OPTIMIZATION OF CUTTING PARAMETERS AND SURFACE ROUGHNESS ON DRY TURNING OF LOW CARBON STEEL

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Thesis submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

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

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ACKNOWLEDGEMENT

First of all, I would like to express my sincerely appreciation to my beloved Final Year Project supervisor, Mr. Lee Giok Chui, SMP, KMN for his dedications and the unrequited encouragement. He is willing to share his priceless knowledge and experiences to me to advise me. Without his continuous support and motivation, this thesis would not have been the same as presented here. I also want to express my deeply thankful to the lab instructor, Mr. Aziha for provided assistance in various occasions at lathe turning lab. He is kindly in teaching me the techniques of using lathe machine and his opinions and tips are useful indeed.

My deeply thanks also extends to my beloved family members especially to my mother Eng Bing Leh and father, Lo Yiek Kai who give me support and motivation anytime anywhere. Their blessings give me strength and spirit to complete this project.

Lastly, I want to express my appreciation to all my beloved friends all for those who involve directly or indirectly in provide me assistances and co-operations at various occasions. I feel very grateful for their kindly helps and supports.

ABSTRACT

Cutting fluid play a very important role in machining but it also brings a lot of detrimental effects such as health hazards and environmental pollutions when it handled improperly. In addition, the cutting fluids also increase the amount of machining cost since it had been issues lately of its cost frequently higher than the cost of cutting tools. With this issue, dry machining becomes one of the solutions to solve this problem. The objective of this project is to optimize the cutting parameters and surface roughness on dry machining. Material chosen to be perform in this study is low carbon steel AISI 1019. The experiment is carried out with a full factorial design of 3 cutting parameters with 3 levels each onto dry Lathe machining. The surface roughness of workpiece is measured by using perthometer and the result is analyzed statistical by using STATISTICA software version 7.1. The optimum cutting parameters and surface roughness can be investigated through the ANOVA prediction with a level of confident 95 percent. The result investigate can help the industries to solve the problem by applying the investigated values of parameters not only in reducing the machining cost but also present a more environmental friendly machining operation.

ABSTRAK

Cecair pemotongan memainkan peranan yang amat penting dalam pemesinan tetapi ia juga membawa banyak kesan yang memudaratkan seperti masalah kesihatan dan pencemaran alam sekitar apabila ia dikendalikan dengan tidak sesuai. Di samping itu, cecair pemotongan juga meningkatkan jumlah kos pemesinan kerana ia telah menjadi isu sejak kebelakangan ini kos ia yang kerap melebihi kos alat pemotong. Dengan isu ini, pemesinan kering menjadi salah satu penyelesaian untuk menyelesaikan masalah ini. Objektif projek ini adalah untuk mengoptimumkan parameter pemotongan dan kekasaran permukaan pada pemesinan kering. Bahan yang dipilih untuk melaksanakan kajian ini adalah keluli berkarbon rendah AISI 1019. Eksperimen dijalankan dengan reka bentuk faktoran penuh daripada 3 pemotongan parameter dengan 3 tingkat setiap parameter ke pemesinan kering Larik. Kekasaran permukaan benda kerja diukur dengan menggunakan perthometer dan hasilnya dianalisis statistik dengan menggunakan versi perisian Statistica 7.1. Parameter pemotongan optimum dan kekasaran permukaan boleh disiasat melalui ramalan ANOVA dengan tahap yakin 95 peratus. Hasilnya menyiasat boleh membantu industri untuk menyelesaikan masalah dengan menerapkan nilai-nilai yang disiasat parameter bukan sahaja dalam mengurangkan kos pemesinan tetapi juga membentangkan operasi pemesinan yang lebih mesra alam sekitar.

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LIST OF SYMBOLS

t_{min}	Minimum chip Thickness
v	Cutting Speed
D	Diameter of the Work Piece
N	Spindle Speed
D	Final Diameter
d_{cut}	Depth Should be Cut
Fm	Feed
f	Feed per Revolution
Vc	Surface Speed
ap	Depth of Cut
kr	Entering Angle

LIST OF ABBREVIATIONS

fpr	Feed per Revolution
RPM	Revolution per Minute
BUE	Built Up Edge
MQL	Minimum Quantity of Lubricant
AISI	American Iron and Steel Institute
CVD	Chemical Vapor Deposition
PVD	Physical Vapor Deposition
PCD	Polycrystalline Diamond
Rc	Rockwell Scale
IC	Inscribed Circle
Fe	Iron
Al_2O_3	Aluminum Oxide
Si_3N_4	Silicon Nitride
ZrO_2	Zirconium Oxide
SiC	Silicon Carbide
SiN	Silicon Nitride
T	Tungsten
Ti	Titanium
Pb	Plumbum
S	Sulphur
Si	Silicon
Cl	Chlorine
CNC	Computer Numerical Control
HSS	High Strength Steel
ANOVA	Analysis of Variance
MS Residual	Mean Square Residual

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Machining is the process in which a tool removes material from the surface of a less resistant body, through relative movement and application of force. The material removed, called chip, slides on the face of tool, known as tool rake face, submitting it to high normal and shear stresses and, moreover, to a high coefficient of friction during chip formation. Most of the mechanical energy used to form the chip becomes heat, which generates high temperatures in the cutting region. Due to the fact that the higher the tool temperature, the faster it wears, the use of cutting fluids in machining processes has, as its main goal, the reduction of the cutting region temperature, either through lubrication reducing friction wear, or through cooling by conduction, or through a combination of these functions.

In recent time, many machining industries are try to achieve high quality, dimensional accuracy, surface finish, high production rate and cost saving product. Using turning process, large amount of cutting fluids is required and that caused the total cost of productions increased. When inappropriately handled, cutting fluids may damage soil and water resources, causing serious loss to the environment. Therefore, the handling and disposal of cutting fluids must obey rigid rules of environmental protection. On the shop floor, the machine operators may be affected by the bad effects of cutting fluids, such as by skin and breathing problems. Due to the technological innovations, machining without cutting fluid, such as dry machining, machining with MQL and cryogenic machining, is already possible, in some situations. However, it is important to remove cutting fluids from the process without harming productivity, tool life and work piece quality.

Technological evolution has provided some options for the use of cutting fluids in machining processes. Tool material properties have been improved and new tool materials have been developed in order to avoid or minimize the use of cutting fluids. Therefore, properties such as resistance against abrasion and diffusion, hot hardness and ductility have been greatly improved with the new tool materials. Tool coatings have provided high hardness, low friction coefficient and chemical and thermal stability to the tool. Tool geometries have been optimized to better break chips and also to produce lower surface roughness values in the workpiece. New concepts of machine tool design have allowed machining speeds to become faster, and increased rigidity enables more severe cutting operations to be used.

In dry cutting operations, the friction and adhesion between chip and tool tend to be higher, which causes higher temperatures, higher wear rates and, consequently, shorter tool lives. Therefore, completely dry operation is not suitable for all processes and all materials especially hard materials. So, in this experiment, the optimum parameters have to be found out in order to achieve the desired surface roughness. In turning operation, there are a lot of parameters those could affect the surface roughness of the work piece, such as depth of cut, feed rate, cutting speed, operating temperature, material used, and so on.

Surface finish of the machined parts is one of the important criteria by which the success of a machining operation is judged. In addition, surface finish is also an important characteristic that may dominate the functional requirements of many component parts. A good surface finish component part has a lot of advantages compared to a bad surface finish component part. For example, in prevention of premature fatigue failure, the good surface finish is one of the necessary criteria. Besides that, good surface finish can improve corrosion resistance; reduce friction, wear and noise. Thus, the life of product or component part can be improved with good surface finish. In economy, a better and long-life product is always the choice of consumers.

1.2 PROJECT BACKGROUND

Currently, there is a wide-scale evaluation of the use of cutting fluids in machining. Industries are looking for ways to reduce the amount of lubricants in metal removing operations due to the ecological, economical and most importantly human health. Therefore, it is important to find a way to manufacture products using the sustainable methods and processes that minimize the use of cutting fluids in machining operations. In addition, it is essential to determine the optimal cutting conditions and parameters, while maintaining long tool life, acceptable surface finish and good part accuracy to achieve ecological and coolant less objective.

Lathe machine is the oldest machine tool that is still the most common used machine in the manufacturing industry to produce cylindrical parts. It is widely used in variety of manufacturing industries including automotive and aerospace sectors. Quality of surface plays a very important role in the performance of turning as good-quality turned surface is significant in improving fatigue strength, corrosion resistance, and creep life. Surface roughness also affects several functional attributes of parts, such as wearing, heat transmission, and ability of holding a lubricant, coating, or resisting fatigue. 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. Surface roughness has been receiving attention for many years in the machining industries. It is an important design feature in many situations, such as parts subject to fatigue loads, precision fits, and fastener holes and so on. In terms of tolerances, surface roughness imposes one of the most crucial constraints for the machines and cutting parameters selection in process planning.

In this project, mild steel AISI 1019 is turning with lathe machine. This experiment will be held in only dry conditions which mean there is no any lubricant applied to the work pieces during the operation. Three machine parameters are varies during this experiment, which are depth of cut, cutting speed and feed rate. STATISCA software is using in this experiment to contribute a set of random combination of parameters data.

1.3 PROBLEM STATEMENTS

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work part dimensional accuracy and surface finish, high production rate and cost saving, with a reduced environmental impact. In machining process, it is necessary to attain the desired surface quality in order to produce parts providing the required functions.

The surface quality can affects some mechanical properties of the product, such as wear resistance, corrosion resistance, friction and so on. By the way, surface finish quality is influenced by various parameters. It will be costly and time consuming to acquire the knowledge of appropriate cutting parameters. At this point, surface roughness prediction will be helpful, which is mostly based on cutting parameters and sometimes some other parameters on dry machining. The concept of dry machining which is no any lubrication and cutting fluid applied during the operation, has been suggested since a decade ago, as a means of addressing the issues of environmental intrusiveness and occupational hazards, associated with the airborne cutting fluid particles on factory shop floors.

The absence of cutting fluid also leads to economic benefits by way of saving lubricant costs and work piece, tool machine cleaning cycle time. Health problem is caused by the long-term exposure to cutting fluids and the environment problem is caused by inappropriate way to handle the cutting fluids. In order to eliminate the effect of cutting fluids, dry machining has become a reliable choice in machining of some materials. However, some engineering materials still require cutting fluid in their machining operations and this is because of the needed surface quality, tool life, and machining dimensional accuracy. Hence the implementation of machining without coolant will bring down the manufacturing cost but can cause tool wear problems and low surfaces finish. Minimum quantity of lubricant can cut of manufacturing cost and produce better surface finish than dry cutting.

1.4 PROJECT OBJECTIVE

The objective of this study is to optimize the cutting parameters those carry out the optimum surface roughness in dry turning operation on mild steel AISI 1019.

1.5 PROJECT SCOPES

a. No any lubricant and cutting fluid present during the turning operation.
b. Machining variables considered are cutting speed, depth of cut, and feed rate.
c. Turning operation is performed using conventional lathe machine, Pinacho S90 VS/180.
d. Material use to test is Mild steel AISI 1019.
e. Surface roughness of workpiece is analyzed by using Mahr S2 perthometer.
f. STATISTICA software is used to contribute a table of random combinations of all parameters.
g. The cutting tool inserts is cemented carbide and it is assumed sharp always.
h. The tool wear and vibration are not take into consideration.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is discusses on some literature studies related to the surface roughness of dry machining in turning operation. A large number of analytical and experimental studies on surface roughness related to turning operations have been conducted.

2.2 SURFACE ROUGHNESS

Turning, milling, grinding and all other machining processes impose characteristic irregularities on a part's surface. Additional factors such as cutting tool selection, machine tool condition, speeds, feeds, vibration and other environmental influences will further influence these irregularities (Albrecht A.B., 1956; Boubekri N., Schneider M. H., and Asfour S., 1992).

Roughness is essentially synonymous with tool marks. Every pass of a cutting tool leaves a groove of some width and depth. In the case of grinding, the individual abrasive granules on the wheel constitute millions of tiny cutting tools, each of which leaves a mark on the surface. Roughness plays an important role to determine how a real object interacts with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

Surface roughness is used to determine and evaluate the quality of a product, is one of the major quality attributes of an end-milled product. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process take place. This good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. Thus, it is necessary to know how to control the machining parameters to produce a fine surface quality for these parts. The control factors for the machining parameters are spindle speed, feed rate and depth of cut and the uncontrollable factors such as tool diameter, tool chip and tool wear.

The quality of machined components is evaluated by how closely they adhere to set product specifications of length, width, diameter, surface finish, and reflective properties. High speed turning operations, dimensional accuracy, tool wear, and quality of surface finish are three factors that manufacturers must be able to control (Lahidji, B., 1997). Among various process conditions, surface finish is central to determining the quality of a work piece (Coker, S. A., and Shin, Y. C., 1996).

Surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface roughness. Some of these factors can be controlled and some cannot. Controllable process parameters include feed, cutting speed, tool geometry, and tool setup (J.A. Arsecularatne, L.C. Zhang, C. Montross, and P. Mathew, 2006; Y.K. Chou, H. Song, 2004). Other factors, such as tool, work piece and machine vibration, tool wear and degradation and work piece and tool material variability cannot be controlled as easily (Coker, S. A., and Shin, Y. C., 1996).

The surface of a turned part has grooves produced by the corner of the cutting tool insert. The groove depth is a function of the corner radius and the feed per revolution, fpr. A reduction in fpr or an increase in corner radius will improve the obtained surface finish so much for that theory.

Unfortunately in practice it doesn't work that easily. There are a few more items which come into play: built-up edge, insert wear, turning speed, spindle bearing accuracy, and machine and part rigidity. Last, but not least, the type of steel and metallurgical structure has a great influence on the surface finish that can be obtained. The lead angle and chip breaker form has to be chosen to prevent the chip from running over the turned surface and damaging it.

The built-up edge (BUE) can be avoided with increased surface speed especially on steels with low carbon content, like AISI 1010, 1015 and 1115. Speeds up to 1200 sfpm can be used with coated carbide. Where a coolant is used, it should be directed underneath the cutting tool under pressure. On the top, the flowing chip acts like an umbrella and the coolant can't reach the point on the cutting insert where the material is separated. Changing to a cermet insert instead of carbide will also reduce the BUE formation.

Insert wear, depending on where it occurs, has an influence on surface finish. Flank wear has the biggest influence. Cratering is negligible as long as the crater does not reach the cutting edge. And a side notch caused by scale is usually far enough away from the nose radius not to have an influence on part finish. Higher surface speed with the same feed per revolution improves the part finish in many different steels.

The spindle bearings, preload and ball screw condition are others factors which influence the surface finish. The metallurgical structure of the steel can also play havoc with the finish.

2.3 FACTORS AFFECTING SURFACE ROUGHNESS

2.3.1 Nose Radius

Nose radius is a major factor that affects surface roughness. A larger nose radius produces a smoother surface at lower feed rates and a higher cutting speed (M.A. Yallese, K. Chaoui, N. Zeghib, and L. Boulanouar, 2009). However, a larger nose radius reduces damping at higher cutting speeds, thereby contributing to a rougher surface. The material side flow can be better defined when using a large nose radius. Again, this can be explained by studying the effect of the nose radius on the chip formation.

During cutting with a tool that has a large nose radius, a large part of the chip will have a chip thickness less than the minimum chip thickness value. In addition, increasing the nose radius has a direct effect on cutting forces, leading to a significant increase in the ploughing effect in the cutting zone. Increasing the ploughing effect leads to more material side flow on the machined surface. In general, increasing the nose radius increases the level of tool flank wear. Cutting with a large nose radius will result in higher value of cutting forces due to the thrust force component. On the other hand, cutting with a small nose radius prolongs tool life, which can be explained by the reduction in the ploughing force. Edge preparation has an effect on the surface roughness. Although the chamfered tool is recommended to prevent the chipping of the cutting edge, there is no significant difference in the rate of tool wear. The surface finish generally degrades with cutting time due to tool wear development.

Large nose radius tools have, along the whole cutting period, slightly better surface finish than small nose radius tools. Tool wear development with cutting time showed, after high initial wear rate, which flank wear land width increases in a linear way. The tool nose radii in the range of 0.8–2.4 [mm] seem to have no effect on the tool wear process, showing comparable wear rate and similar tool life.

