321, 0.686345)
8	0.538333	0.0129769	(0.504975, 0.571692)	(0.478196, 0.598471)
9	0.620833	0.0129769	(0.587475, 0.654192)	(0.560696, 0.680971)

4.5.2 Response Surface Regression: Ra versus Depth of Cut, RPM (Linear Regression) for Aluminium Oxide

Table 4.10: Estimated Regression Coefficients for surface roughness

Term	SE	Coef	T	P
Constant	0.44133	0.008679	50.850	0.000
table speed	0.11317	0.010630	10.646	0.000
depth of cut	0.03400	0.010630	3.199	0.024
dressing mode	0.05617	0.010630	5.284	0.003

S = 0.0260372   PRESS = 0.0105093

R-Sq = 96.81%   R-Sq(pred) = 90.09%   R-Sq(adj) = 94.89%

Table 4.11: Analysis of Variance for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	0.102704	0.102704	0.034235	50.50	0.000
Linear	3	0.102704	0.102704	0.034235	50.50	0.000
Residual Error	5	0.003390	0.003390	0.000678		
Total	8	0.106094				

Table 4.12: Unusual observations for Ra

Obs	StdOrder	Surface roughness	Fit	SE Fit	Residual	St Resid
2	2	0.376	0.328	0.014	0.048	2.16 R

R denotes an observation with a large standardized residual.

Table 4.13: Estimated linear regression equation

Term	Coef
Constant	0.0572500
table speed	0.0113167
depth of cut	0.00680000
dressing mode	0.00561667

Table 4.14: Predicted Response for New Design Points Using Model for surface roughness

Point	Fit	SE Fit	95% CI	95% PI
1	0.238000	0.0203542	(0.185678, 0.290322)	(0.153045, 0.322955)
2	0.328167	0.0137228	(0.292891, 0.363442)	(0.252509, 0.403824)
3	0.418333	0.0203542	(0.366011, 0.470655)	(0.333379, 0.503288)
4	0.407333	0.0137228	(0.372058, 0.442609)	(0.331676, 0.482991)
5	0.497500	0.0137228	(0.462224, 0.532776)	(0.421842, 0.573158)
6	0.419167	0.0173581	(0.374546, 0.463787)	(0.338726, 0.499607)
7	0.576667	0.0203542	(0.524345, 0.628989)	(0.491712, 0.661621)
8	0.498333	0.0173581	(0.453713, 0.542954)	(0.417893, 0.578774)
9	0.588500	0.0173581	(0.543880, 0.633120)	(0.508059, 0.668941)

Minitab software used to analysis the effect of depth of cut, table speed, and dressing mode on surface roughness values using different types of grinding wheels. For that purpose, ANOVAs approach used in the process of analyzing the effects of parameters on the results obtained. Then, the results of the analysis are shown in table 4.5, table 4.6, table 4.10, and table 4.11. The significant of parameters on the surface roughness will be described based on those tables. Those analyses were conducted under 95 % level of confident which is level of significant of 5 %. The P-value is used to determine which parameters are significant on surface roughness values.

For Silicon Carbide wheel linear regression model, the P-value for table speed is 0.000, depth of cut is 0.020 and dressing mode is 0.001. All the parameters are highly significant on surface roughness. Then, the P-value for Aluminium Oxide linear model regression also showed all the parameters are highly significant and took effect on surface roughness which table speed is 0.000, depth of cut is 0.024 and dressing mode is 0.003.

The correlation between the parameters and the surface roughness were obtained by both linear regression analyses. The linear mathematical model suggested for Silicon Carbide wheel is in Equation 4.1;

$$y = 0.143833 + 0.0103333A + 0.00536667B + 0.00556667C \tag{4.1}$$

The linear mathematical model for Aluminium Oxide wheel suggested is in Equation 4.2;

$$y = 0.0572500 + 0.0113167A + 0.00680000B + 0.00561667C \tag{4.2}$$

Where, y is the response, which refers to surface roughness. A refers to table speed, B refers to depth of cut and C refers to mode of dressing. Correlation coefficient, R-sq as a guide in measured on how well the model fits the data. Calculation of constant approaches the accuracy when the value of R-sq is higher. For Silicon Carbide wheel, the R-sq value is 97.87 % and predicted R value is 93.74 %. And as for Aluminium Oxide linear regression model, R-sq value is 96.81 % and predicted value is 90.09 %.Based on these analyses, the experiment results are more significant compared to predicted results.

