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JUDUL: PREDICTION OF GRINDING MACHINABILITY WHEN GRIND ALUMINIUM ALLOY USING WATER BASED COOLANT

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PREDICTION OF GRINDING MACHINABILITY WHEN GRIND ALUMINIUM ALLOY USING WATER BASED COOLANT

JAMILAH BINTI MUSTAFHA

BACHELOR OF MECHANICAL ENGINEERING WITH MANUFACTURING ENGINEERING

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PREDICTION OF GRINDING MACHINABILITY WHEN GRIND ALUMINIUM ALLOY USING WATER BASED COOLANT

JAMILAH BINTI MUSTAFHA

Report submitted in partial fulfillment of the requirements for the award of the degree of
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FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled “Prediction of Grinding Machinability when Grind Aluminium Alloy using Water Based Coolant” is written by Jamilah Binti Mustafha. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality of the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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SUPERVISOR'S DECLARATION

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

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Specially dedicated to
my beloved family and those people who have guided and inspired me
throughout my journey of education

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ABSTRACT

Optimization of parameters for the surface quality of material is very important for this research because of higher demands for surface finishing products especially in the manufacturing process. More researchers have tried various methods in order to reduce production cost and to produce very economical machining process. One of the most common machines in the finishing process of the product is grinding machine. For this thesis, the present study involves prediction of grinding machine when grinds aluminium using water based coolant. This thesis has been run to find optimum parameters such as wheel wear and depth of cut. Different number of passes which are single pass and multi pass with different parameters will be studied and compared. Another objective of this thesis is to investigate surface roughness produced during grinding process. Prediction model of surface roughness was developed to present accurate data. The selected material for this study was Aluminium Alloy 6061 T6 and was used water based coolant as cooling lubrication. Experiments were conducted based on Design of Experiment (DOE) and the Neural Network is employed to find optimum parameters and predicted of surface roughness and wheel wear for the selected material. These experiments were divided into two by using two different grinders which are aluminium oxide and silicon carbide. The surface roughness was measured at every increment of 2μm depth of cut. The results have found that the surface roughness increased when the depth of cut increased while the surface roughness decreased when number of passes increased. Besides, the surface quality becomes smoother when using Aluminium Carbide as grinder compared to Silicon Carbide.

ABSTRAK

Pengoptimuman parameter untuk kualiti permukaan bahan produk adalah sangat penting untuk kajian ini kerana permintaan yang lebih tinggi bagi kemasan permukaan produk terutamanya di dalam proses pembuatan.Pada masa dahulu, ramai penyelidik telah mencuba pelbagai kaedah untuk mengurangkan kos pengeluaran dan menghasilkan proses pemesinan yang menjimatkan.Salah satu mesin yang biasa digunakan bagi proses kemasan produk ialah mesin pemipisan. Kajian ini melibatkan ramalan pengisaran pemesinan apabila mengisar aluminium alloy menggunakan penyejuk berasaskan air. Tesis ini telah dijalankan untuk mencari parameter yang optimum seperti kelajuan, diameter dan kedalaman pemotongan. Jumlah laluan pemipisan dengan parameter yang berbeza akan dikaji dan dibandingkan. Objektif yang lain untuk tesis ini adalah untuk menyiasat jenis kekasaran, suhu permukaan, dan memakai dihasilkan semasa eksperimen. Model ramalan kekasaran permukaan telah dibangunkan untuk mempersembahkan data. Bahan yang dipilih untuk kajian ini adalah Aluminium Aloi 6061 T6 dan penyejuk berasaskan air digunakan sebagai pelinciran. Eksperimen telah dijalankan berdasarkan Reka bentuk Eksperimen (DOE) dan Rangkaian Neural digunakan untuk mencari parameter yang optimum dan menganalisis kesan parameter terhadap kekasaran permukaan untuk bahan yang dipilih. Eksperimen ini telah dibahagikan kepada dua dengan menggunakan dua pemipis yang berbeza iaitu Aluminium Oksida dan Silikon Karbida. Kekasaran permukaan diukur pada setiap peningkatan kedalaman 2µm potongan.Keputusan telah menunjukkan bahawa kekasaran permukaan meningkat apabila kedalaman pemotongan meningkat manakala kekasaran permukaan menurun apabila jumlah laluan pemipisan meningkat. Selain itu, kualiti permukaan menjadi licin apabila menggunakan Aluminium Oksida sebagai pemipis berbanding dengan Silikon Karbida.