2.3.2 Cutting Speed

Cutting speed has no major impact on surface roughness. It affects the surface roughness when operating at lower feed rates, which leads to the formation of a built up edge. Higher speeds are important in yielding accurate results. At speeds higher than 300 feet per second, actual surface roughness comes closer to the calculated value of surface roughness.

2.3.3 Depth of Cut

The depth of cut has a proven effect on tool life and cutting forces; it has no significant effect on surface roughness except when a small tool is used (Albrecht A.B. ,1956; Olsen K.V., 1968). Therefore, a larger depth of cut can be used to save machining time when machining small quantities of workpieces. On the other hand, combining a low depth of cut with a higher cutting speed prevents the formation of a built-up edge, thereby aiding the process by yielding a better surface finish (Axinite, R.C. Dewes, 2002; Hasegawa M., Seireg A. and Lindberg R.A., 1976; Taraman K., 1974).

2.3.4 Feed Rate

Feed rate is another major factor that has a direct impact on surface roughness. Surface roughness is directly proportional to the feed rate. The feed rate produces effective results when combined with a larger nose radius, higher cutting speed, and a smaller cutting edge angle (M.A. Yallese, K. Chaoui, N. Zeghib, and L. Boulanouar, 2009). Regarding the workpiece machined with a smaller feed rate, the machined surface shows that extensive material side plastic flow existed. This explains the better surface finish obtained at lower feed rates. A lower feed rate increased the area in which the chip thickness was lower than the minimum chip thickness, t_{min}. Hence, instead of cutting, a large part of the material was ploughed, which led to material side flow.

2.3.5 Build-Up Edge (BUE)

A built-up edge (BUE) usually forms at the tip of the tool cutting edge during machining. As the BUE becomes larger, it becomes unstable and eventually breaks up. The BUE is partly carried away by the chip; the rest is deposited on the work surface. The process of BUE formation is continuous, and destruction is continuous. It is one of the factors that adversely affect surface roughness. Although a thin stable BUE that protects the tool‟s surface is desirable, BUE is generally undesirable. BUE does not form at higher cutting speeds, low depth of cuts, and higher rake angles.

2.3.6 Material Side Flow

One of the factors that deteriorate the machined surface is the material side flow. It is defined as the displacement of a workpiece material in a direction opposite to the feed direction, such that burrs form on the feed mark ridges. Workpiece material in the cutting zone is subjected to a high enough temperature and pressure to cause a complete plastification of the workpiece material. Chip material flow in a direction perpendicular to that of the usual chip flow during the machining of hardened steel has been observed. This material sticks on the new machined surface and causes a deterioration of the machined surface quality, even if the surface roughness is kept within the desired tolerance. In addition, the adhered material is hard and abrasive, such that it wears on any surface that comes into contact with the machined surface.

The surface deterioration is mainly attributed to material side flow that existed on the machined surface as a result of machining with a worn tool. In addition, the cutting speed has a significant influence on material side flow. The high temperature generated during high speed machining facilitates the material plastification and, therefore, causes a tendency for more material side flow.

2.3.7 Chip Morphology

An increase in the nose radius increases the chip edge serration; the chip edge serration can be explained by the reduction in the actual chip thickness near the trailing edge. Since the chip formation takes place mainly along the nose radius, it is expected that the chip thickness varies along the cutting edge.

Due to the nose radius, the chip thickness is decreased gradually to zero, causing high pressure at the trailing edge. Thus, the material at the trailing edge of the tool, where the chip thickness is a minimum, is subjected to high stress that causes tearing on the weakest edge of the chip.

In addition, the variation in the chip velocity facilitates the non-uniform displacement along the chip width, which leads to chip edge serration. The existence of the chip edge serration facilitates trailing edge wear. Grooves are worn in the tool at the positions where the chip edge moves over the tool. These grooves deteriorate the surface roughness and, in turn, reduce the tool life.

2.4 MACHINING CONDITION

2.4.1 Dry Machining

Dry machining is elimination on the use of cutting fluid. The interest in dry machining is often related to the low cost, healthy issues and environmentally friendly (P.S. Sreejith and B.K.A. Ngoi, 2000). Dry machining requires less power. However, they are sometimes less effective. This is because in dry machining higher order friction between tool and work and between tool and chip can lead to high temperature in the machining zone. This high temperature at the machining zone will ultimately cause dimensional inaccuracies for the work piece and too wear problems and also produce less surface finish.

Dry machining is ecologically desirable and it will be considered as a necessity for manufacturing enterprises in the near future. Industries will be compelled to consider dry machining to enforce environmental protection laws for occupational safety and health regulations. The advantages of dry machining include: non-pollution of the atmosphere (or water); no residue on the dwarf which will be reacted in reduced disposal and cleaning costs; no danger to health; and it is non-injurious to skin and is allergy free. Moreover, it offers cost reduction in machining (Narutaki, N., Yamane, Y., Tashima, S. and Kuroki, H., 1997).

Recently, dry machining is gaining popularity due to the increase in concerns regarding the safety of machinists and the environment. Dry machining helps in reducing the manufacturing costs. However, the implementation of dry machining cannot be accomplished by simply turning off the cutting fluid supply. It needs the usage of hard, wear resistant, low thermal diffusivity tool materials and coatings that can retain their properties at higher machining temperatures. Dry or green machining is stated to be environmental friendly as it does not pollute the atmosphere. It does not cause any health hazards to the people involved in this environment .It also helps in reducing disposal and cleaning cost. The absence of a coolant results in increase in machining temperatures and friction between the tool and the chips generated. This can cause forming of a built-up edge on the cutting tool. Transportation of chips also becomes difficult.

The various possible routes to achieve clean machining processes were analyzed and discussed by Byrne, 1993 (G. Byrne, E. Scholta, 1993). Elimination on the use of cutting fluids, if possible, can be a significant incentive. The costs connected with the use of cutting fluids are estimated to be many more times than the labor and overhead costs (F. Klocke and G. Eisennblatter, 1997; G. Byrne, E. Scholta, 1993). Hence the implementation of dry machining will reduce manufacturing costs. In the manufacturing industry, cutting fluids help to remove the heat generated due to friction during cutting to achieve better tool life, surface finish and dimensional tolerances to prevent the formation of built-up edge and to facilitate the transportation of chips. Coolants are 5essential in the machining of materials such as aluminium alloys and most stainless steels, which tend to adhere to the tool and cause a built-up edge. At the same time, the coolants produce problems in the working environment and also create problems in waste disposal. This creates a large number of ecological problems, but which in turn result in more economical overheads for manufacturing industries. If industries were to practice dry machining, then all of the above-mentioned problems should be addressed satisfactorily. The cutting fluid industries are reformulating new composites that are more environmental friendly and which do not contain Pb, S or Cl compounds.

Consumption of cutting fluids has been reduced considerably by using mist lubrication. However, mist in the industrial environment can have serious respiratory effects on the operator (A.S. Varadarajan, P.K. Philip, and B. Ramamoorthy, 2002; M. Sokovic and K. Mijanovic, 2001). The use of cutting fluids will be increasingly more expensive as stricter enforcement of new regulation and standards are imposed, leaving no alternative but to consider dry machining. Many metal-cutting processes have been developed and improved based on the availability of coolants. It is well known that coolants improve the tool life and tool performance to a great extent. In dry machining, there will be more friction and adhesion between the tool and the work piece, since they will be subjected to higher temperatures.

This will result in increased tool wear and hence reduction in tool life. Higher machining temperatures will produce ribbon-like chips and this will affect the form and dimensional accuracy of the machined surface. However, dry cutting also has some positive effects, such as reduction in thermal shock and hence improved tool life in an interrupted-cutting environment (J.R. Koelsch, 1992).

2.5 MACHINING PARAMETER

2.5.1 Cutting Speed

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (RPM) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute [*m/min*], and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

$$v = \frac{\pi DN}{1000} [\mathrm{mmin}^{-1}] \tag{2.1}$$

Where, v is the cutting speed of turning in [m/min], D is the initial diameter of the work piece in [mm], and N is the spindle speed in [RPM].

2.5.2 Depth of Cut

Depth of cut is practically self-explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

$$d_{cut} = \frac{D-d}{2}\,[\text{mm}] \tag{2.2}$$

Where, D and d represent initial and final diameter in [mm] of the job respectively. d_{cut} is represent the total diameter or depth in [mm] should be cut.

2.5.3 Feed rate

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or [mm/rev].

$$F_m = fN\ [\text{mmmin}^{-1}] \tag{2.3}$$

Where, *Fm* is the feed in [mm/min], *f* is the feed in [mm/rev] and *N* is the spindle speed in [RPM].

2.6 LATHE MACHINE

The lathe is a one of the machine tools most well used by machining. It used principally for shaping pieces of metal and sometimes wood or other materials by causing the work piece to be held and rotated by the lathe while a tool bit is advanced into the work causing the cutting action. The basic lathe that was designed to cut cylindrical metal stock has been developed further to produce screw threads, tapered work, drilled holes, knurled surfaces, and crankshafts. In order to get an efficient process and beautiful surface at the lathe machining, it is important to adjust a rotating speed, a cutting depth and sending speed.

2.6.1 Basic Parts of Lathe Machine

In lathe machine, there are a lot of general or basic parts those are very important. Each component or part ash its own function and specifications. Basically the lathe machine has basic parts such as headstock, bed, carriage, tailstock, and so on.

2.6.2 Headstock

It contains the gears, pulleys, or a combination of both, which drives the workpiece and the feed units. The headstock contains also the motor, spindle speed selector, feed-unit selector and feed direction selector. It provides a means of support and rotation to the workpiece by attaching a work-holding device to its spindle. Headstocks have a hollow spindle to which work holding devices, such as chucks and collets, are attached, and long bars can be fed through for various turning operations.

2.6.3 Bed

It provides support for the other units of the lathe. V-shaped ways are located on the top of the bed providing alignment of the headstock, bed and tailstock. The top portion of the bed has two ways, with various cross-sections, that are hardened and machined accurately for wear resistance and dimensional accuracy during use.

2.6.4 Carriage

It slides along the ways and consists of an assembly of the cross-slide, tool post, and apron. The cutting tool is mounted on the tool post, usually with a compound rest that swivels for tool positioning and adjustment. The cross-slide moves in and out, thus controlling the radial position of the cutting tool, as in facing operations. The apron is equipped with mechanisms for both-manual and the cross-slide, by means of the lead screw.

2.6.5 Tailstock

It can slide along the ways and can be clamped at any position, supporting the other end of the work piece. It is equipped with a center that may be fixed (dead center), or it may be free to rotate with the work piece (live center). Drills and reamers can be mounted on the tailstock quill to produce axial holes in the work piece. A hand wheel allows for the extension of the tailstock spindle.

2.6.6 Feed Rod and Lead Screw

The feed rod is powered by a set of gears from the head stock It rotates during operation of the lathe and provides movement to the carriage and the cross-slide by means of gears, a fiction clutch, and a keyway along the length of the rod. The lead screw is used for cutting threads accurately. Closing a split nut around the lead screw engages it with the carriage.

2.6.7 Turning Process

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool. Turning produces solids of revolution which can be tightly tolerance because of the specialized nature of the operation. Turning is performed on a machine called a lathe in which the tool is stationary and the part is rotated. The work piece is a piece of pre-shaped material that is secured to the fixture, which itself is attached to the turning machine, and allowed to rotate at high speeds. The cutter is typically a single-point cutting tool that is also secured in the machine, although some operations make use of multi-point tools. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desired shape. Turning is used to produce rotational, typically axis symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners.

Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed. The work piece rotates in the lathe, with a certain spindle speed (n), at a certain number of revolutions per minute. In relation to the diameter of the work piece, at the point it is being machined, this will give rise to a cutting speed, or surface speed (Vc) in [m/min]. This is the speed at which the cutting edge machines the surface of the work piece and it is the speed at which the periphery of the cut diameter passes the cutting edge.

The cutting speed is only constant for as long as the spindle speed and/or part diameter remains the same. In a facing operation, where the tool is fed in towards the center, the cutting speed will change progressively if the work piece rotates at a fixed spindle speed. On most modern CNC-lathes, the spindle speed is increased as the tool moves in towards the center. For some of the cut, this makes up for the decreasing diameter but for very small diameters, and very close to the center, this compensation will be impractical as the speed range on machines is limited. Also if a work piece, as is often the case, has different diameters or is tapered or curved, the cutting speed should be taken into account along the variations.

The feed (f) in [mm/rev] is the movement of the tool in relation to the revolving work piece. This is a key value in determining the quality of the surface being machined and for ensuring that the chip formation is within the scope of the tool geometry. This value influences, not only how thick the chip is, but also how the chip forms against the insert geometry. The entering angle can be selected for accessibility and to enable the tool to machine in several feed directions, giving versatility and reducing the number of tools needed. Alternatively it can be made to provide the cutting edge with a larger corner and can add cutting edge strength by distributing machining pressure along a greater length of the cutting edge. It can also give strength to the tool at entry and exit of cut and it can direct forces to provide stability during the cut.

The cutting depth (ap) in mm is the difference between un-cut and cut surface. It is half of the difference between the uncut and cut diameter of the work piece. The cutting depth is always measured at right angles to the feed direction of the tool. The cutting edge approach to the work-piece is expressed through the entering angle (*kr*). This is the angle between the cutting edge and the direction of feed and is an important angle in the basic selection of a turning tool for an operation. In addition to influencing the chip formation, it affects factors such as the direction offers involved, the length of cutting edge engaged in cut, the way in which the cutting edge makes contact with the work piece and the variation of cuts that can be taken with the tool in question. The entering angle usually varies between 45 to 95 degrees but for profiling operations, even larger entering angles are useful.

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2.7 CUTTING TOOL

2.7.1 Cutting Tool Geometry

The geometry of the tool holder itself largely determines how the insert is presented to the work (Klocke, F., Brinksmeier, E. and Weinert, K, 2005; Özel, T., 2009). However, the elements of geometry for turning inserts include:

- Basic insert shape and size
- Relief angle, angle of inclination, rake angle, and lead angle
- Nose radius
- Chip breaker design.

The most important determinant of general insert shape is work piece geometry. An 80" diamond insert, for example, is very versatile; it allows users to cut a 90' shoulder and perform facing operations on a variety of part configurations. But parts with many contours may require a different shape. Insert shape is a trade-off between strength and versatility. Larger point angles are stronger and often used for roughing operations. Smaller angles (35 – 55’) are more versatile for intricate work. Generally, the largest point angle suitable for the job should be applied. This approach assures use of the strongest possible insert and thus minimizes the possibility of a sudden tool failure.

Insert size is designated by the largest circle which can be inscribed within the perimeter of the insert, called the inscribed circle (IC). Insert size is determined largely by the size of the pocket in the tool holder, and also by the expected cutting depth. Because carbide is sold essentially by weight, it often makes economic sense for users to apply the smallest IC insert that will perform the task at hand. Lower initial cost of smaller inserts, however, must be weighed against the improved reliability offered by larger, thicker inserts.

Relief angle allows the cutting edge to work freely without unnecessary rubbing on the work piece. Several angles are important when introducing the tool edge into the rotating work piece. Angle of inclination is the angle of the insert seat or pocket in the tool holder, from front to back. This inclination can be positive, negative, or neutral.

Rake angle is the angle at which the trailing face of the insert falls away from the work piece. It may also be positive, negative, or neutral. Effective rake angle is determined by the combination of the tool holder's angle of inclination and the rake built into the insert.

Lead angle is the angle between the direction of the cutting tool feed and the cutting edge is important for chip formation, as well as for determining the direction of cutting forces, the length of cutting edge that contacts the work piece, and the way the edge contacts the work.

Tool nose radius is a key factor that affects both insert strength and work piece surface finish. The radius may be large for strength, or sharp for fine-radius turning. A large nose radius distributes the cut along a greater length, providing better heat dissipation and improved tool life. Nose radius also influences chip formation.