4.5.3: Discussion of Response Surface Methodology Modelling Results

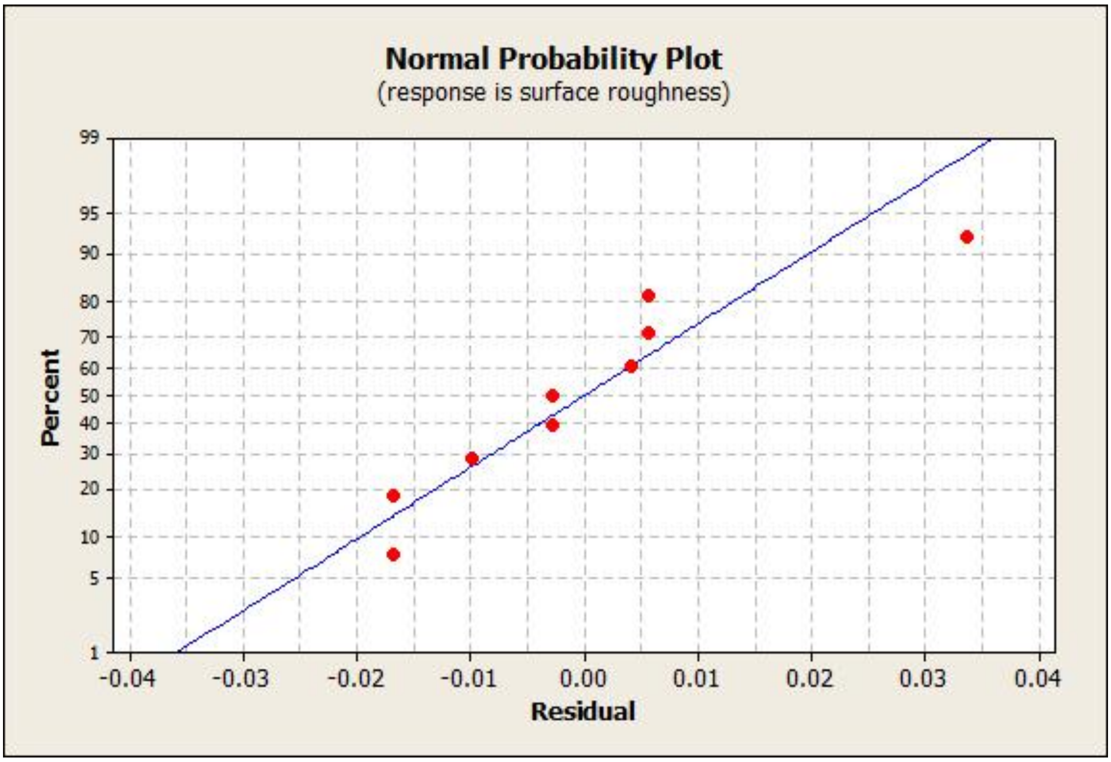


Figure 4.7: Linear normal plot (Silicon carbide wheel)