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LIST OF ABBREVIATIONS

AA	Aluminium Alloy
r	R-squared
n	Total number depth of cut
x	Depth of cut
y	Surface roughness or wheel wears results
MSE	Mean Square Error
MAPE	Mean Absolute Percentage Error
MAD	Mean Absolute Deviation
y_t	Actual value
$\bar{y}_t$	Predicted value
Si	Silicon
Cu	Copper
Mn	Manganese
Mg	Magnesium
Cr	Chromium
Zn	Zinc
Ti	Titanium
Fe	Iron
HP	Horse Power
RPM	Revolution per Minute
ANN	Artificial Neural Network
Ra	Surface roughness
SiC	Silicon Carbide
Al_2O_3	Aluminium Oxide
ZnO	Zinc Oxide
AE	Absolute Error
ARE	Absolute Relative Error

TRN	Training
TST	Testing
VLD	Validation

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Nowadays, more researcher in modern machining industries is mainly focused on the achievement of high quality, in terms of work piece surface finish or less wear on cutting tools, and also the economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact.

Besides that, the quality of any products is depending on surface roughness because the increase of surface roughness will cause the quality product also decrease. Surface roughness and wear are important roles in many areas and factors of great importance the evaluation of machining accuracy. In this scenario, the grinding process was chosen for this project to get optimum parameters. There has been high demand for better adequacy of industrial grinding process in order to meet the present requirements of standardization and safety.

The selection of material type also needed in this project. Aluminum Alloy 6061 T6 was used as the work piece for this project. The main reasons are because the aluminium alloys are extensively used in engineering structures and have many properties of behaviour and several type series in the world which are 1xxx until 7xxx series.

1.2 PROBLEM STATEMENT

The findings of optimum parameters in grinding process are very important due to challenges in modern machine nowadays especially in terms of surface quality and also low cost manufacturing. Besides that, the effect of coolant very important in order to reduce surface cracking and subsurface damage and to prevent high temperature occurs during grinding process. This need to avoid ensuring that good surface quality was produced. Therefore, water based coolant is using to see the consequences. The suitable depth of cut is also needed because it can affect the surface texture have been rougher and the surface is not shining. The results of the experiment must consider in different perspective of the parameter to get accurate results.

1.3 OBJECTIVES

From the discussion above, this project has set three objectives:

1. To find the optimum parameters of grinding process (depth of cut).
2. To investigate surface roughness produced during grinding process.
3. To develop prediction model of surface roughness using artificial neural network.

1.4 SCOPE OF STUDY

In the present study, the grinding parameters and variables will be considered is the depth of cut (μm), number of passes of (n), abrasives material and type of coolant. Table speed is set as constant for the whole experiments with 200 RPM. Two abrasive materials which are silicon carbide and aluminium oxide were used as a grinding wheel. Eighteen number experiments will be conducted for every single pass and multi-passes grinding. A range of thirty six experiments will be expected to be running on the aluminium alloy. The surface roughness of different number of passes and abrasives material with different depth of cut will be studied and compared.

In analyzing the data in this project, it will see based on the surface roughness and wear produced by adjusting the parameters of the material example depth of cut and number of passes when using water based coolant.

After finishing conduct all experiments, all the data will be gathered and will be plotted in a graph based on data obtained. The results will be analyzed by using neural network software. Then, the results will be interpreted to state the discussion, conclusion and to summarize the objective of the project.