Edge preparation is another important aspect of insert geometry. Sharp edges tend to be weak and prone to fracture, so insert cutting edges are generally prepared with particular forms that strengthen them. These include a honed radius, a chamfer, a land, or a combination of the three. A radius is applied to most comers to round the sharp edge. Radii for carbide turning inserts generally range between 0.0002 and 0.0030" (5 - 75 *pm*). A chamfer breaks the corner, while a land is a relief that stretches back some distance on the insert face. Placing a land on the edge before the actual rake angle takes effect strengthens the cutting edge by redirecting cutting forces into the body of the insert.

Advances in pressing technology are making possible "up sharp" inserts, with an as-pressed edge. These inserts have a small, natural hone, but are not ground with chamfers or lands. Up-sharp edges are used to slice through materials such as aluminum alloys and some high-temperature alloys. A special type of edge preparation that has come into wide use recently for both turning and milling operations is the wiper geometry. Like conventional turning inserts, wiper tools use their leading edge to remove metal and leave a surface of peaks and grooves. But wiper inserts feature additional radii behind the tool nose that are kept in contact with the work piece after the initial cut. This burnishes peaks, leaving a smoother surface finish.

Wiper geometries are often promoted as giving a mirror finish, but the real benefit, according to tool suppliers, is reduced cycle times resulting from increased feed rates. Users may even be able to double feed rates and maintain the same surface finish as that obtained using a standard insert. Wiper geometries, however, are not for every application. They are not suited to light finishing operations, because they require more stock and slightly heavier depths of cut to work correctly. Also, they must be run at higher feeds to take full advantage of the wiper geometry.

Chip forming is critical to efficient turning operations and good work piece surface finish. Next to speed, the chip former geometry of a turning insert has the most influence on the amount of heat generated in the cutting zone. Chip formers are often referred to as chip breakers. Reality is that this component of insert geometry forms the chip and causes it break either by itself, by deflecting against the tool, or by deflecting against the work piece. The more aggressively the chip former bends the chips, the more heat it generates. So chip former selection is a trade-off, and the geometry chosen must be matched with the work material feed rate, and depth of cut. The efficiency of some chip formers depends on the depth of cut. Others are more sensitive to feed rate.

The basic types of chips produced by turning include small, curled chips; helical or spiral chips; long, stringy chips; and corrugated chips. The first type is generally considered ideal. Other types of chips are often taken as indicating the need for speed and feed adjustments or selection of a different chip former design. Depending on the application, however, making very small chips may not be necessary. One cutting tool supplier says an obsession with making very short chips may actually lead to chip forming overkill that can overpower the chip former and reduce tool life. Reality, according to the supplier, is that any chip that drops flake and doesn't cause problems is a good chip.

2.8 CUTTING TOOL MATERIAL

The selection of cutting tool materials for a particular application is among the most important factors in machining operations, as is the selection of mold and die material for forming and shaping process. The cutting tool is subjected to high temperatures, high contact stress, and rubbing along the tool chip interface and along the machined surface. Consequently, the cutting tool material must possess the following characteristic like hot hardness, toughness and impact strength, thermal shock resistance, wear resistance, and chemical stability and inertness. The classes of cutting tool materials currently in use for machining operation are high speed tool steel, cobalt-base alloys, cemented carbides, ceramic, polycrystalline cubic boron nitride and polycrystalline diamond.

To effectively select tools for machining, a machinist or engineer must have specific information about:

- The starting and finished part shape
- The work piece hardness
- The material's tensile strength
- The material's abrasiveness
- The type of chip generated
- The work holding setup
- The power and speed capacity of the machine tool

2.8.1 Carbon steels

Carbon steels have been used since the 1880s for cutting tools (G.T. Smith, 1989). However carbon steels start to soften at a temperature of about 180°C. This limitation means that such tools are rarely used for metal cutting operations. Plain carbon steel tools, containing about 0.9% carbon and about 1% manganese, hardened to about 62 Rc, are widely used for woodworking and they can be used in a router to machine aluminium sheet up to about 3mm thick.

2.8.2 High speed steels (HSS)

HSS tools are so named because they were developed to cut at higher speeds. Developed around 1900 HSS are the most highly alloyed tool steels. The tungsten (T series) was developed first and typically contains 12 - 18% tungsten, plus about 4% chromium and 1 7- 5% vanadium. Most grades contain about 0.5% molybdenum and most grades contain 4 - 12% cobalt. It was soon discovered that molybdenum (smaller proportions) could be substituted for most of the tungsten resulting in a more economical formulation which had better abrasion resistance than the T series and undergoes less distortion during heat treatment. Consequently about 95% of all HSS tools are made from M series grades. These contain 5 - 10% molybdenum, 1.5 - 10% tungsten, 1 - 4% vanadium, 4% Chromium and many grades contain 5 - 10% cobalt. HSS tools are tough and suitable for interrupted cutting and are used to manufacture tools of complex shape such as drills, reamers, taps, dies and gear cutters. Tools may also be coated to improve wear resistance. HSS accounts for the largest tonnage of tool materials currently used. Typical cutting speeds: 10 - 60 [*m/min*].

2.8.3 Cast Cobalt alloys

Introduced in early 1900s these alloys have compositions of about 40 - 55% cobalt, 30% chromium and 10 - 20% tungsten and are not heat treatable. Maximum hardness values of 55 - 64 Rc. They have good wear resistance but are not as tough as HSS but can be used at somewhat higher speeds than HSS. Now only in limited use.

2.8.4 Carbides

Also known as cemented carbides or sintered carbides were introduced in the 1930s and have high hardness over a wide range of temperatures, high thermal conductivity, high Young's modulus making them effective tool and die materials for a range of applications. The two groups used for machining are tungsten carbide and titanium carbide; both types may be coated or uncoated. Tungsten carbide particles (1 to 5 micrometer) are bonded together in a cobalt matrix using powder metallurgy. The powder is pressed and sintered to the required insert shape. Titanium and niobium carbides may also be included to impart special properties. A wide range of grades are available for different applications. Sintered carbide tips are the dominant type of material used in metal cutting. The proportion of cobalt (the usual matrix material) present has a significant effect on the properties of carbide tools. 3 - 6% matrix of cobalt gives greater 8hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing the hardness, wear resistance and strength. Tungsten carbide tools are commonly used for machining steels, cast irons and abrasive non-ferrous materials. Titanium carbide has a higher wear resistance than tungsten but is not as tough. With a nickel-molybdenum alloy as the matrix, TiC is suitable for machining at higher speeds than those which can be used for tungsten carbide. Typical cutting speeds are: 30 - 150 [m/min] or 100 - 250 when coated.

2.8.5 Coatings

Coatings are frequently applied to carbide tool tips to improve tool life or to enable higher cutting speeds. Coated tips typically have lives 10 times greater than uncoated tips. Common coating materials include titanium nitride, titanium carbide and aluminium oxide, usually 2 - 15 micro-m thick. Often several different layers may be applied, one on top of another, depending upon the intended application of the tip. The techniques used for applying coatings include chemical vapor deposition (CVD) plasma assisted CVD and physical vapor deposition (PVD) (J.R. Koelsch, 1992; V.C. Venkatesh, C.T. Ye, D.T. Quinto, and D.E.P. Hoy, 1991). Diamond coatings are also in use and being further developed.

2.8.6 Cermet

Developed in the 1960s, these typically contain 70% aluminium oxide and 30% titanium carbide. Some formulation contains molybdenum carbide, niobium carbide and tantalum carbide. Their performance is between those of carbides and ceramics and coatings seem to offer few benefits. Typical cutting speeds: 150 - 350 [m/min].

2.8.7 Ceramics

Introduced in the early 1950s, two classes are used for cutting tools: fine grained high purity aluminium oxide (Al_2O_3) and silicon nitride (Si_3N_4) are pressed into insert tip shapes and sintered at high temperatures. Additions of titanium carbide and zirconium oxide (ZrO_2) may be made to improve properties. But while ZrO_2 improves the fracture toughness, it reduces the hardness and thermal conductivity. Silicon carbide (SiC) 9 whiskers may be added to give better toughness and improved thermal shock resistance. The tips have high abrasion resistance and hot hardness and their superior chemical stability compared to HSS and carbides means they are less likely to adhere to the metals during cutting and consequently have a lower tendency to form a built up edge. Their main weakness is low toughness and negative rake angles are often used to avoid chipping due to their low tensile strengths. Stiff machine tools and work set ups should be used when machining with ceramic tips as otherwise vibration is likely to lead to premature failure of the tip (A.K. Rakhit, M.O.M. Osman and T.S. Dankar, 1973; G.M. Zhang, S.G. Kapoor, 1991). Typical cutting speeds: 150-650 [m/min].

2.8.8 Silicon Nitride

In the 1970s a tool material based on silicon nitride was developed, these may also contain aluminium oxide, yttrium oxide and titanium carbide. SiN has an affinity for iron and is not suitable for machining steels. A specific type is 'Sialon', containing the elements: silicon, aluminium, oxygen and nitrogen. This has higher thermal shock resistance than silicon nitride and is recommended for machining cast irons and nickel based super alloys at intermediate cutting speeds.

2.8.9 Cubic Boron Nitride (CBN)

Introduced in the early 1960s, this is the second hardest material available after diamond. CBN tools may be used either in the form of small solid tips or as a 0.5 to 1 mm thick layer of polycrystalline boron nitride sintered onto a carbide substrate under pressure. In the latter case the carbide provides shock resistance and the CBN layer provides very high wear resistance and cutting edge strength. Cubic boron nitride is the standard choice for machining alloy and tool steels with a hardness of 50 Rc or higher. Typical cutting speeds: 30 - 310 [m/min].

2.8.10 Diamond

The hardest known substance is diamond. Although single crystal diamond has been used as a tool, they are brittle and need to be mounted at the correct crystal orientation to obtain optimal tool life. Single crystal diamond tools have been mainly replaced by 10 polycrystalline diamond (PCD). This consists of very small synthetic crystals fused by a high temperature high pressure process to a thickness of between 0.5 and 1mm and bonded to a carbide substrate. The result is similar to CBN tools. The random orientation of the diamond crystals prevents the propagation of cracks, improving toughness. Because of its reactivity, PCD is not suitable for machining plain carbon steels or nickel, titanium and cobalt based alloys. PCD is most suited to light uninterrupted finishing cuts at almost any speed and is mainly used for very high speed machining of aluminium - silicon alloys, composites and other non - metallic materials. Typical cutting speeds: 200 - 2000 [m/min].

To improve the toughness of tools, developments are being carried out with whisker reinforcement, such as silicon nitride reinforced with silicon carbide whiskers. As rates of metal removal have increased, so has the need for heat resistant cutting tools. The result has been a progression from high-speed steels to carbide, and on to ceramics and other super hard materials. High-speed steels cut four times faster than the carbon steels they replaced. There are over 30 grades of high-speed steel, in three main categories: tungsten, molybdenum, and molybdenum-cobalt based grades.

In industry today, carbide tools have replaced high-speed steels in most applications. These carbide and coated carbide tools cut about 3 to 5 times faster than high-speed steels. Cemented carbide is a powder metal product consisting of fine carbide particles cemented together with a binder of cobalt. The major categories of hard carbide include tungsten carbide, titanium carbide, tantalum carbide, and niobium carbide. Ceramic cutting tools are harder and more heat-resistant than carbides, but more brittle. They are well suited for machining cast iron, hard steels, and the super alloys. Two types of ceramic cutting tools are available: the alumina-based and the silicon nitride-based ceramics. The alumina-based ceramics are used for high speed semi- and final-finishing of ferrous and some non-ferrous materials. The silicon nitride-based ceramics are generally used for rougher and heavier machining of cast iron and the super alloys.

2.9 WORK MATERIAL

In turning, the raw form of the material is a piece of stock from which the work pieces are cut. This stock is available in a variety of shapes such as solid cylindrical bars and hollow tubes. Custom extrusions or existing parts such as castings or forgings are also sometimes used. Turning can be performed on a variety of materials, including most metals and plastics. Common materials that are used in turning include aluminum, brass, magnesium, nickel, steel, thermoplastics, titanium and zinc. When selecting a material, several factors must be considered, including the cost, strength, resistance to wear, and machinability. The machinability of a material is difficult to quantify, but can be said to possess the following characteristics:

- Results in a good surface finish
- Promotes long tool life
- Requires low force and power to turn
- Provides easy collection of chips

2.9.1 AISI 1019 Carbon Steel

Steel is the common name for a large family of iron alloys. Steels can either be cast directly to shape, or into ingots which are reheated and hot worked into a wrought shape by forging, extrusion, rolling, or other processes. Wrought steels are the most common engineering material used, and come in a variety of forms with different finishes and properties.

AISI 1019 is a Standard grade Carbon Steel. It is composed of (in weight percentage) 0.15-0.20% Carbon (C), 0.70-1.00% Manganese (Mn), 0.04%(max) Phosphorus (P), 0.05%(max) Sulfur (S), and the base metal Iron (Fe). Other designations of AISI 1019 carbon steel include UNS G10190 and AISI 1019.

AISI 1019 carbon steel at 25°C has density of 7700 – 8030 [kg/m^3], Poison's ratio of 0.27 – 0.30, and Elastic Modulus of 190 – 210 GPa. The typical tensile strength varies between 276 and 1882 MPa. The wide range of ultimate tensile strength is largely due to different heat treatment conditions.

2.10 CONCLUSION

In short, throughout these literature reviews, the proper way to operate the Pinacho S90 VS/180 lathe machine is studied. Besides that, from researches, mild steel has high machining ability and it is very suitable to perform this experiment. In this study, it is focused in dry turning on mild steel; a lot of factors have to be taken in consideration. But from most of the researches, the main 3 factors those are basically affect the surface roughness is cutting speed, depth of cut, and feed rate. Therefore, in this study, other factors such as vibration, tool length, working temperature and so on are neglected.

Furthermore, the cutting tool insert of lathe machine use to perform the dry turning operation on mild steel can be selected after reviews of journals and researches. Moreover, the ways to analysis also can be selected through the reviews of journals in order to achieve high accuracy results.

Besides that, through this chapter, it is helpful not only in how to perform this study but also to improve the knowledge on how to do a research. Next chapter is discussed about methodology of this study in order to meet the project objective.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Based on the literature review and assessment of experimental studies, a methodology was developed to investigate the effects of process parameters on surface roughness produced by dry turning operation. In this study, the material chosen to be performed is low-carbon steel which is mild steel AISI 1019. A full factorial design was selected to allow all three level interactions between the independent variables to be effectively investigated. The independent variables are cutting speed, feed rate and depth of cut in this study which are included in machining parameters. For the dependent variable, surface roughness is the only one variable that would be measured. Furthermore, there have two fixed parameters which are workpiece length and workpiece diameter. The cutting tool insert used in this study is cemented carbide insert. The output that has to be estimate is surface roughness produced by normal dry turning operation.

In this study, dry turning condition was applied to cut the workpiece. According to Sreejith and Ngoi (2000), dry machining is becoming more and more popular due to the lower cost and reduced impact on the environment and health problems in the shop floor. In addition to dry cutting, several efforts have been made to reduce the use of cutting fluids, among them the use of high water content cutting fluids, the use of a fluid mist and vegetal-based cutting fluids (Li et al., 2000; Diniz and Micaroni, 2002). This chapter describes the steps that were under taken to achieve the objective of this study from workpiece preparation, measuring data and data analysis. With using the appropriate machining parameter so that the experiment would simulate the conditions according to the standard operation and requirements.