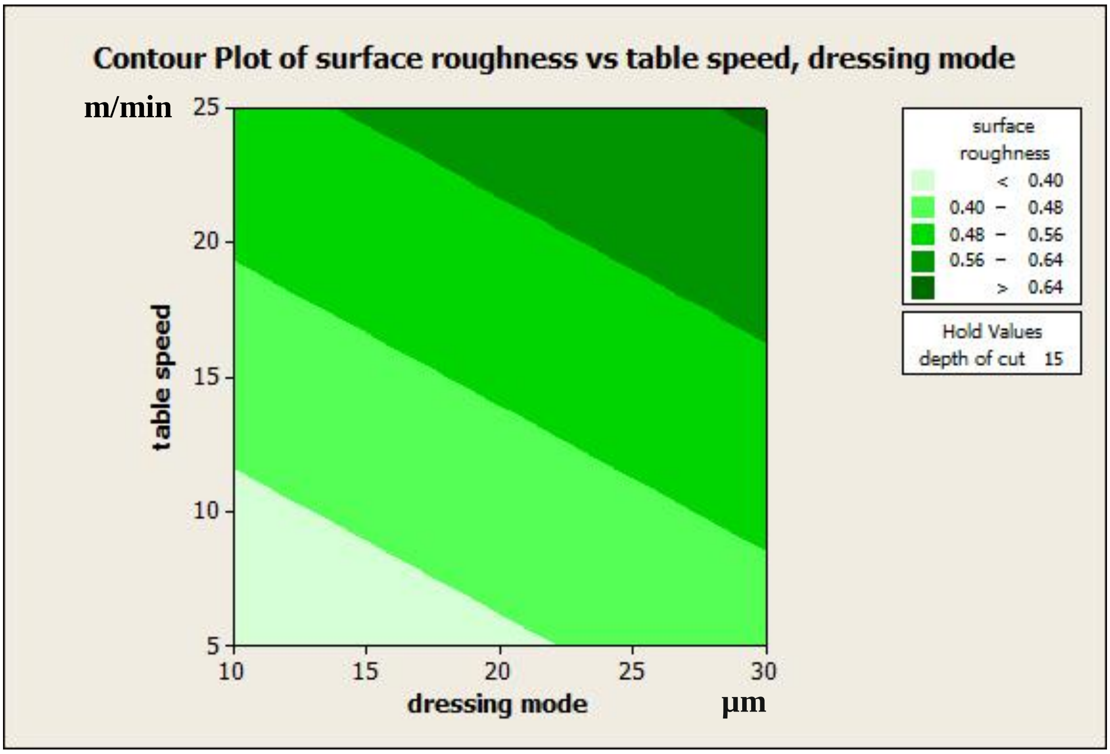


Figure 4.8: Linear contour plot (Silicon carbide wheel)

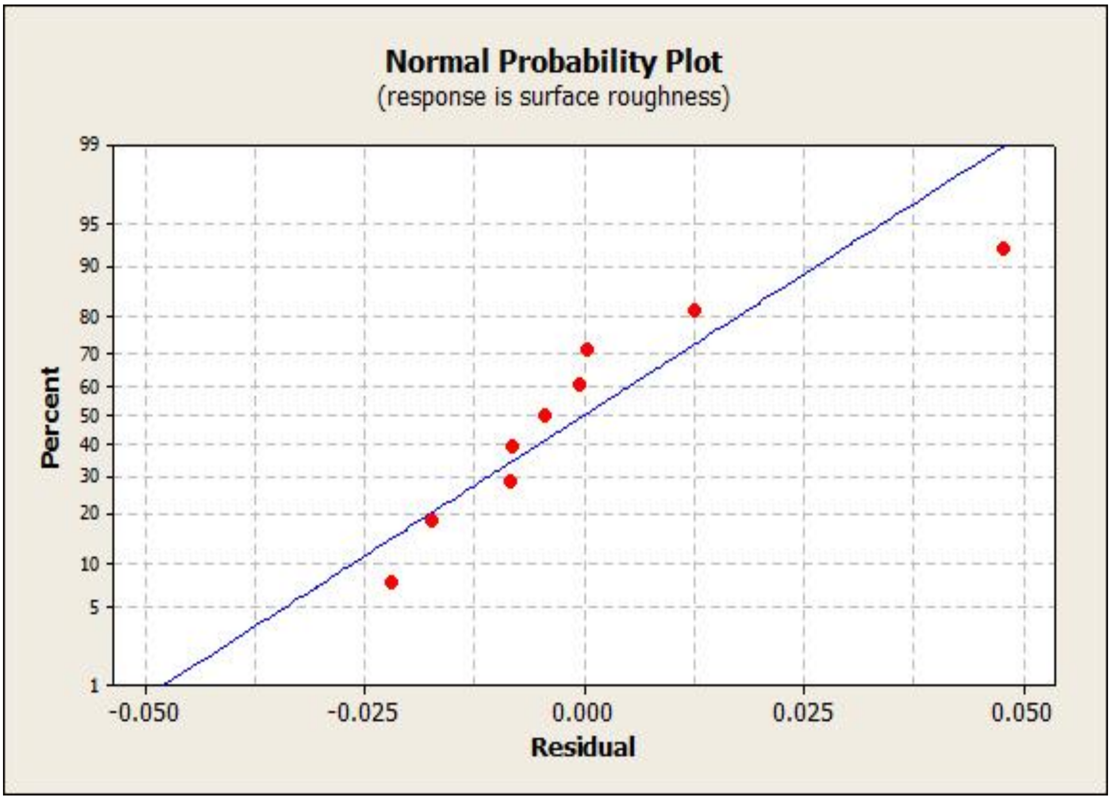


Figure 4.9: Linear normal plot (Aluminium oxide wheel)