1.5 THESIS ONLINES

This present study is organized into five chapters. The first chapter has been discussing the project background, problem statement, objectives, and also the scope of the work of this project. Chapter two discussed the literature review of the project. It focused on recent studies that approximately close to the titles. The literature reviews very important to predict the result for the project based on the previous results and knowledge from the journals, books and internet. Chapter three represents the research methodology, design of experiments and application tools have been used in this present study. Chapter four represents the result of this project and then discussion of the overall result based on all data obtained. This present study will summarize in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the background of grinding machine, response surface method and aluminium alloy. This chapter also will focus on recent studies or research by authors related to the effect of grinding process parameters on surface roughness, temperature and wear of aluminium alloy or approximately close to the titles of the project.

2.2 THE GRINDING PROCESS

Almost every manufacturing process requires a final machining process in order to get smooth surface and fine tolerances. Thus, grinding process is very important in the manufacturing process because it plays as sharpen cutting tools for drilling, turning and milling. The objective of a grinding process is to remove material as quickly and efficiently as possible with little concern for surface quality (S. Malking and C.Guo, 2008). Grinding also is a finishing machining or operations by removing a small amount of material during the process. Grinding used to improve surface finish for any shape and geometry of hard material (E. Mehmood, n.d).

One of the advantages the grinding process is it becomes more economical as a single process for machining directly to the final dimensions without the need for prior turning and milling.

The most common of the grinding process is surface grinding process even though there are many types of grinding in manufacturing and machining industry. The grinding process is very important because it can produce surface finishes from rough to extremely fine. The surface grinding machine also used for grinding flat surfaces as we can see in the figure below. The specification of surface grinding machine is it has a magnetic table to place the work piece.

In grinding machine, the speed of power driven grinding wheel is determined by wheel's diameter. Work piece stays in fixed position and machine vice required to hold the work piece tightly. Only the machine table will move right and left during the grinding process. Coolant tube is used to provide water- based coolant when operation is running (T.J. Vickerstaff, 1973).

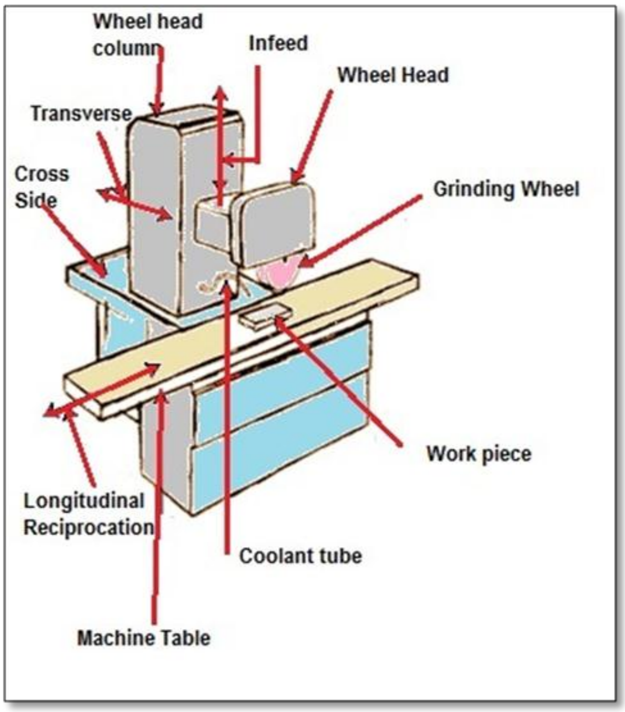


Figure 2.1: Surface Grinding Machine used in the present study

From the research, grinding machines can be classified as utility grinding machines, cylindrical grinding machines and surface grinding machines. Surface grinding machines generally have horizontal wheel spindles and mount straight or cylinder-type grinding abrasive wheels. From the Figure 2.1, we also can see that the work piece is supported on a rectangular table which moves back and forth and reciprocates beneath the grinding wheel. The function of coolant tube is to drain the coolant during the machining. It also can reduce excessive friction between work piece surface and grinding wheel.