3.2 FLOW CHART

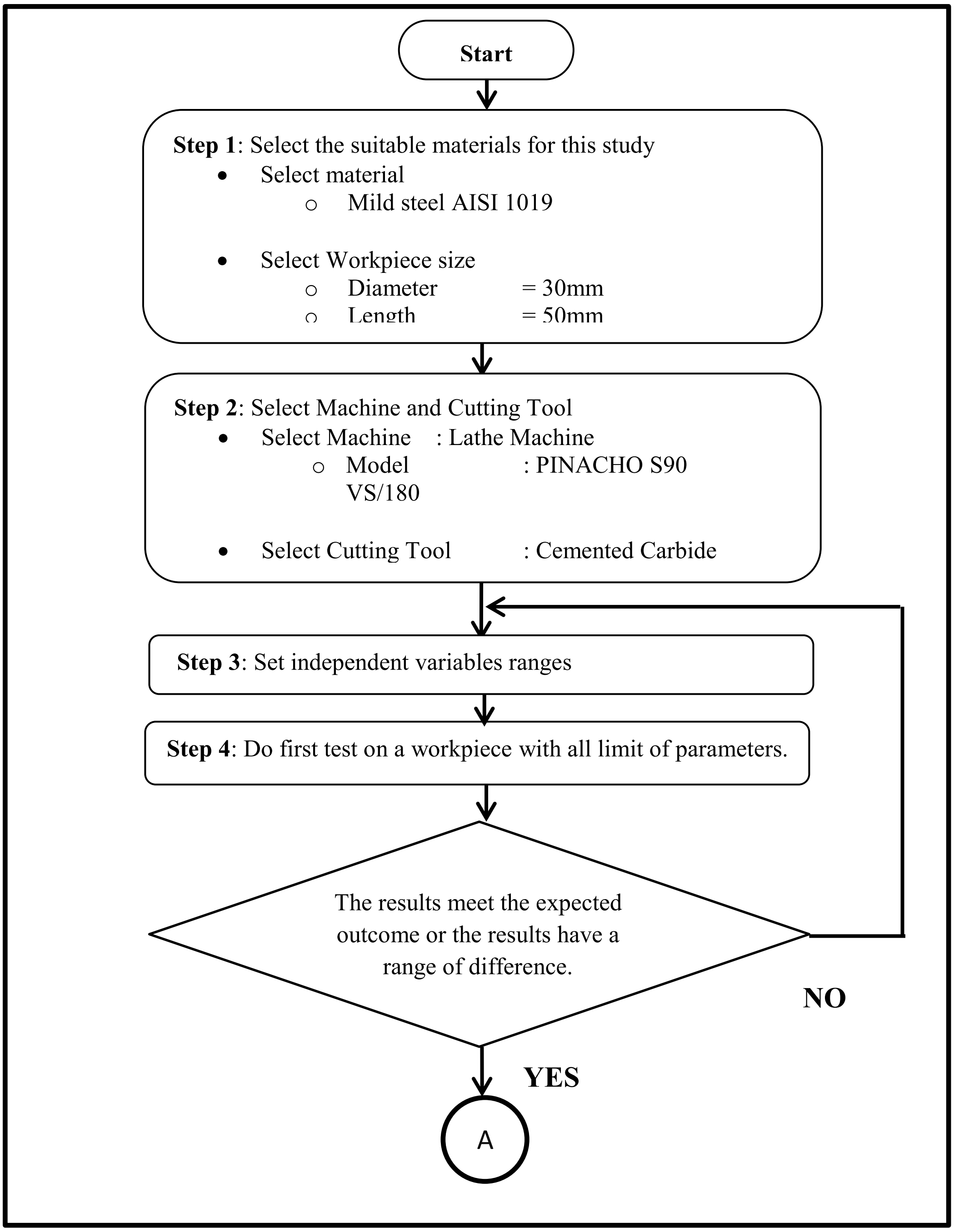

Figure 3.1: Flow Chart

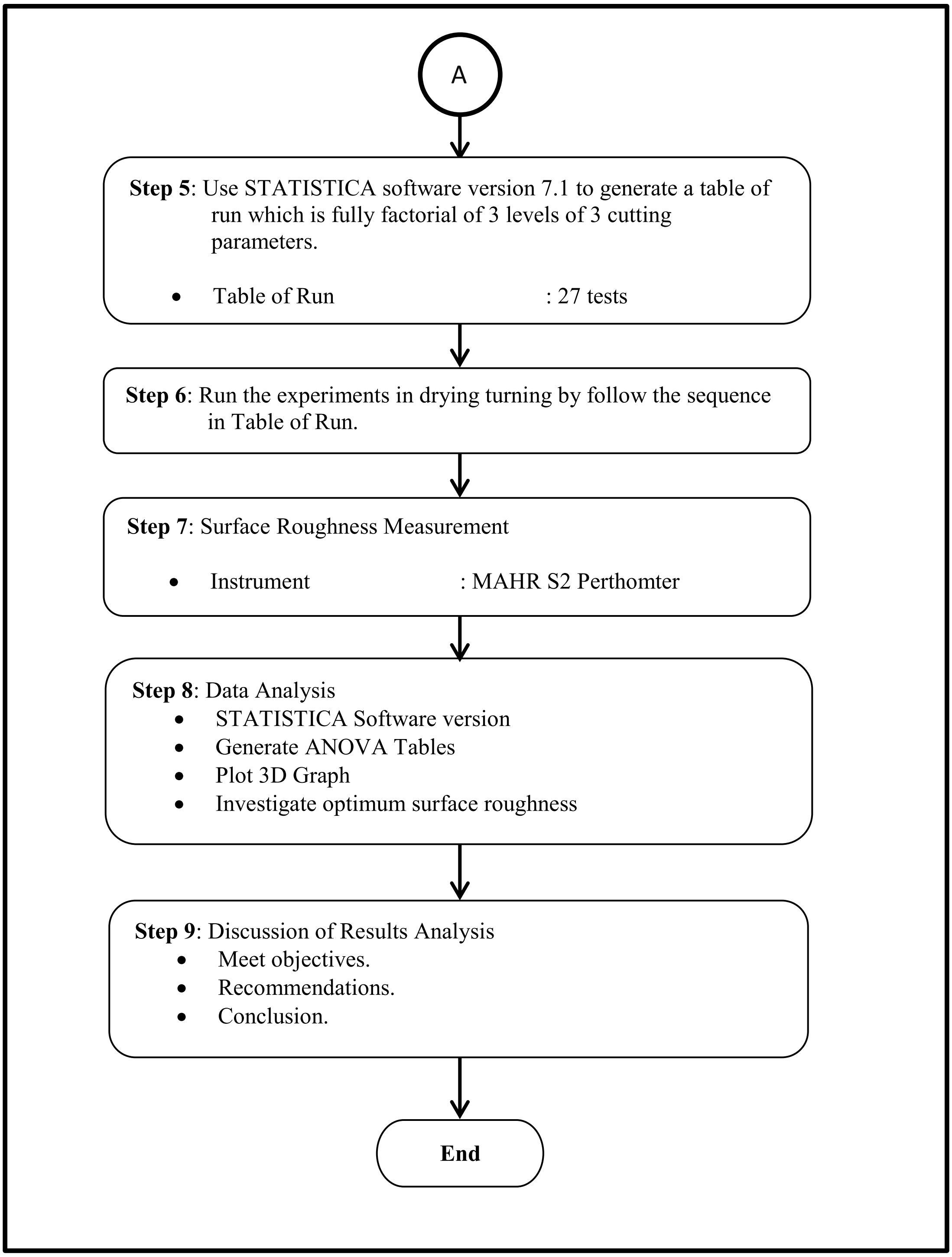

Figure 3.1: Continued

3.3 DESIGN OF EXPERIMENT

Design of Experiment (DOE) is a useful method in identifying the significant parameters and in studying the possible effect of the variables during the machining trials. This method also can developed experiment between a ranges from uncontrollable factors, which will be introduced randomly to carefully controlled parameters. The factors must be either quantitative or qualitative. The range of values for quantitative factors must be decided on how they are going to be measured and the level at which they will be controlled during the trials. Meanwhile, the qualitative factors are parameters that will be determined discretely.

Design of experiment includes determining controllable factors and the levels to be investigate. While, analysis of results is to determine the best possible factor combination from individual factor influences. Lastly, confirmation tests would be carried out as a proof to the optimum results studied.

In this study, three factors will be employed with three levels of full factorial design experiment for three different materials. The number of experiments (combinations) required is 27 (3^3) experiments. The combinations were generated in a Table of Run by using STATISTICA software. After that, by using STATISTICA software also, 3 different models of ANOVA tables were generated. The three models are no interaction model, interaction in linear time linear model, and interaction in linear time quadratic model. These 3 different models gave 3 different coefficient of determination, R^2. R^2 is a statistical term saying how good one term is at predicting another. If R-Squared is 1.0 then given the value of one term, you can perfectly predict the value of another term. If R^2 is 0.0, then knowing one term does not help you know the other term at all. More generally, a higher value of R^2 means that you can better predict one term from another.

Finally, 3-D graphs and the graph of expected result versus experiment result were generated by using STATISTICA. The software was predicted the critical combination of cutting parameters which means the optimum surface roughness was investigated.

3.3.1 Machine and Equipment

In order to achieved the goal of this experimental work, such as to establish the correlation between cutting conditions and the roughness evaluating parameter, machining issues with different cutting condition, aiming at simulating them for surface finish. The cutting tests were carried out in a lathe machine. Among the lathe machine's tools, the tool chosen to perform all experiments is cemented carbide insert tool.

The machine chosen to perform this experiment is PINACHO S90 VS/180. Pinacho is very famous manufacturer of lathe machine in the world and its main products are conventional lathe machines and CNC Smart Lathe machines. The S90 VS/180 model of lathe has very high capability in turning machining. Figure 3.1 shows the S90 VS/180 model look like. The S90 VS/180 model of lathe machine's capacity is showed in Table 3.1.

Figure 3.2: Lathe Machine of Pinacho S90 VS/180

Table 3.1: Capacity of Lathe Machine of Pinacho S90 VS/180

CAPACITY	**LIMIT AND RANGE (UNIT)**
Centre Height	180mm
Centre Distance	750 – 1000mm
Swing Over Bed	360mm
Swing Over Carriage	335mm
Swing Over Cross Slide	205mm
Bed Width	250mm
Gap Length In Front of Face Plate	130mm
Main Spindle Bore	42mm
Main Spindle Nose	DIN 55027 N˚.5 CAMLOCK N˚.5
Main spindle Taper	4 MT
Speed Range	I => 0 – 310 rpm II => 310 – 890 rpm III => 890 – 2500 rpm
Maximum Tool Dimension	20mm x 20mm
Tailstock Shank Diameter	245mm
Tailstock Shank Travel	140mm
Main Motor Power	4kW
Pump Motor Power	0.06kW
Max-Min Capacity of Fixed Steady	10 – 115 mm
Max-Min Capacity of Travelling Steady	10 – 70mm

Another equipment will use in this study is perthometer. Perthometer is a device that uses to analysis the surface roughness. The skidless detector and the curved surface compensation function make it so efficient to evaluate cylinder surface roughness. Ultra-fine steps, straightness and waviness can be measured by using the skidless measurement function.

The MAHR S2 model of perthometer will use in this experiment in order to collect my workpieces' average surface roughness, Ra. This perthometer is automatic function for setting standardized filters and tracing lengths - Monitoring of calibration and maintenance intervals - ARC function for arc elimination- Dynamic and static calibration routines - Evaluation of 41 parameters according to DIN EN ISO, JIS, ASME, MOTIF, - Variable selection of filters and tracing lengths - Tolerance monitoring with sound and optical signals. Besides that, it roughness and waviness measurements according to current standards (DIN EN ISO 3274, e.g. band-pass filter) Its low weight, despite the included powerful rechargeable battery. A large high resolution graphics display let user easily to indicate results and profiles. It is easy operation based on the automatic teller principle and large operation buttons and quick documentation via the integrated high-resolution thermal printer. Storage facility on PCMCIA memory card for measuring programs, results and profiles Add-On program S2Prog for easy creation of measuring programs.

Figure 3.3: MAHR S2 Perthometer

Table 3.2: Capacity of MAHR S2 Perthometer

CAPACITY	LIMIT AND RANGE
Measuring range	$\underline{+}$25, $\underline{+}$250, $\underline{+}$2500µm, R-series; $\underline{+}$50/250µm/.002/.001in (skid)
Standards	DIN EN ISO/JIS/ASME B46.1
Profile resolution	approx. 60,000 steps/vertical range 11,200 measuring points/standard tracing length
Vertical scale	0.~5,000µm/.00004~.200in or auto
Horizontal scale	1~5,000µm/.0004~.200in or auto
Tracing lengths Lt.	0.56, 1.75, 5.6, 17.5, 56mm
Special tracing lengths	0.56~120mm
No. of sampling lengths	1~5 adjustable
Cutoff lc	.08, .25, .8, 2.5, 8mm
Parameters (41, with tolerance limits)	Ra, Rq; Rz, Rt, Rp, Rv, RSm RDq, Rsk, Rku,Rdc, Rmr, Pmr, Pt, Wt, Pdc (DIN EN ISO 4287) Rmax (DIN 4288), Rpk, Rk, Rvk, Mr1, Mr2, Pdc, A1, A2, (DIN EN ISO 13565), RPc (prEN 10049) R, Ar, W, Aw, Rx,Wx, Wte, Nr, Ncrx, Nw, CPM (ISO 12085) R3z (DB N 31007), Rzl, S (JIS B 601)
Drive units	PZK, PGK 20/120; PRK via PAV 62
Tracing speed [mm/in per s]	0.1 and 0.5mm/.04 and .02in per second
Display	graphics LCD module with background lighting, b/w, 480x320 pixels, profile presentation
Keyboard	membrane keypad
Printer	thermal graphics printer, 384 dots/horizontal line; 8 dots/mm; 200 dots/in printing speed 25mm/1in per second
Temperature range	Storage: 15~+55°C/°5~131°F Operational: 5~40°C/41~104°F
Weight	<3 kg/6.6 lbs
Dimensions (HxWxD)	approx. 150x320x250mm
Power supply	plug-in power supply unit 9V; NiMH battery
Software	S2Prog Windows program; Perthometer Concept (optional)
Memory	internal for 10 measuring programs; PCMCIA memory card for profiles, results, measuring programs

3.3.2 Software

In this experiment, the software used is STATISTICA. STATISTICA is a statistics and analytics software package developed by StatSoft. STATISTICA provides data analysis, data management, data mining, and data visualization procedures. The software includes an array of data analysis, data management, data visualization, and data mining procedures; as well as a variety of predictive modeling, clustering, classification, and exploratory techniques. Additional techniques are available through integration with the free, open source R programming environment.

STATISTICA software can perform 3x3 levels full factorial experiment. In this software, table of run can be generated will randomly combination of 3 levels of 3 variable parameters. After measured all operated work pieces' surface roughness and inserted in the table of run, the software was helped me generated out the ANOVA tables with 3 different models. Besides that, it also helped me generated 3D graphs in order to visualize the results easily. In addition, the STATISTICA software also helped me in find out the combination of variable parameters and hence the optimum surface roughness.

3.4 PERFORMING OF EXPERIMENT

3.4.1 Materials

In dry turning operations, material with high hardness cannot be used because it will produce higher temperature, BUE, and decrease the tool's life with a continuous operation. Hence, after review from some journals and researches, the material that suitable to perform in dry turning is low carbon steel. So, in this experiment, mild steel AISI 1019 has been chosen as test material. This material has good capabilities in machining and its hardness is not very high.

3.4.2 Parameters

In this study, there are a lot of parameters those can affect the surface finish of the work piece. Because of the problem of time and sources, some parameters must be variable and others must be fixed. Hence, from review of some journals and researches, three major parameters are chosen to be the variable parameters with 3 levels each. The Table 3.3 shows the variable parameters chosen and their levels.

The main objective of this study is to investigate the optimum cutting parameters that carry out the optimum surface roughness. In order to perform this experiment, the work piece dimensions have to be fixed and the work piece dimensions are shown in Table 3.4.

Table 3.3: Variable Parameter and Design Level

Parameter	Low	Mid	High
Cutting Speed(m/min)	50	125	200
Feed rate(mm/rev)	0.05	0.075	0.10
Depth of cut(mm)	0.2	0.4	0.6

Source: J.Paulo Davim. (2009)

Table 3.4: Work Piece Specifications

Specification	Dimension
Length of materials	50mm
Diameter of material	30mm

3.4.3 Cutting Profile

The mild steel AISI 1019 is cut into 30mm in diameter and 50mm in length. The geometry of the work piece is shown in Figure 3.4.