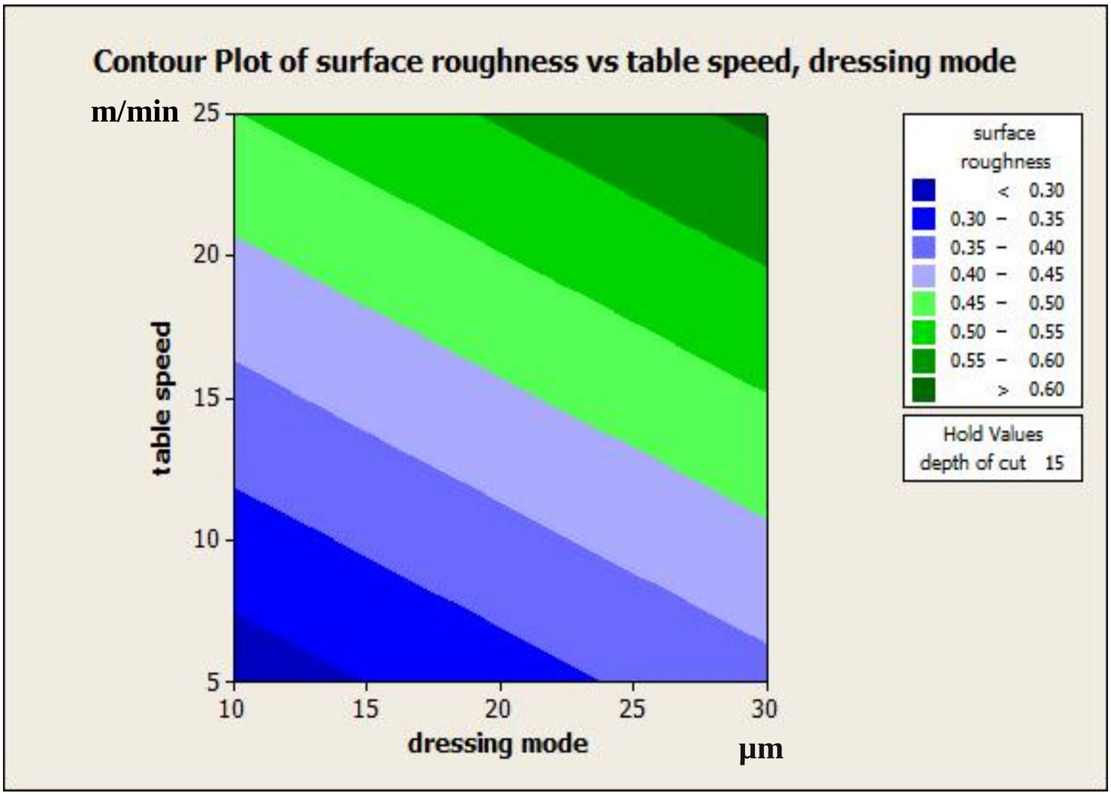


Figure 4.10: Linear contour plot (Aluminium oxide wheel)

Figure 4.7 and 4.9 shows the normal probability plot for predicted values of linear regression based on different type of wheels. These plots are useful to indicate the variation of residual that occurred in the observed data. Prediction result is better if the variability of residual value become smaller.

The contour plots for predicted values of linear regression for different type of wheels are shown in Figure 4.8 and 4.10. Based on Figure 4.8 above, the wheel used is Silicon Carbide wheel. The middle level of depth of cut, which is 15 µm, was set as a constant. Then the relationship between the dressing mode and the table speed was analyzed. From the observation, the surface roughness values that are less than 0.40 µm can be seen in the area of table speed which is less than 12 m/min and dressing mode is less than 22 µm. For the surface roughness values greater than 0.64 µm, it can be shown in the area of table speed greater than 24 m/min and dressing mode value greater than 28 µm.

The contour plot of surface roughness versus table speed and dressing mode for Aluminium Oxide wheel, it was shown in Figure 4.10. The middle value of depth of cut (15 µm) also set as a constant. Based on that plot, the fine values for surface roughness can be observed from area of lower table speed and dressing mode values which is less than 7.5 m/min for table speed and less than 15 µm for dressing mode. Then, we can conclude that table speed is directly proportional to the dressing mode for both wheels used. From the observation using RSM, the Silicon Carbide linear regression model shows better prediction.