S. Kalpakjian (n.d) mentioned that grinding machines are used for cutting off steel, especially tubes, structural shapes, and hard metals. In grinding operations, grinding users can choose two techniques in grinding whether to use single-passes grinding and multi-passes grinding. A grinding wheel with a large grit size result in a large damage depth to the ground work piece in single-pass grinding while in multi-pass grinding, machine stiffness becomes less important than in a single pass grinding in terms of stock removal rate and wheel (B. Zhang, et al., 1999).

2.2.1 Specification of Surface Grinding Machine

Surface grinding is the act of producing and finishing flat surfaces by means of a grinding machine employing a revolving abrasive head. The maximum speed of surface grinding machine is 2800 RPM. It also has a magnetic table to place the work piece. The cylindrical shaped job can't be machined by this grinding machine, but only flat jobs can be machined.

The reciprocating surface grinding machine is a horizontal type surface grinding machine. The work pieces are fastened to the work piece table. It can be moved beneath the grinding abrasive wheel by hand or power feed. A magnetic chuck may be used for fastening the workpiece to the table (Figure 2.2).

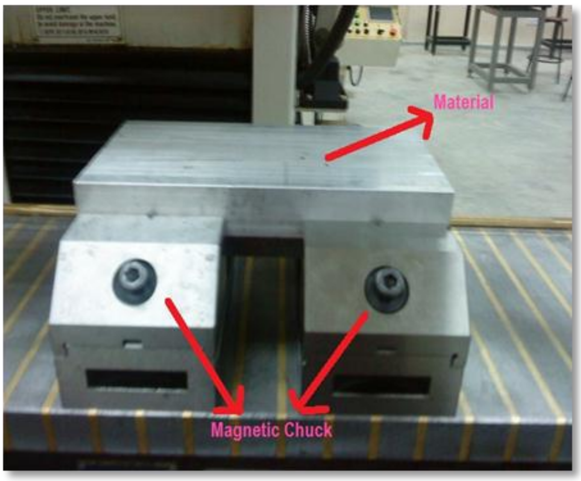


Figure 2.2: Magnetic chuck

2.2.2 Horizontal Grinding Machine

The society today has more advantages compared to old society in manufacturing process fields. Old society using traditional machines to get the best and smooth surface finish of any materials and products. But today, due to technology development, the modern machines such as milling, turning, drilling, and others have used in the manufacturing process. A horizontal grinding machine also always used as we can see in Figure 2.3.

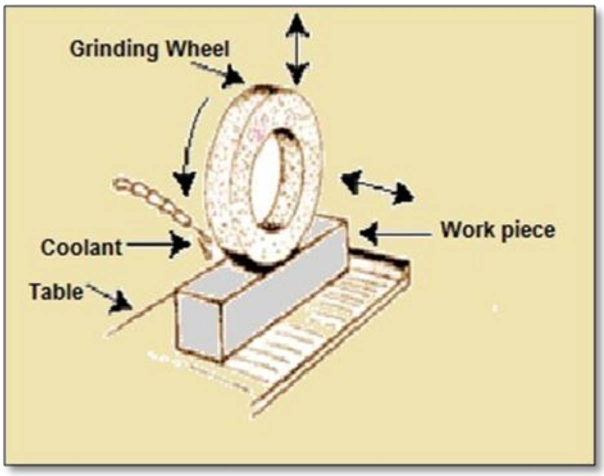


Figure 2.3: Horizontal Grinding Machines

Horizontal surface grinding used in tool making work of small production work to large sizes used production work. It also ranges from small capacity (S. Kalpakjian, n.d).