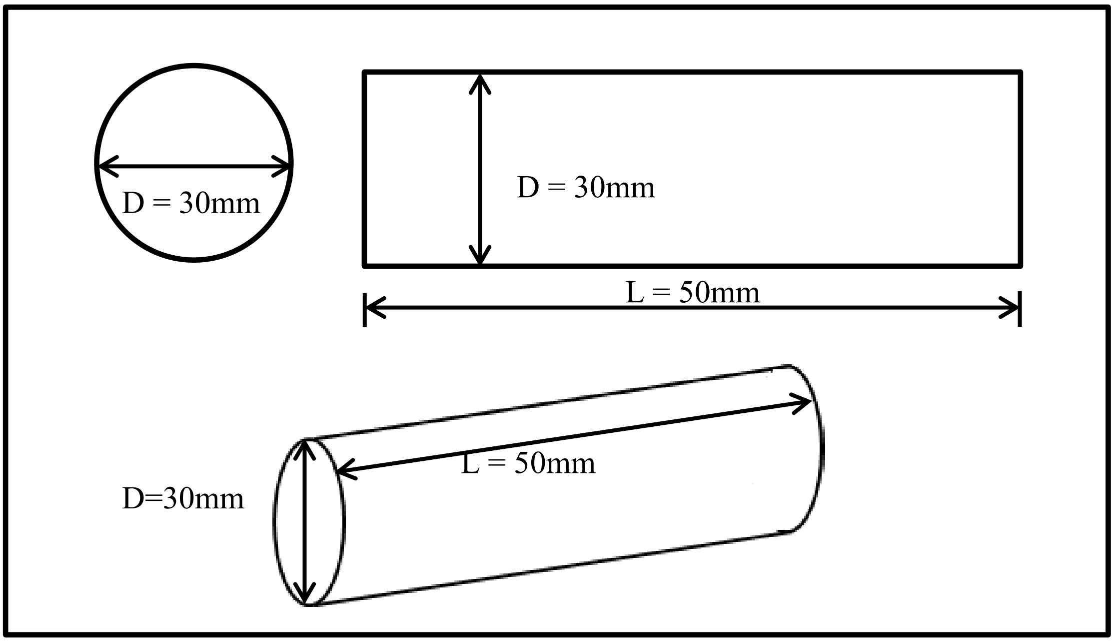

Figure 3.4: Design and Dimension of Work Piece

3.5 EXPERIMENT PROCEDURES

I. The mild steel long round bar with 32 mm diameter is cut into 27 pieces with designed dimensions using cutting machine.
II. Table of Run is generated by using STATISCA software with 3 levels of variable parameters as inputs (27 tests will be generated).
III. Dry turning operation is run onto work piece. Firstly, work piece is cut into diameter of 30mm. Hence, the work piece is cut by following the parameters set in Table of Run by using Pinacho S90 VS/180 lathe machine and coated Carbide cutting tool.
IV. Analyze the surface roughness of work piece once it is finished the dry turning operation by using Mahr S2 perthometer.

V. The average surface roughness, Ra is measured and recorded. 5 measurements for each workpiece in order to get more accuracy result.

VI. 26 tests are repeated by follow the step I to V.

VII. All surface roughness measurements are inserted into Table of Run and the 3 different models of ANOVA tables are generated.

VIII. 3D graphs are plotted and the optimum surface roughness is determined by using STATISTICA software.

3.6 CONCLUSION

The objective is to investigate the optimum cutting parameters and also the surface roughness, therefore from the flow chart and the experiment procedure, the experiment is definitely can run and obtain the result. Because of the project scope, there are only 3 cutting parameters counted in and only these parameters and surface roughness have to be determined.

Moreover, the lathe machine used in this experiment is Pinacho S90 VS/180 model and perthometer used is Mahr S2 model. The experiment is performed under assistance of the software named STATISTICA version 7.1. This software not only generated the table of run and it can also help to analysis the experimental result in statistical way. The design of this experiment is fully factorial the 3 cutting parameters with 3 level each in order to find out all the relationship between the independent variables o each other and the surface roughness.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The results of the dry turning operation onto surface roughness is discussed and analyzed in impact of cutting parameter and also the optimization the surface roughness. The objective of this chapter is to optimize the surface roughness and investigate the optimum cutting parameters. The result is analyzed statistical by using STATISTICA software (version 7.1) after the table of run is generated and the measured average surface roughness value are inserted into table of run. In this chapter, the STATISTICA software is solved the complicated design of experiment statistically and precisely. For example, 3 parameters with 3 levels experiment can be analyzed and the complicated relationship between the parameters can be investigated in ANOVA table. The significant factors that affect the surface roughness are investigated and also the optimum cutting parameters and the surface roughness.

4.2 EXPERIMENTAL RESULT

The experimental result in this study is only focused in average surface roughness, which is Ra value is the only dependent variable. Figure 4.1 below shows the Table of Run generated in STATISTICA software with 3^3 full factorial experiment design, which is 27 tests. We can observe that the sequence of the test is randomly arranged, which means the three cutting parameters are also in randomly combination. So, the flow of the experiment is followed the Table of Run from top to the bottom. The measured average surface roughness, Ra of all work pieces after dry turning operation are inserted into the Table of Run.

Table 4.1: Table of Run generated by STATISTICA software version 7.1.

Standard Run	3**(3-0) full factorial design, 1 block , 27 runs (Spreadsheet1) CUTTING SPEED	FEEDRATE	DEPTH OF CUT	Ra
14	125.0000	0.075000	0.400000	1.50
25	200.0000	0.100000	0.200000	1.53
26	200.0000	0.100000	0.400000	2.26
17	125.0000	0.100000	0.400000	1.71
27	200.0000	0.100000	0.600000	2.19
6	50.0000	0.075000	0.600000	2.36
4	50.0000	0.075000	0.200000	3.37
9	50.0000	0.100000	0.600000	3.35
18	125.0000	0.100000	0.600000	2.24
16	125.0000	0.100000	0.200000	1.84
21	200.0000	0.050000	0.600000	0.87
10	125.0000	0.050000	0.200000	2.96
11	125.0000	0.050000	0.400000	1.96
20	200.0000	0.050000	0.400000	2.67
5	50.0000	0.075000	0.400000	2.79
1	50.0000	0.050000	0.200000	4.35
2	50.0000	0.050000	0.400000	3.49
23	200.0000	0.075000	0.400000	1.82
12	125.0000	0.050000	0.600000	2.32
19	200.0000	0.050000	0.200000	2.20
24	200.0000	0.075000	0.600000	1.78
3	50.0000	0.050000	0.600000	3.30
8	50.0000	0.100000	0.400000	3.35
7	50.0000	0.100000	0.200000	3.56
22	200.0000	0.075000	0.200000	0.93
15	125.0000	0.075000	0.600000	1.21
13	125.0000	0.075000	0.200000	1.06

From figure 4.1, the minimum Ra value is 0.87µm and it is the result of test number 21, which is the combination of cutting speed = 200m/min, feed rate = 0.05 mm/rev, and depth of cut = 0.6mm. On the other hand, the highest value of Ra value is 4.35µm, which is the result from test number 1, combination of cutting speed = 50m/min, feed rate = 0.05mm/rev, and depth of cut = 0.02mm.

The minimum or maximum Ra value does not mean the optimum surface roughness value. Optimum means most favorable condition or greatest degree or amount possible under given circumstances. The minimum Ra value 0.87µm mignt not be the optimum surface roughness and it is minimum value for the work of experiments. Therefore, the optimum cutting parameters and surface roughness have to be determined by the 3D graphs because the graph pattern of surface roughness versus cutting parameters is not linear, it is parabola shape. Thus, from the measured Ra values, the STATISTICA is predicted the 3D graphs and hence the optimum surface roughness and the cutting parameters can be investigate.

4.3 STATISTICAL ANALYSIS

4.3.1 Observed Values versus Predicted Values

From the Figure 4.1, the MS Residual is 0.2332139. The MS Residual is means the residual mean square, is a measure of how poorly or how well the regression line fits the actual data points. A larger residual mean square indicates poor fit. From the graph, the observed values which are the small blue circles are considered far from the predicted values which are the red line shown in figure. So, the error of no interaction model is large and it means the result of this model is not very accurate. In order to get better result for analysis, another model of 2-way interaction is generated and it is shown in Figure 4.2.

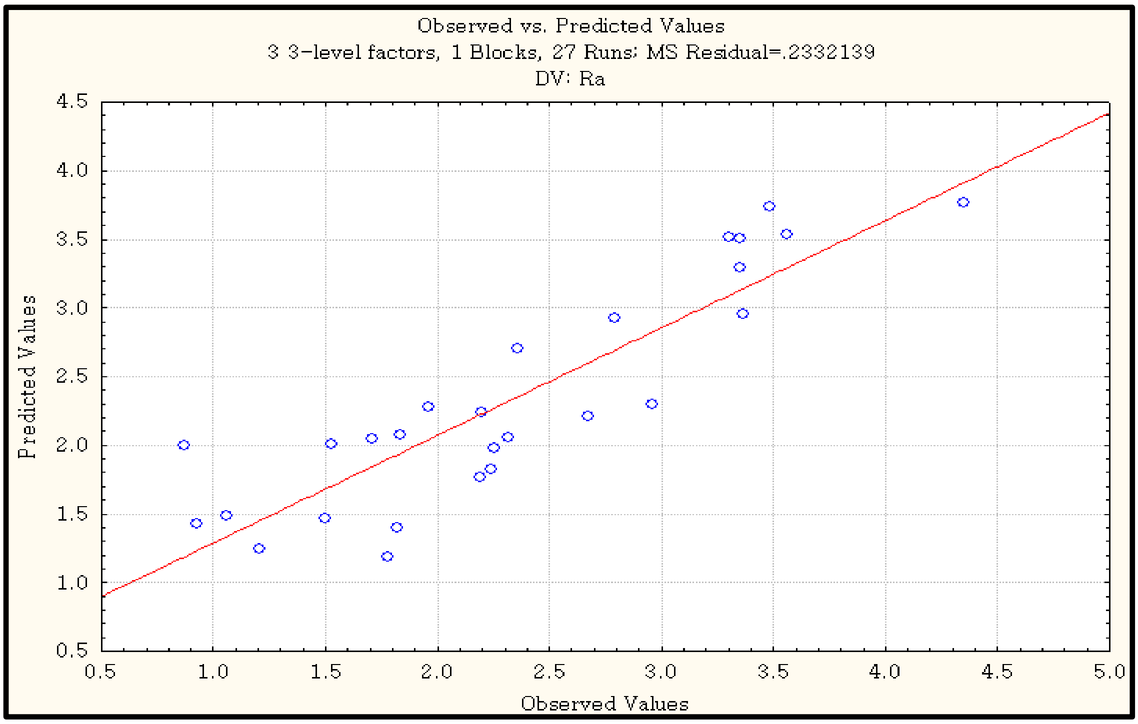

Figure 4.1: Graph of Observed Values versus Predicted Values for No Interaction Model

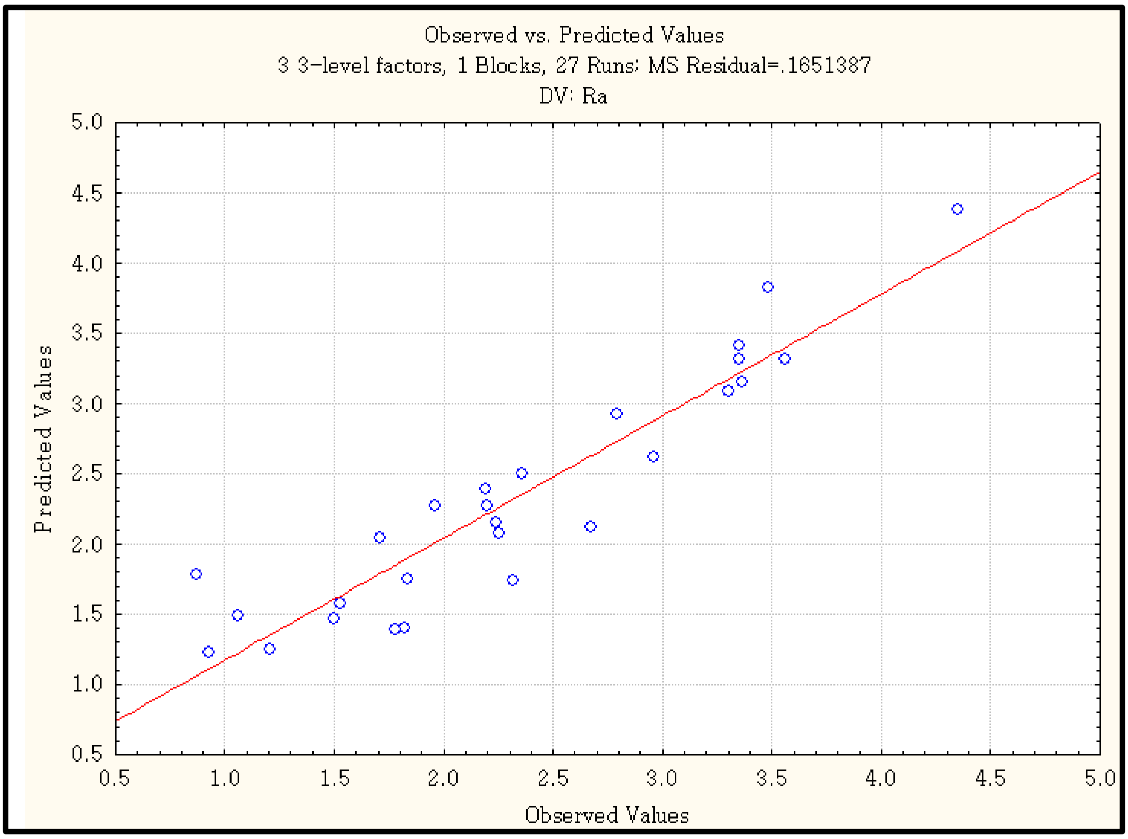

Figure 4.2: Graph of Observed Values versus Predicted Values for 2-way Interaction Model of Linear x Linear

From the figure 4.2, the residual mean square value of 2-way interaction model of linear x linear is smaller than the no interaction model, which is 0.1651387. The observed values in figure above are closer to the predicted values .This means the error of this model is smaller than the no interaction model and the result analysis through this model is more accurate. But the MS residual value of this model is not the lowest. Another model, 2-way interaction of linear x quadratic model is generated to compare the result with this model.

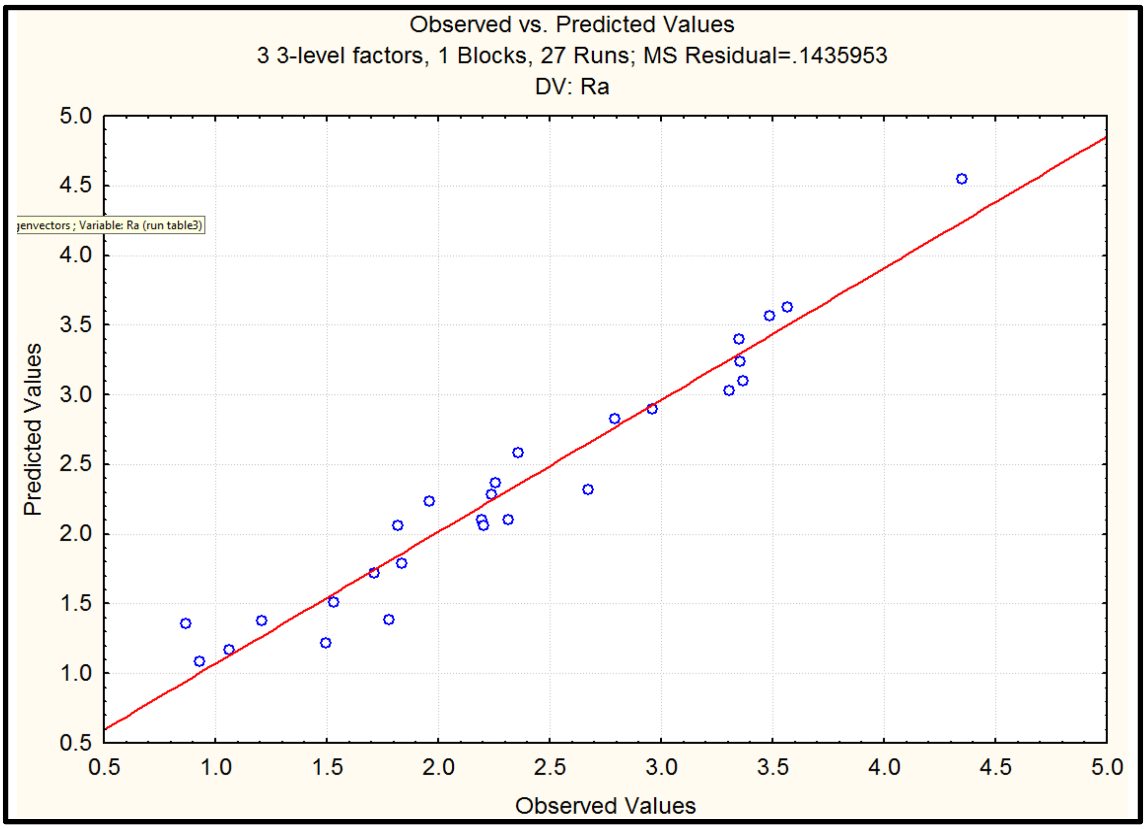

Figure 4.3: Graph of Observed Values versus Predicted Values for 2-way Interaction of Linear x Quadratic Model

From the Figure 4.3, the MS Residual is 0.1435953, it is the smallest value compared to the two models previous. All the observed values (blue circles) are close to the predicted value (red line) and there are several circles lie on the red line, this shows the observed values of those experiments are very accurate. The error of this model is also the smallest. Therefore, the result analysis though this model is most accurate and favorable compared with the no interaction model and 2-way interaction of linear x linear model.