4.6 COMPARISON OF SURFACE TEXTURES

a) Using Aluminium Oxide wheel   b) Using Silicon Carbide wheel

Figure 4.11: Surface conditions and metallurgical analysis of surface

Figure 4.11 shows the comparison of surface textures when grinding mild steel (AISI 1022) by using different type of wheels with optimum parameters are used (table speed = 5 m/min, depth of cut = 10 µm, dressing mode = 10 µm). The surface finish produced when grinding mild steel using Aluminium Oxide wheel was better than that obtained from Silicon Carbide wheel as shown in Figure 7(a). It can be seen that the surface texture of mild steel more finely. For Figure 7(b), surface texture of workpiece using Silicon Carbide wheel looked coarse although used same parameters conditions. On that surface, it can be seen more ploughing occurred. This is happen because the abrasive grains' for Silicon Carbide wheel not strong enough to cut the materials of workpiece because mild steel is very hard and tough materials.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

In this chapter, all about the whole research has been summarized. The observation, results analysis and discussion from the experiment are concluded. Besides that, recommendations also have given in this chapter for the future improvement.

5.2 CONCLUSION

Based on the results, it shown that Aluminium Oxide wheel produced better surface finish which is lowest surface roughness values compared to Silicon Carbide wheel. This is because Silicon Carbide wheel grind workpiece at the higher temperature. The increased of temperature also can affect the surface structures. Besides, the abrasive grains' for Silicon Carbide wheel is not strong enough to grinding hard and tough materials such as mild steel. In terms of parameters, lower table speed and depth of cut produced better surface roughness. Lower mode of dressing as well improves surface finish of workpiece. As the depth of cut increase, the tangential grinding force also increases. The increase in grinding force is expected because of increased chip thickness at higher depth of cut. If the cutting depth is large enough to cause cracks, a chip removal will be due to the fracture of material surface. So, the surface finish of workpiece becomes rough. In this experiment, the optimum parameter for table speed is 5 m/min, depth of cut is 10 µm and for mode of dressing is 10 µm. For the response surface method (RSM), the predicted results are not much difference compared to the experimental results. This shows that the results of the experiments quite accurately.

5.3 RECOMMENDATIONS

For every studies and researches that has been done, there is always room for further improvements. From this experiment, there are several suggestions that could be implanted for further improvements when running this research next time. Firstly, the next researchers can select more parameters and levels when running the experiment. It can be helps to reduce the errors occur and also can lead to get better accuracy. Secondly, researchers also can select more grinding wheels in order to get better understanding about effects of abrasive tools on surface finish. Finally, try to use the CNC grinding machines because they have wide range for spindle speed, table speed and so on.

REFERENCES

Agarwal, S. And Rao, P.V. 2007. *Experimental investigation of surface/subsurface damage formation and material removal mechanisms in SiC grinding,* Department of Mechanical Engineering, Indian Institute of Technology, New Delhi 110016, India

Bhateja, C.P., Chisholm, A.W.J., and Pattinson, E.J. 1972. *The influence of grinding wheel wear and dressing on the quality of ground surface,* Proc. Int. Grinding Conf., pp

Bright, E. and Wu, M. 2004. *Porous abrasive articles with agglomerated abrasives,* US Patent 6679758

Butler, D.L., Blunt, L.A., See, B.K., Webster, J.A., and Stout, K.J. 2002. *The characterisation of grinding wheels using 3d surface measurement techniques,* Journal of Materials Processing Technology **127**

Drozda, T.J. and Wick C. 1983. *Tool and Manufacturing Engineers Handbook, vol. 1, Machining,* Society of Manufacturing Engineers, Michigan

Hahn, R.S. and Lindsay, R.P. 1982. *Principles of grinding, part 1: basic relationships in precision grinding,* Grinding Theory Techniques and Troubleshooting, SME, Michigan

Howes, T.D., Toenshoff, H.K., and Heur, W. 1991. *Environmental aspects of grinding fluids,* Ann. CIRP 40

Jackson, M.J., Mills, B., and Hitchiner, M.P. 2003. *Controlled wear of vitrified abrasive materials for precision grinding applications,* Proceedings of Engineering Sciences

Kalpakjian, S. and Schmid, S. 2006. *Manufacturing Engineering and Technology 5th Edition in SI Unit*, Singapore: Prentice Hall.