2.2.3 Grinding Wheel

S. Malking and C. Guo (2008) stated that the abrasive materials of greatest commercial importance are included aluminium oxide (Al_2O_3), silicon carbide (SiC), cubic boron nitride (cBN) and diamond. Aluminium oxide with 2100 relative hardness used to grind steel and other ferrous and high-strength alloys. SiC is harder than Al_2O_3, but not as tough and the value of hardness is 2500. It also cannot be used effectively for grinding steel because of the strong chemical affinity between the carbon in SiC and the iron in steel. cBN is produced under the trade name Borazon by the General Electric Company. It has 5000 of relative hardness. Borazon grinding wheels are used for hard materials such as hardened tool steel and aerospace alloys. Diamond wheels are generally used in grinding applications on hard, abrasive materials such as ceramics, cemented carbides and glass. It also occurs naturally with relative hardness is 7000.

Mostly, silicon carbide and aluminium oxide are always used in the laboratory and also in manufacturing industry. These two types of abrasive are suited to different materials as we can show in Table 2.1 below (S. Malking and C. Guo, 2008).

Table 2.1: Types of abrasive wheel with suited materials

Type of abrasive	Materials
Silicon Carbide	- Gray and chilled iron - Aluminium and copper - Brass and soft bronze - Cemented carbide - Very hard alloys - Others
Aluminium Oxide	- Alloy steels - Carbon steels - Wrought iron - Hard bronzes - High speed stells - Annealed malleable iron - Others

The factors affecting the grain size, the grade of hardness, the structure and bonding materials are depends on the ductility of the material. It also can affect the results form when grind, so much better selected the suited abrasives when grind materials.

Abrasive particles and bonding material was consists in a grinding wheel. The bonding material in a grinding wheel holds the particles in place and then establishes the shape and structure of the wheel. These two ingredients, and the way they are fabricated; determine the parameters of the grinding wheel, which are: 1) abrasive material, 2) grain size, 3) bonding material, 4) wheel grade and 5) wheel structure (S. Malking and C. Guo, 2008).

In the grinding process, the preparation of grinding tools is the most important factor. Mechanical, thermal and chemical loads are applied to the grinding wheel during the grinding process. The wear is one of the effects these loads, where macro wear describes the deterioration of the macro geometry which consists of radial wear and edge wear. Conditioning is the veil in front of the grinding process since the condition of the grinding wheel severely influences the grinding result (K. Wegner, et al., 2011). Besides that, the rate of material removal depends upon the process variables such as wheel parameters, speeds, machine and coolant (R. Gupta, et al., 2000).

2.2.4 Grinding Wheel Dressing

S. Kalpakjian (n.d) mentioned that there are many types of wheel dressers used to dress the grinding wheel whenever it lost the shape and geometry such as diamond, dresser, and abrasive stick. The wheel dresser as we can see in the figure above is fixed into a magnetic table at a slight angle to the grinding wheel and driven by the contact with the wheel. Dressing is cutting the face of a grinding wheel to restore its original cutting qualities (J.S Calton, 2009).

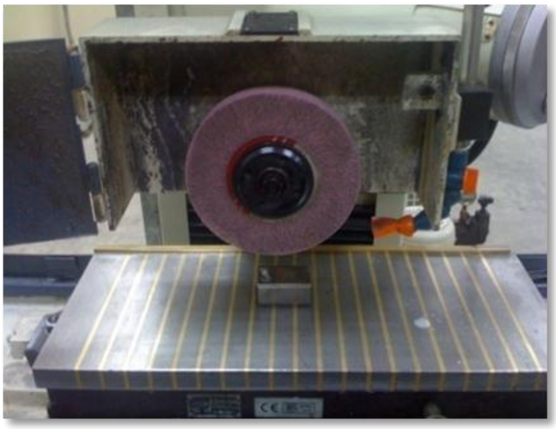


Figure 2.4: Position of dressing grinding wheel

To gain the desired grinding results, it is absolutely necessary to know the influence of the input parameters and their combinations on the dressing result (K.Wegener, et al., 2011).