So, for further analysis, the best result can easily to select after the study of the graphs of observed values versus predicted values with different models. In addition, after the study of these graphs, the significant factors should be investigated through the Analysis of variance (ANOVA).

4.3.2 ANOVA Table

ANOVA; Var.:Ra; R-sqr=.78268; Adj:.71748 (run table3)
3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.2332139
DV: Ra

Factor	SS	df	MS	F	p
(1)CUTTING SPEED(L)	10.39163	1	10.39163	44.55837	0.000002
CUTTING SPEED(Q)	2.93841	1	2.93841	12.59965	0.002010
(2)FEEDRATE(L)	1.51763	1	1.51763	6.50746	0.019037
FEEDRATE(Q)	2.90965	1	2.90965	12.47632	0.002093
(3)DEPTH OF CUT(L)	0.00350	1	0.00350	0.01501	0.903720
DEPTH OF CUT(Q)	0.05244	1	0.05244	0.22486	0.640496
Error	4.66428	20	0.23321		
Total SS	21.46233	26			

Figure 4.4: ANOVA Table of for No Interaction Model

The Figure 4.4 has shown the ANOVA Table generated from the Table of run shown in Table 4.1 with a model of no interaction, which means the relations between x-axis and y-axis are in linear and quadratic but no any interaction between each other. Level of confident is set to 95%, which means the error must be less than 5%, the p-values shown in Figure 4.4 above represent the percentage of the errors. The independent variables can consider as a significant factor only if its p-value is less than 0.05.

The coefficient of determination, R^2 is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information. It is the proportion of variability in a data set that is accounted for by the statistical model. It provides a measure of how well future outcomes are likely to be predicted by the model. The R^2 value is ranged 0 to 1 and if it is closer to 1, it means the regression line is more approximately to the real data points. In this study, the R^2 value must greater than 85% then only considered acceptable.

From Figure 4.4, the model is no interaction, the R^2 value is 0.78268. It is less than 0.85. This means 78.268% of the total variation in y can be explained by the linear relationship between x and y. The other 21.732% of the total variation in y remains unexplained. With a MS residual of 0.2332139, same with the value showed in Figure

4.1 previous and the adjacent is 0.71748. The adjacent represent the distance of the experimental results to the predicted results. The adjacent closer to 1 means the experimental results are nearer to the real data. So, the observed values in no interaction model are 71.748% close to the predicted values in average.

Moreover, the cutting speed and feed rate are the two significant factors as shown in Figure 4.4; both cutting speed linear regression and quadratic regression are showed the cutting speed is a significant factor with p-values of 0.000002 and 0.002010. In addition, the feed rate linear regression and quadratic regression are also showed the feed rate is a significant factor. The p-value of feed rate linear regression is 0.19037 while the p-value of feed rate quadratic regression is 0.002093. On the other hand, Figure 4.4 has shown another independent variable which is depth of cut is not a significant factor neither linear regression nor quadratic regression.

In addition, the errors of the no interaction model have shown in Figure 4.4. The total error of sum square of y-axis values is 4.66428 and the error in degree of freedom (df) is 20 out of 26.

	ANOVA; Var.:Ra; R-sqr=.78268; Adj:.71748 (run table3) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.2332139 DV: Ra				
Factor	SS	df	MS	F	p
(1)CUTTING SPEED L+Q	13.33005	2	6.665023	28.57901	0.000001
(2)FEEDRATE L+Q	3.15038	2	1.575189	6.75426	0.005738
(3)DEPTH OF CUT L+Q	0.31763	2	0.158814	0.68098	0.517475
Error	4.66428	20	0.233214		
Total SS	21.46233	26			

Figure 4.5: ANOVA Table of Model of No Interaction with Sum of Linear and Quadratic Regressions

Figure 4.5 is the sum of the linear regression and the quadratic regression for each independent variable from Figure 4.4. The results have shown the cutting speed and feed rate are still two significant factors that affect the surface roughness. With the sum of linear and quadratic regressions of cutting speed variable, the error is just 0.000001 or 0.0001%, it can be considered as a very significant factor already but in case of the R^2 value is not acceptable, therefore the further analysis is still required. Besides that, the results are still showed the feed rate is a significant factor with p-value of 0.005738. Same with the results in Figure 4.4, the depth of cut variable is not a significant factor, the p-value in Figure 4.5 is 0.517475; it is greater than 0.05.

	ANOVA; Var.:Ra; R-sqr=.8692; Adj:.79995 (run table3) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.1651387 DV: Ra				
Factor	SS	df	MS	F	p
(1)CUTTING SPEED(L)	10.39163	1	10.39163	62.92668	0.000000
CUTTING SPEED(Q)	2.93841	1	2.93841	17.79360	0.000578
(2)FEEDRATE(L)	1.51763	1	1.51763	9.19003	0.007531
FEEDRATE(Q)	2.90965	1	2.90965	17.61944	0.000605
(3)DEPTH OF CUT(L)	0.00350	1	0.00350	0.02119	0.885962
DEPTH OF CUT(Q)	0.05244	1	0.05244	0.31756	0.580437
1L by 2L	0.10383	1	0.10383	0.62871	0.438754
1L by 3L	0.50037	1	0.50037	3.03001	0.099805
2L by 3L	1.25272	1	1.25272	7.58588	0.013547
Error	2.80736	17	0.16514		
Total SS	21.46233	26			

Figure 4.6: ANOVA Table of Model of 2-way Interaction of Linear x Linear

For the model of 2-way interaction in linear x linear, the ANOVA table generated by STATISTICA software is shown in Figure 4.6. In this model, the coefficient of determination, R^2 is 0.8692 or 86.92%. It is higher than 85% and also the R^2 value in no interaction model. This represent the accuracy of this model is acceptable because of the R^2 value is higher than 0.85. The mean square residual is also decreased compared to the no interaction model, which is 0.1651387. It has shown the error between the observed values and predicted values is decreased. The adjacent (Adj) value shown in Figure 4.6 is 0.79995. Compared to the no interaction model, the adjacent value is higher, that means the distance of the observed values are closer to the predicted values. Therefore, this 2-way interaction model is better than the no interaction model with compared this 3 aspects and the result analyzed through this model is more accurate and precisely.

From the Figure 4.6, there have 5 significant factors. Firstly, the results had still shown the cutting speed is a significant factor. Both linear and quadratic regressions of cutting speed variable are showed the p-values are less than 0.05. For linear regression of cutting speed, the p-value is 0.000000; this means no error between the observed values and the predicted values of cutting speed onto average surface roughness values and the observed linear regression is totally overlapped the predicted linear regression. For quadratic regression of cutting speed variable, the p-value showed is 0.000578. The error is also very small. Compared both regressions of cutting speed variable of this model to no interaction model; the p-values of both regressions in this model are lower than the no interaction model. This shown again the 2-way interaction with linear x linear model is more accurate compared to the no interaction model.

Moreover, the results in Figure 4.6 also shown the feed rate variable is also a significant factor. Feed rate variable's linear and quadratic regressions also gave a p-value lower than 0.05. The linear regression of feed rate variable has a p-value of 0.007531 while the quadratic regression has a p-value of 0.000605. Same with the cutting speed variable, both regressions of feed rate variable in this model is decreased compared to no interaction model.

For the depth of cut variable, the result still shown it is not a significant factor. Both linear and quadratic regressions of this variable do not give a p-value less than 0.05. The p-value shown is 0.885962 for linear regression and 0.580437 for quadratic regression. So, the depth of cut cannot be considered as a significant factor for the surface roughness. Compared of the p-values of this variable in this model to no interaction model, the p-values of depth of cut variable in this model are decreased.

From the Figure 4.6, there has 3 more factors shown in table, which are 1L by 2L, 1L by 3L, and 2L by 3L. These 3 factors mean there have interactions between the linear regressions of each independent variable. The number 1, 2, 3 is stated that which independent variables' linear regression are interacted. For example, the number 1 is represented the cutting speed variable; number 2 is represented feed rate variable; number 3 is represented the depth of cut variable; and then the 1L by 2L is the interaction between linear regressions of the cutting speed variable and feed rate variable.

Therefore, the interaction between linear regressions of cutting speed and feed rate had a p-value of 0.438754. This means the linear regressions of both variables have much different of gradient although both of them are significant factors. Compared to the 1L by 3L, which is interaction between linear regressions of cutting speed and depth f cut, the p-value is 0.099805; it is lower than the p-value of 1L by 2L. Furthermore, the p-value obtained from interaction 2L by 3L is less than 0.05, which is 0.013547. The reason why this phenomenon occurred is the pattern of linear regression of depth of cut variable might much similar to the pattern of linear regression of the feed rate variable. The errors of both linear regressions are also small and hence the p-value became small. This factor of 2L by 3L does not means the depth of cut variable is a significant factor. These 3 additional factors are not the used to investigate the significant factors but it is just comparisons of each relationship of independent variable to the average surface roughness value, Ra.

Factor	ANOVA; Var.:Ra; R-sqr=.8692; Adj:.79995 (run table3) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.1651387 DV: Ra				
	SS	df	MS	F	p
(1)CUTTING SPEED L+Q	13.33005	2	6.665023	40.36014	0.000000
(2)FEEDRATE L+Q	3.15038	2	1.575189	9.53858	0.001669
(3)DEPTH OF CUT L+Q	0.31763	2	0.158814	0.96170	0.402090
1*2	0.10383	1	0.103825	0.62871	0.438754
1*3	0.50037	1	0.500372	3.03001	0.099805
2*3	1.25272	1	1.252723	7.58588	0.013547
Error	2.80736	17	0.165139		
Total SS	21.46233	26			

Figure 4.7: ANOVA Table of Model of 2-way Interaction of Linear x Linear with Sum of Linear and Quadratic Regressions

Figure 4.7 is shown the ANOVA table generated by STATISTICA with a model of 2-way interaction of linear x linear with the sum of linear and quadratic regressions. This can be considered of the summary of the ANOVA table shown in Figure 4.6. The results are still showed that, the cutting speed is a significant factor for surface roughness with a p-value of 0.000000; no error in the observed and predicted relations between the cutting speed and surface roughness. The cutting speed variable actually can be considered as a significant factor with a coefficient of determination greater than 85%, which is 86.92%. On the other hand, the feed rate variable is also a significant factor in this model with a p-value of 0.001669 while the depth of cut variable is still cannot be considered as a significant factor because its p-value is greater than 0.05, which is 0.402090. Compared all these p-values of 3 independent variables in this model to the no interaction model, all p-values are decreased.

In Figure 4.7, the factors of 1*2, 1*3, and 2*3 have same results with the results of 1L by 2L, 1L by 3L, and the 2L by 3L respectively shown in Figure 4.6. These factors are not independent variables; they are the interactions between the linear regressions of the independent variables. So, the results should be same. From the Figure 4.7, the total error of sum square of the values of y-axis is 2.80736 and the degree of freedom is17 out of 26. Compared to the ANOVA table of no interaction model, the error and the degree of freedom are decreased. Therefore, the mean square residual is also decreased.

With all these results, the model of 2-way interaction of linear x linear showed better results compared to the no interaction model. This model has higher coefficient of determination, lower mean square residual, lower sum square of y-axis values, lower degree of freedom, and higher adjacent.

Furthermore, in order to get a better analysis than the 2-way interaction with linear x linear model, another model named 2-way interaction with linear x quadratic is used. This is because the 2-way interaction with linear x quadratic has lower error in degree of freedom and hence the mean square residual will also lower compared to the 2-way interaction with linear x linear model. The ANOVA tables of 2-way interaction with linear x quadratic are generated and shown in Figure 4.8.

	ANOVA; Var.:Ra; R-sqr=.94648; Adj:.82605 (run table3) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.1435953 DV: Ra				
Factor	SS	df	MS	F	p
(1)CUTTING SPEED(L)	4.62672	1	4.626720	32.22055	0.000467
CUTTING SPEED(Q)	0.03594	1	0.035942	0.25030	0.630331
(2)FEEDRATE(L)	0.85942	1	0.859422	5.98503	0.040160
FEEDRATE(Q)	1.46509	1	1.465092	10.20292	0.012723
(3)DEPTH OF CUT(L)	0.14105	1	0.141046	0.98225	0.350670
DEPTH OF CUT(Q)	0.00872	1	0.008718	0.06071	0.811580
1L by 2L	0.00717	1	0.007174	0.04996	0.828740
1L by 2Q	0.08056	1	0.080561	0.56103	0.475290
1Q by 2L	0.01974	1	0.019740	0.13747	0.720433
1Q by 2Q	0.14387	1	0.143868	1.00190	0.346161
1L by 3L	1.16464	1	1.164636	8.11054	0.021548
1L by 3Q	0.70180	1	0.701797	4.88733	0.058015
1Q by 3L	0.09209	1	0.092092	0.64133	0.446359
1Q by 3Q	0.28414	1	0.284140	1.97876	0.197159
2L by 3L	0.01081	1	0.010812	0.07529	0.790730
2L by 3Q	0.06985	1	0.069854	0.48647	0.505268
2Q by 3L	0.17484	1	0.174835	1.21756	0.301923
2Q by 3Q	0.07633	1	0.076331	0.53157	0.486740
Error	1.14876	8	0.143595		
Total SS	21.46233	26			

Figure 4.8: ANOVA Table of Model of 2-way Interaction of Linear x Quadratic

From the Figure 4.8, the coefficient of determination, R^2 of this model is the highest among the three models, which is 0.94648 or 94.648%. It is very close to 1, and this means the results from this model is the most accurate compared to no interaction model and 2-way interaction with linear x linear model. Besides that, the adjacent of this model is 0.82605; compared to two models previously, this model has highest value of adjacent. This means the observed values is nearest to the predicted values among the models used. In addition, the mean square residual is 0.1435953 in this model and it is also the lowest among all models used in analysis.

In Figure 4.8, it shown the cutting speed linear regression is significant but the quadratic regression is not. The p-value of cutting speed linear regression is 0.000467 and for quadratic regression has a p-value of 0.630331; it is much greater than 0.05. This phenomenon occurred is because the relationship between the cutting speed and surface roughness is inversely proportional and it is in linear regression but not quadratic. Compared to the two models used which are no interaction and 2-way interaction with linear x linear, both models showed the cutting speed variable quadratic regression is significant factor but both model have lower R^2 values and higher mean square residual values compared to the 2-way interaction with linear x quadratic model. Therefore, the results analyzed through this model are more preferable and more accurate.

Besides that, Figure 4.8 also shown the feed rate variable is significant factor in both linear and quadratic regressions. The p-values of the feed rate variable are 0.040160 for linear regression and 0.012723 for quadratic regression. From the p-value of the feed rate variable, the quadratic regression has a lower p-value compared to the linear regression. Therefore, the relationship between the surface roughness and the feed rate is more to quadratic regression.