Karpac, C., Honaker K., and Fogarty, T. 2004. *Save time and money with the right abrasive wheels,* Welding Journal

Kato, K. 1992. *Micro-mechanisms of wear–wear modes*, Wear **153**

Komanduri, R. 1971. *Some aspects of machining with negative rake tools simulating grinding*, International Journal of Machine and Tool Design Research

Kwak, J.S. 2005. *Application of Taguchi and Response surface methodologies for geometric error in surface grinding process,* International Journal of Machine Tools and Manufacturing

Montgomery, V. 2005. *Design and analysis of experiments,* New York: John Wiley and Sons.

Pahlitzsch, G. and Brunswick, A.J. 1954. *Effect of truing conditions on circular grinding*, Ind. Diamond Rev

Ross, P.J. 1996. *Taguchi Techniques for Quality Engineering,* McGraw- Hill, New York

Salmon, S.C. 1992. *Modern Grinding Process Technology,* McGraw-Hill, New York

Shaji, S. and Radhakrishnan, V. 2002. *Analysis of process parameters in surface grinding with graphite as lubricant based on the Taguchi method,* Manufacturing Engineering Section, Department of Mechanical Engineering, Indian Institute of Technology-Madras, Chennai 600 036, India

Silva, L.R., Bianchi, E.C., Catai, R.E., Fusse, R.Y., França, T.V.,and Aguiar, P.R. 2005. *Study on the behaviour of the minimum quantity lubricant-MQL technique under* *different lubrication and cooling conditions when grinding ABNT 4340 steel*, J Braz Soc Mech Sci Eng XXVII

Takenaka, N. 1966. *A study on the grinding action by single grit,* Annals of CIRP

Tawakoli, T. and Azarhoushang, B. 2008. *Influence of ultrasonic vibrations on dry grinding of soft steel*, Int J Mach Tools Manuf

Tawakoli, T., Westkaemper E., and Rabiey M. 2007. *Dry grinding by special conditioning,* Int J Adv Manuf Techno

Tawakoli, T., Westkaemper, E., and Rabiey, M. 2007. *Dry grinding by special conditioning,* Int J Adv Manuf Technol 33

Tuan, W.H. and Kuo, J.C. 1997. *Effect of Abrasive Grinding on the Strength and Reliability of Alumina,* Institute of Materials Science and Engineering, National Taiwan University, Taipei, 10764, Taiwan

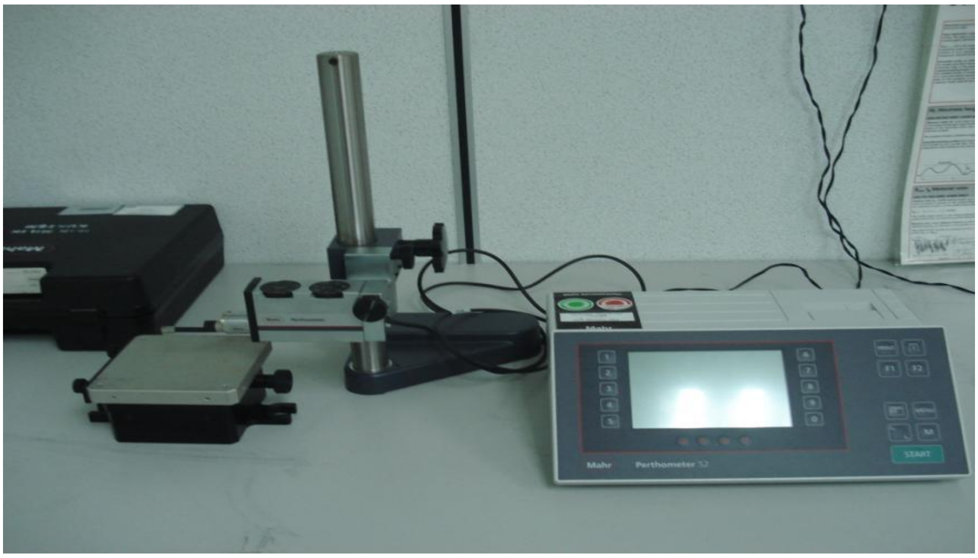
Xie, Y. and Williams, J.A. 1996. *The prediction of friction and wear when a soft surface slides against a harder rough surface,* Wear **196**

APPENDIX

MACHINES/EQUIPMENTS AND PROCESS USED IN EXPERIMENT

BAND SAW MACHINE

GRIND PROCESS



PERTHOMETER S2

MACHINING PROCESS

MEASUREMENT OF SURFACE ROUGHNESS


METALLURGICAL ANALYSIS

ALUMINIUM OXIDE WHEEL


SILICON CARBIDE WHEEL

MILLING MACHINE