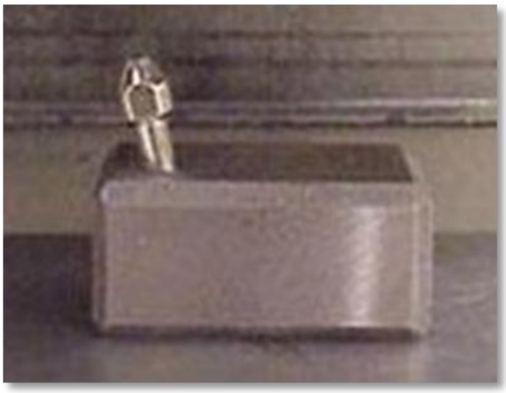


Figure 2.5: Wheel Dresser

Mostly, in the laboratory this type of wheel dresser is commonly used to dress the grinding wheel. Dressing before and after grinding process is very important in order to get the best result and also can improve surface roughness.

2.3 COOLANT

Most grinding operations need coolant to keep the wheel surface clean and provide corrosion protection for newly machines surfaces. Coolant has a high thermal capacity, low viscosity, is low-cost, non-toxic, and chemically inert, neither causing nor promoting corrosion of the cooling system (J.F. Kellya and M.G. Cotterell, 2002). K.Wegener et al. (2011) and C. Heinzel et al. (1999) explained that the friction and wear associated with grinding process will reduce by using lubrication of grinding fluids. Furthermore, the coolant provides the required cooling of the grinding in order to prevent heat accumulation. This heat is formed by the friction that develops in the contact zones between the tool and work piece as well as between tool and chip. Heat generated may cause some burns in some cases, but it can overcome by using the coolant. Therefore, abrasives and work piece will incorporate a coolant to cool the work piece so that it does not overheat and go outside its tolerance (E. Mehmood, n.d).

Nowadays, mostly industry and research institutions are looking for ways to reduce the use of lubricants because of ecological and economical reasons. Some of benefits coolants improves machinability and also increase productivity by reducing the tool wear. The portion of the heat absorbed by coolants and the reduction of heat build-up due to lubrication depends strongly on the cutting process (J.F. Kellya and M.G. Cotterell, 2002).

In many precision machining processes such as surface grinding, coolant is typically used to provide functions such as lubrication and cooling in order to reduce surface grinding temperature (Y. Gao et al., 2003). Green cutting also can become environmental protection and ecological. Water vapor is cheap, pollution-free and ecofriendly. Therefore water vapor is a good and economical coolant and lubricant (J.Liu et al., 2004).

Better surface roughness would be observed by using cutting fluids in machining processes. The selection of cutting fluids for machining processes generally provides various benefits such as longer tool life, higher surface finish quality and better dimensional accuracy. These results also offer higher cutting speeds, feed rates and depths of cut. The product of machining process will be much higher with combination of selecting higher machining parameters (O. Cakir et al., 2007). Every coolant consists of a basic fluid, to which are added other products such as anti-wear, anticorrosion or emulsifying agents (E. Brinksmeier et al., 1999).

2.3.1 Water Based Coolant

In our real life, water is not only important for natural ecosystems and sustaining human communities, but also important for raw material in industry. Every production process uses water for some purposes such as for washing, cooling, fabricating, processing and others.

E. Brinksmeier et al. (1999) explained that coolant for metal working processes can be divided into three which are oil-based coolant, additives and water-based coolant. Oil-based coolant normally consists of 80- 95% basic oil. It can be divided into four groups which are; 1) basic oils without additives, 2) basic oils with chemically active additives, 3) basic oils with surface active additives, and 4) basic oils with chemically active additives and EP-additives.

Water based coolant can be divided into two groups which are water- based solution and water-based emulsion. Water-based solutions consist of inorganic and/ or organic substances while water-based emulsion concentrates contain 20-70% basic oil. Common oil concentrations in emulsions for grinding operations are between two and 15%. Water based coolants contain up to 20 components in which, each of the components can themselves be multi- component mixtures (E. Brinksmeier et al., 1999 and J.F.G. Oliveira1 and S.M. Alves, n.d).