In addition, with such high of the R^2 value, this model still shown that the depth of cut variable is not a significant factor of surface roughness. The p-values of depth of cut variable are 0.350670 for linear regression and 0.811580 for quadratic regression. Compared to the p-values in no interaction model and 2-way interaction with linear x linear model, the p-value of linear regression is decreased but the p-value of quadratic regression is increased. So, the result show the relationship between depth of cut and surface roughness is more like linear regression.

Moreover, there are 12 more factors shown in Figure 4.8. All of them are the interactions between the linear and the quadratic regressions of each variable to other variables. For example, 1L by 2Q means interaction between cutting speed linear regression and feed rate quadratic regression. From the figure, among the 12 interactions, there is only one factor shown it is significant; which is 1L by 3Q or the cutting speed linear regression and the depth of cut quadratic regression with a p-value of 0.021548. The reason of this phenomenon is p-value is the level of error; therefore, the factor of 1L by 3L has p-value lower than 0.05 means their patterns of regressions are almost same and more to linear regression in the relationship with surface roughness. Just like previous mentioned, the p-value of depth of cut linear regression is decreased as the R^2 value is increased, some more the linear regression of cutting speed has almost zero p-value shown in Figures 4.4 and 4.6.

Compared to the ANOVA table shown in Figure 4.6, which is ANOVA table for model 2-way interaction with linear x linear, the feed rate linear regression interact with the depth of cut linear regression is significant (p-value = 0.013547), but in this model, this interaction shown insignificant with a p-value of 0.790730. By taking consideration of the R^2 value, the 2-way interaction with linear x quadratic model can give better result compared to another 2 models. And hence, the result shown in this model is most preferred.

Factor	ANOVA; Var.:Ra; R-sqr=.94648; Adj:.82605 (run table3) 3 3-level factors, 1 Blocks, 27 Runs; MS Residual=.1435953 DV: Ra				
	SS	df	MS	F	p
(1)CUTTING SPEED L+Q	4.66266	2	2.331331	16.23543	0.001527
(2)FEEDRATE L+Q	1.52384	2	0.761922	5.30604	0.034133
(3)DEPTH OF CUT L+Q	0.35611	2	0.178056	1.23999	0.339562
1*2	0.46961	4	0.117401	0.81759	0.548534
1*3	1.58638	4	0.396594	2.76189	0.103310
2*3	1.45953	4	0.364884	2.54106	0.121845
Error	1.14876	8	0.143595		
Total SS	21.46233	26			

Figure 4.9: ANOVA Table of Model of 2-way Interaction of Linear x Quadratic with Sum of Linear and Quadratic Regression

The Figure 4.9 is a summary of ANOVA table shown in Figure 4.8. From Figure 4.9, the sum of linear and quadratic regression of cutting speed variable shown it is a significant factor for surface roughness. The p-value of the cutting speed variable is 0.001527; compared to the p-values in another 2 models used, the p-value in this model is higher but in term of coefficient of determination, this model give better result that most approximate to real data. Anyway, the cutting speed variable is a significant factor for surface roughness and it is resulted in three models.

In addition, feed rate is also shown it is a significant factor for surface roughness with a p-value of 0.034133. Compared to p-values shown in Figures 4.5 and 4.7, p-value of feed rate variable in this model is also higher and the reason is same with cutting speed variable. Furthermore, this variable is also shown significant in all models used.

Moreover, another variable, depth of cut still not a significant factor for surface roughness. It p-value in this model is 0.339562. Although depth of cut is not a significant factor in this study, but its p-value is decreasing with the R^2 value is increasing. Besides that, the total error in this model is shown lowest among the three models, which is 1.14876. And the degree of freedom is also shown lowest, which is 8 out of 26. Therefore, the mean square residual is also shown lowest. Thus, the results analyzed by this model are most accurate and preferable.

4.3.3 Surface Plot and Contour Plot

To obtain the most accurate result, the model use to generate surface plot and contour plot is depends on the model's coefficient of determination, R^2 value and also the mean square residual value. So, among three models used, no interaction model, 2-way interaction with linear x linear model, and 2-way interaction with linear x quadratic model, the 2-way interaction with linear x quadratic model has highest R^2 value which is 0.94648 and lowest mean square residual which is 0.1435953. Therefore, the surface plot and contour plot are generated by this model and the purpose is use to discuss the impact of the cutting parameters on the surface roughness.

From Figure 4.10, the lowest point of the surface plot is located slightly lower than Ra = 1µm. Therefore, the number of the specimen that has the Ra value nearest to this lowest point has to be investigated. Besides that, the contour plot actually is the top view of the surface plot; hence, to investigate the number of specimen, the study on the contour plot shown in Figure 4.11 is important. From the contour plot showed in Figure 4.11, there are two specimens nearest to the lowest Ra value area, the darkest green area. Those two specimens are shown in Table 4.2.

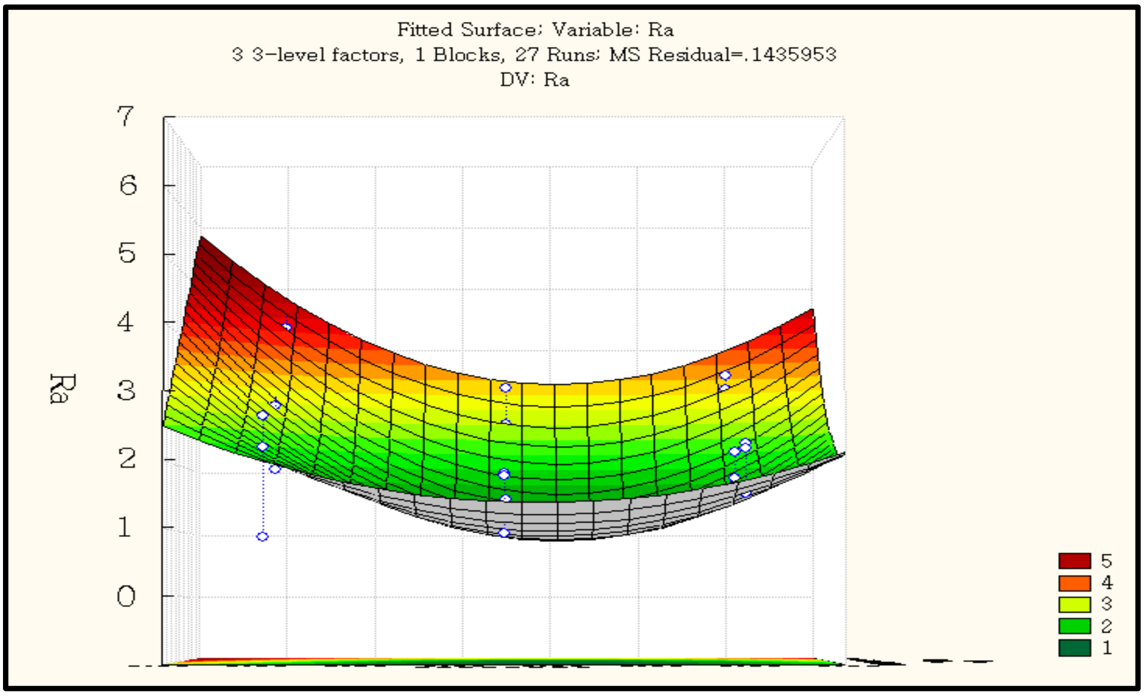

Figure 4.10: Surface Plot of Ra-value versus Feed Rate and Cutting Speed with a Depth of Cut of 0.2mm

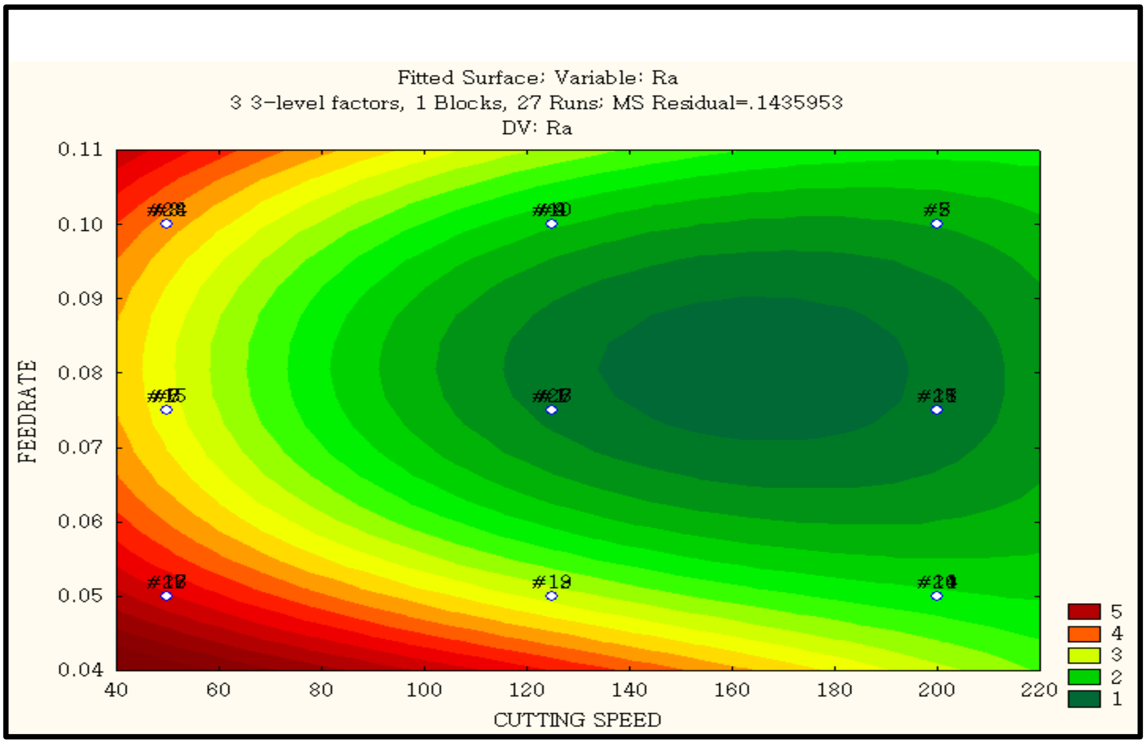

Figure 4.11: Contour plot of Ra-value versus Feed Rate and Cutting Speed with a Depth of Cut of 0.2mm

From the Table 4.2, the specimen 22 has lower Ra value which is 0.93µm and the cutting parameters are cutting speed = 200m/min, feed rate = 0.075mm/rev and depth of cut = 0.2mm. So, the specimen 22 is chosen to predict the optimum cutting parameters and optimum surface roughness later. But, from the surface plot in Figure 4.10, the optimum surface roughness is located at cutting speed = 170 m/min and feed rate = 0.08mm/rev.

Table 4.2: Cutting Parameters and Ra Value of Specimens Nearest to Lowest Ra Value Area of Contour Plot with Depth of Cut = 0.2mm

Specimen	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Ra (µm)
13	125	0.075	0.2	1.06
22	200	0.075	0.2	0.93

In Figure 4.12, the lowest Ra value is located between 1 and 1.5µm. Compared to the surface plot with depth of cut is 0.2mm, shown in Figure 4.10, the lowest Ra value in Figure 4.12 is higher. Therefore, to investigate the specimen that is nearest to the lowest Ra value area is very important and the contour plot of depth of cut = 0.4mm is generated and shown in Figure 4.13.

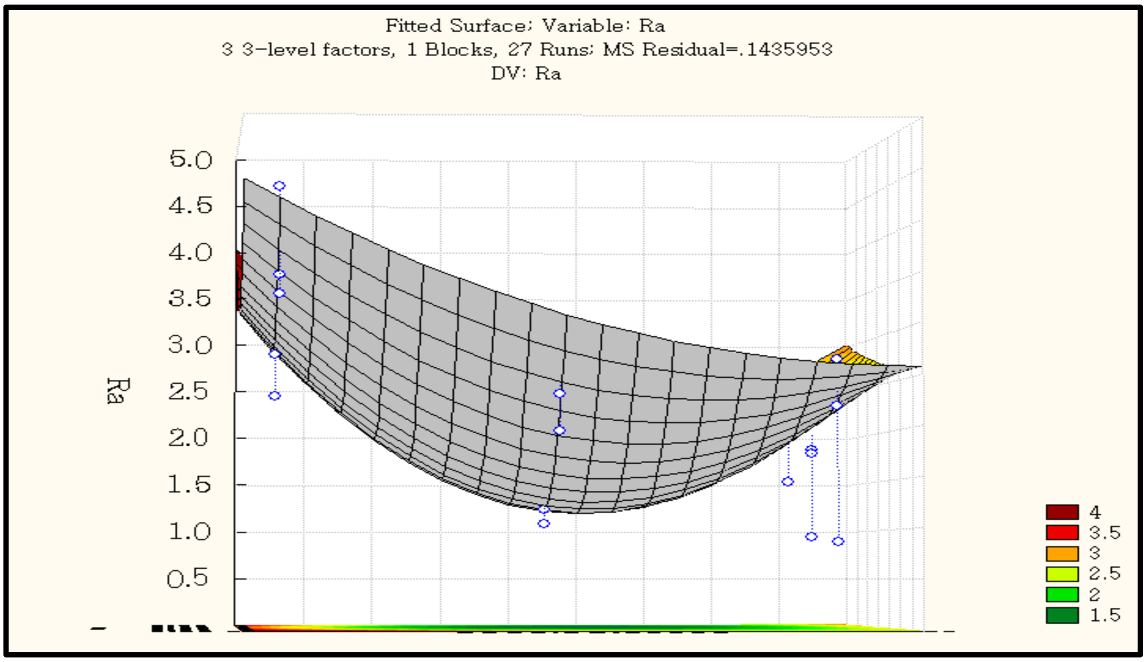

Figure 4.12: Surface Plot of Ra-value versus Feed Rate and Cutting Speed with a Depth of Cut of 0.4mm

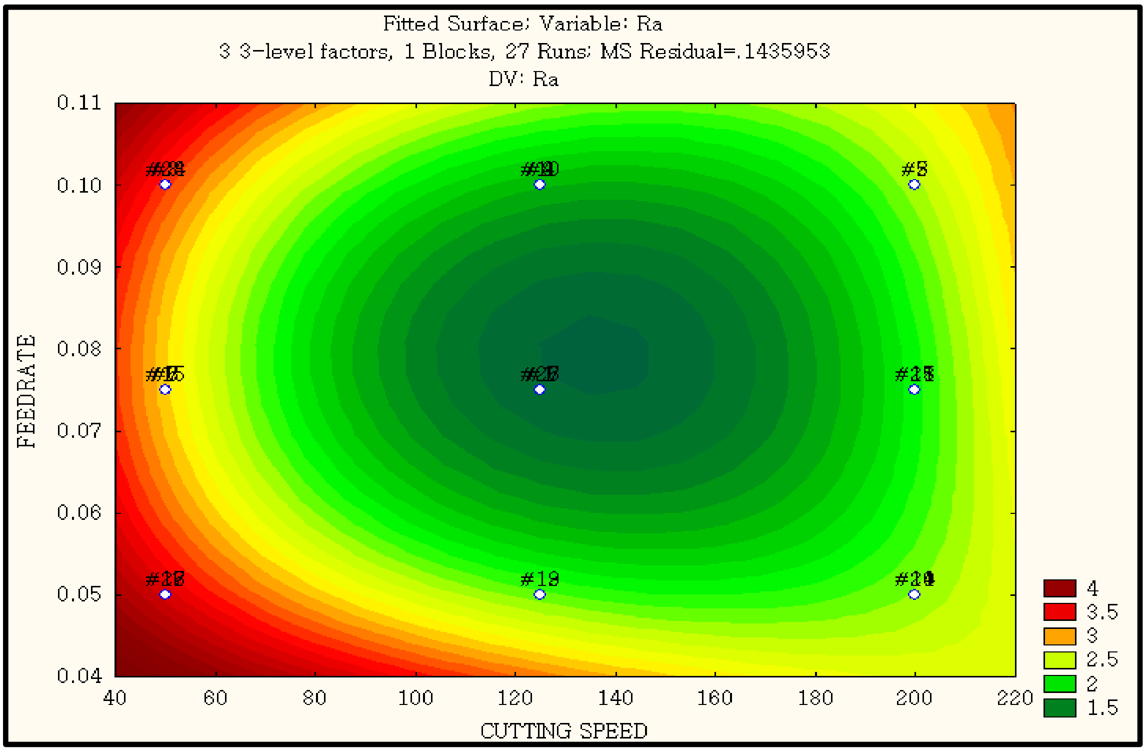

Figure 4.13: Contour Plot of Ra-value versus Feed Rate and Cutting Speed with a Depth of Cut of 0.4mm

After study the contour plot showed Figure 4.13, for depth of cut is equal to 0.4mm, there is only 1 specimen that nearest to the lowest Ra value area and its details are shown in Table 4.3.