Besides that, water can divide into three types of particle substances which are liquid, gas and solid. It also has several unique properties. For example, water has a high specific heat, so it can absorb a large amount of heat energy before it can hot. Water also can conduct heat easily compared to any liquid excluding mercury.

2.4 EFFECT OF OTHER PARAMETERS ON SURFACE ROUGHNESS

2.4.1 Wheel Speed and Table Speed

Many variables contribute to the ground surface texture as summarized in Figure 2.6 below.

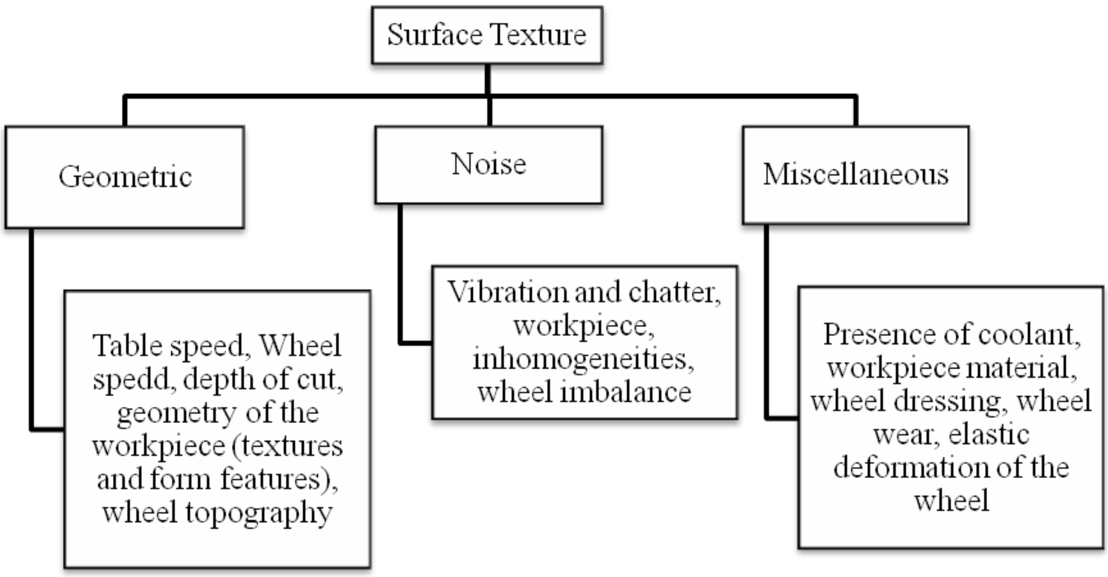


Figure 2.6: Classification of factors affecting the ground surface texture

Source: E.J. Salisbury,K.V.Domala, K.S. Moon,M. H. Miller, J.W. Sutherland, 2011

The geometric factors include the cutting parameters such as wheel speed and table speed, work piece geometry including initial surface texture and form errors, and grinding wheel topography characteristics such as grit size, wheel dressing and wear. The noise factors are disturbances in the grinding environment and are not always significantly involved in the cutting process.

2.4.2 Spindle Speed, Feed Rate and Depth of Cut

A. Mandal et al. (2011) and R. Link et al. (1990) mentioned that the surface roughness mainly depend upon or could be predicted effects with spindle speed, feed rate and depth of cut. The increase in spindle speed produces better surface finish (i.e, reduces the surface roughness). On the other hand, for increased feed rate and depth of cut the value of surface roughness increases. However the effect of depth of cut is least in comparison with feed rate (A. Mandal et al., 2011).

Surface roughness and tolerance are closely intere1ated, as it is generally necessary to specify a smoother finish in order to maintain a finer tolerance in production (S.Malking and C. Guo, 2008).

In a manufacturing process it is very important to achieve a consistent tolerance and surface finish (I.A. Choudhury and M.A. El-Baradie, 1997). The depth of cut is the only significant factor which contributes to the surface roughness. Depth of cut of 1 to 1.5 mm can be used to get the lowest surface roughness (S. Thamizhmanii et al., 2006).