From Table 4.3, the observed value from the experiment of the specimen number 14 is 1.5µm, and the cutting parameters are cutting speed = 125m/min, feed rate = 0.075 mm/rev, and depth of cut = 0.4mm. Compared the Ra value with the surface plot shown in Figure 4.12, there has different between the lowest Ra value and specimen number 14's Ra value because the lowest surface roughness value is predicted by the observed values; and from the surface plot, the optimum surface roughness has cutting parameters of cutting speed = 140 m/min and feed rate = 0.8mm/rev.

Table 4.3: Cutting Parameters and Ra Value of Specimen Nearest to Lowest Ra Value Area of Contour Plot with Depth of Cut = 0.4mm

Specimen	**Cutting Speed (m/min)**	**Feed Rate (mm/rev)**	**Depth of Cut (mm)**	**Ra (µm)**
14	125	0.075	0.4	1.5

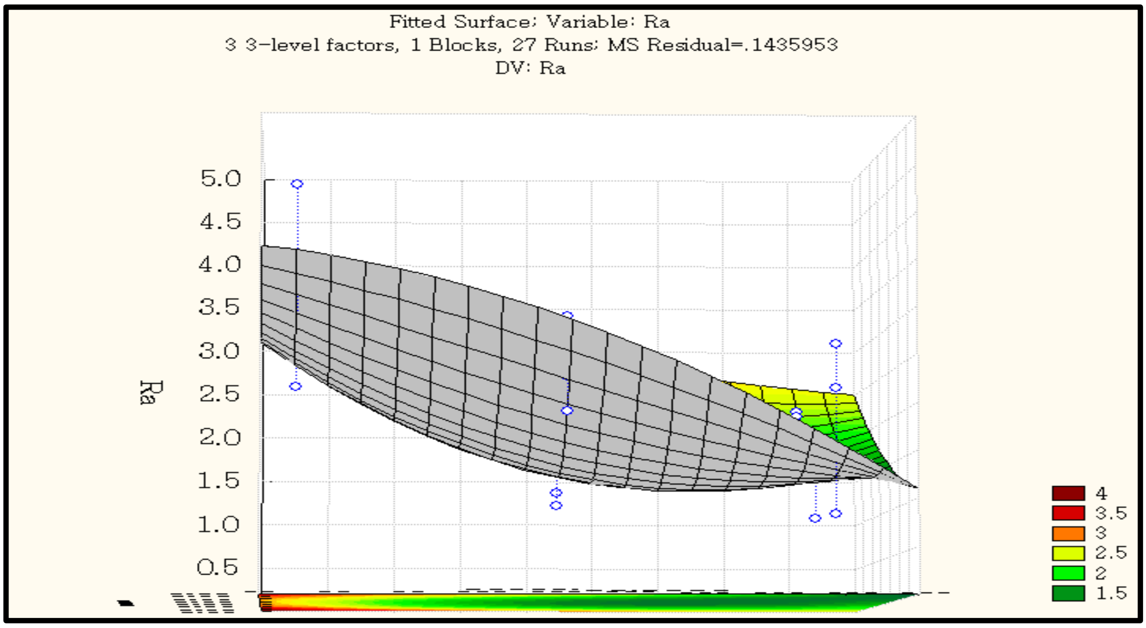

Figure 4.14: Surface Plot of Ra-value versus Feed Rate and Cutting Speed with a Depth of Cut of 0.6mm

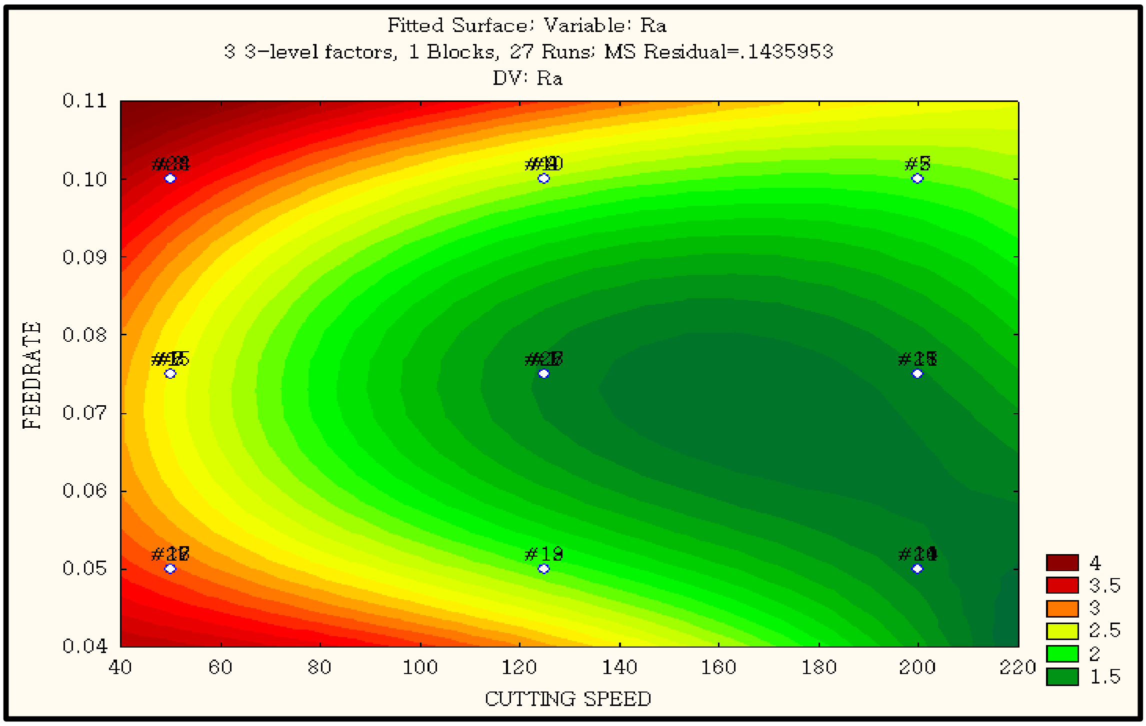

Figure 4.15: Contour Graph of Ra-value versus Feed Rate and Cutting Speed with a Depth of Cut of 0.6mm

As shown in the Figure 4.14, the predicted lowest Ra value is located in between 1 and 1.5µm but it is closer to 1.5µm at the center of the shape. But, an edge of this surface plot has near to 1µm also. Therefore, contour plot of this graph is generated and shown in Figure 4.15 for further analysis.

From the contour plot in Figure 4.15, the lowest Ra value is not focus at the center of the graph. There has 3 points those are nearest to the lowest Ra value area as shown in Figure 4.15. So, the cutting parameters and Ra value of these points are shown in Table 4.4.

Table 4.4: Cutting Parameters and Ra Value of Specimens Nearest to Lowest Ra Value Area of Contour Plot with Depth of Cut = 0.6mm

Specimen	**Cutting Speed (m/min)**	**Feed Rate (mm/rev)**	**Depth of Cut (mm)**	**Ra (µm)**
15	125	0.075	0.6	1.21
21	200	0.05	0.6	0.87
24	200	0.075	0.6	1.78

In Table 4.4, the lowest Ra value is come from the specimen number 21 which is 0.87µm with the cutting parameters of cutting speed = 200m/min, feed rate = 0.05mm/rev, and depth of cut = 0.6m. But, it might not the optimum surface roughness even it is the minimum surface roughness not only in this separated date set but also in whole experiment. The Ra value of specimen number 21 might be affected by other cutting parameters such as working temperature and vibration. Hence, by follow the trend, the optimum surface roughness in the surface plot of depth of cut = 0.6mm is actually near to the specimen 15, which has cutting parameters of cutting speed = 125m/min, feed rate = 0.075mm/rev, and depth of cut = 0.6mm. Besides that, the Ra value of specimen 15 is 1.21µm.

Therefore, the Table 4.5 showed the optimum specimens and their cutting parameters values. From the Table 4.5, compared all Ra values with the surface plots and contour plots, the optimum surface roughness in decided levels of parameters is found, which is specimen 13 with Ra value of 0.93µm, cutting speed = 200m/min, 0.075mm/rev, and depth of cut = 0.2mm. But, from the plots, that the specimens with decided level of parameters is not exactly located in the area of optimum surface roughness. Therefore, by using STATISTICA, the critical values of cutting parameters and surface roughness can be predicted.

Table 4.5: Optimum Results from Surface Plot and Contour Plot

Depth of Cut (mm)	**0.2**	**0.4**	**0.6**
Cutting Speed (m/min)	200	125	125
Feed Rate (mm/rev)	0.075	0.075	0.075
Ra (µm)	0.93	1.5	1.21

4.3.4 Critical Value Predicted

	Critical values; Variable: Ra (run table3) Solution: saddlepoint Predicted value at solution: 1.291408		
Factor	**Observed Minimum**	Critical Values	Observed Maximum
CUTTING SPEED	50.00000	165.7152	200.0000
FEEDRATE	0.05000	0.0771	0.1000
DEPTH OF CUT	0.20000	0.2702	0.6000

Figure 4.16: Critical Values Predicted from Model of No Interaction

For the critical values prediction, there are two models can be used, which are no interaction model and 2-way interaction with linear x linear model. The 2-way interaction with linear with quadratic model cannot perform the critical values prediction because the STATISTICA set this function is available whenever a quadratic response surface model is used to predict the dependent variable.

From the Figure 4.16, the critical values spreadsheet displays information that identifies the point on the quadratic response surface that is the minimum, maximum, or saddle point of the surface. The critical value is the optimum surface roughness value, which is 1.291408µm, cutting speed is 165.7152m/min, feed rate = 0.0771mm/rev, and depth of cut is 0.2702mm.

Factor	Critical values; Variable: Ra (run table3) Solution: saddlepoint Predicted value at solution: 1.255311 Observed Minimum	Critical Values	Observed Maximum
CUTTING SPEED	50.00000	165.3428	200.0000
FEEDRATE	0.05000	0.0761	0.1000
DEPTH OF CUT	0.20000	0.4028	0.6000

Figure 4.17: Critical Value Predicted from Model of Linear x Linear Interaction

Figure 4.17 showed the critical values of the 2-way interaction with linear x linear model. The optimum Ra value is 1.255311µm, cutting speed is 165.3428m/min, feed rate is 0.0761mm /rev, and depth of cut is 0.4028mm.

Compared to the Figure 4.16, the Ra value showed in Figure 4.17 is lower. Besides that, the cutting speed and feed rate only have slightly differences between both Figures 4.16 and 4.17, while the value of depth of cut in Figure 4.16 is lower than the value showed in Figure 4.17, which is 0.2702.

Anyway, several reason that the results should follow the 2-way interaction with linear x linear model. Firstly, the R^2 value of 2-way interaction with linear x linear is higher than the no interaction model, which is 0.8692. Secondly, the optimum average surface roughness value, Ra value is lower in 2-way interaction with linear x linear model which is 1.255311µm. Besides that, the mean square residual for 2-way interaction with linear x linear model is lower than the no interaction model which is 0.1651387. Furthermore, the errors in sum square and degree of freedom are also lower than the no interaction model; which are 2.80736 and 17 respectively.

Therefore, the final optimum cutting parameters and surface roughness are shown in Table 4.6.

Table 4.6: Final Optimum Values of Cutting Parameters and Surface Roughness

Parameter	**Value**
Cutting Speed (m/min)	165.3428
Feed rate (mm/rev)	0.0761
Depth of Cut (mm)	0.4028
Surface Roughness (µm)	1.2553

4.5 SUMMARY

After a lot of analysis methods, from ANOVA tables to table of predicted critical value, finally the optimum cutting parameters are investigated and also the optimum surface roughness. The predicted critical values of cutting parameters and surface roughness from 2-way interaction with linear x linear model are chosen as final optimum cutting parameter and the optimum surface roughness because the linear x linear interaction model has a higher value of coefficient of determination, R^2 compared to the model of no interaction, which is 0.8692. The final optimum cutting parameter values are cutting speed = 165.3428 m/min, feed rate = 0.0761 mm/rev, and depth of cut = 0.4028mm while the optimum surface roughness = 1.2553µm.

The minimum average surface roughness value from Table 4.1 is 0.87µm which is Ra value of specimen number 21 is not chosen to be the optimum surface roughness is because it is the minimum value of the experiment work but not optimum value. After the analysis from surface plot and the contour plot, the specimen number 21 does not shown it is located at the optimum surface roughness area.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter is provided a conclusion of this study in terms of achieving or meeting the project objectives. The conclusion is carried out by summarizing the overall progress of the study and concluded the results and discussion. Besides that, for future reference, several recommendations are enlisted as a subchapter in this chapter for enhancement of knowledge in continuing this research of surface roughness in dry machining.

5.2 CONCLUSION

In conclusion, to optimizing the surface roughness, a multi-factorial design of experiment can be carried out better and more accuracy result. A full factorial design of experiment with 3 levels of 3 factors is generated by using STATISTICA software version 7.1. By generated ANOVA tables in 3 different models gave a better comparison between ANOVA tables. Therefore, the optimum cutting parameters can be investigated by choosing the highest coefficient of determination model of ANOVA table, and hence the optimum surface roughness can be investigated by high accuracy and precisely prediction of STATISTICA software.

From the result analysis, all 3 cutting parameters chosen which are cutting speed, depth of cut, and feed rate can affect the surface finish of the AISI 1019 carbon steel throughout the dry turning process. After the analysis using STATISTICA software, the results show that there are only 2 factors which are significant factors can affect the surface roughness with a level of confident greater than 95%. The 2 significant factors are cutting speed and feed rate while the depth of cut is not significant factor, and it is shown in Figures 4.4, 4.5, 4.6, 4.7, 4.8, and 4.9 Hence, the optimum cutting parameters are investigated after result analysis from Figure 4.17 are cutting speed is 165.3428m/min, feed rate is 0.0761 mm/rev, and depth of cut is 0.4028mm. Thus, the optimum surface roughness is investigated with a value of Ra is equal to 1.2553 µm.

With these optimum cutting parameters investigated, the industries can apply them into their turning operation by using lathe machine of Pinacho S90 VS/180 only in order to get the desired or acceptable surface roughness on AISI 1019 mild steel. Thus, the negative effects of improperly use of cutting fluids such as environment pollutions, health hazards and waste of cost can be decreased.

5.3 RECOMMENDATIONS

There are some recommendations have to be considered in improving the accuracy of the result obtaining and the skills of better performing of this study. In this study, include also

- More factors such as tool length, vibration, work temperature, tool nose radius and so on, and higher level of these factors can be applied in order to investigate the optimum surface roughness more accurate. It is because the more factors taking into consideration with higher level of each parameter will generate more tests and hence the surface roughness can be optimized more accurate.
- More different types of materials and more different types and sizes of cutting tools. With this, more results can be investigated and more applications of dry machining can be applied in industries in the future.
- Another model of lathe machine can be used in order to investigate more results. Different model of lathe machine has different capability and hence, the optimum cutting parameters will also different and also the optimum surface roughness.

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APPENDIX A

Gantt Chart for Final Year Project 1

Job \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discussion ocjective															
Search suitable Literature Review															
Discuss Methodology															
Chapter 1															
Chapter 2															
Chapter 3															
Report Submit															
Preparation for Presentation															
Presentation															

APPENDIX B

Gantt Chart for Final Year Project 2

Job \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cut Work Piece															
Run First Test															
Learn STATISTICA software															
Generate Table of Run															
Run Dry Turning Operation															
Surface Roughness Measurement															
Analyze Result															
Thesis Chapter 4															
Thesis Chapter 5															
Prepare for Presentation															
PSM 2 Presentation															
Submit Full Thesis															