Increase in depth of cut slightly increases the surface roughness values and also increase in feed rate increases the surface roughness. Minimum surface roughness, were obtained at the lowest level of feed rate. The reason being is the increase in feed increases the heat generated and hence, tool wears, which results in higher surface roughness. The increase in feed also increases the chatter, and it produces incomplete machining of work piece, which led to higher surface roughness. The best surface finish was achieved at the lowest feed rate and highest spindle speed combination. The surface roughness decrease as the cutting speed increases (R.Arokiadass et al., 2011).

The most effective control factor on the surface roughness value on the machined surface is feed rate. It has also been observed that feed is the most serviceable factor, still depth of cut and cutting speed play a role as well. The effective parameters for the increase of cutting forces are depth of cut, cutting speed and feed (A. Mustafa, and K.Tanju, 2010).

The surface roughness mainly depends upon predicted effectively with spindle speed, feed rate and depth of cut. The increase in spindle speed produces a better surface finish. On the other hand, for increased feed rate and depth of cut the value of surface roughness increases. However the effect of depth of cut is least in comparison with feed rate (A. Mandal et al., 2011).

2.4.3 Tool Wear

Usually rough surfaces wear more quickly and have higher friction coefficients comparing to smooth surfaces do. Besides that, roughness is one of the best predictor of the performance of a mechanical component. Roughness is difficult and expensive to control during manufacturing although roughness has been usually undesirable. Manufacturing costs will be increased if the surface roughness of a surface decreases (K. Kadirgama et al., 2008).

The component with good surface finish improves the tribological properties, fatigue strength, wear resistant, light reflection, heat transmission, and aesthetic appearance of the product. However, excessively better surface finish may involve higher manufacturing cost. Hence much attention has been paid to estimate the surface finish of the manufactured component and optimum selection of cutting parameters (A. Mandal et al., 2011).

In grinding process, one of the important parameters is the ratio of wheel width to cross feed increment. Increasing this ratio will cause lower wheel wear rates and it improved surface finish. However, increasing this ratio can only be done by accepting a reduced cross feed increment which tends to increase the wheel wear if the wheel width is limited. It always achieved at the higher ratios for these tests minimum wear was, but for wider wheels. At low ratios the steps on the wheel take on a scalloped form which causes excessive an optimum combination of ratio and cross feed increment might be obtained waviness on the work piece surface. The radial wheel wear and surface finish produced are also affected by other grinding conditions. Lower wear rates produce if reductions in table speed and infeed. A better surface finish will obtain when a finely dressed wheel will wear at a much slower rate than a coarse wheel (T. J. Vickerstaff, 1973).

The tool wear while machining aluminium occurs due to abrasion of the free surface. The wear of the free surface depends on the temperature and is caused mainly by abrasion (P. Johne et al., 1994). Wear also depends on the wear resistance of the free surface of the tool.

2.5 EFFECT OF MACHINING ALUMINIUM ALLOY ON SURFACE ROUGHNESS

The quality of the surface produced by machining depends on three independent parameters. Firstly, it depends on the kinematic roughness. The theoretical depth of roughness (peak-to-valley height) is calculated on the basis of the relative movement of the tool and work piece. Then, another independent parameters that influence the material on the quality of the cut surface, adheres to the same rules that apply to the form of chips. The smoother is the surface produced if the higher the strength and hardness of the wrought alloy to be machined. The cutting speed is an important machining parameter which influences the surface quality (P. Johne et al., 1994).

Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy. Many researchers developed many mathematical models to optimize the cutting parameters to get the lowest surface roughness (R.Arokiadass et al., 2011).

2.6 SELECTION OF MATERIAL (ALUMINIUM ALLOY)

Today, we can see that a significant trend in the automotive industry is the increasing use of aluminium alloys. A lot of attention is paid to aluminium alloys and other low-density metals as materials used in transports due to fuel economy.

Besides that, there are many advantages when used aluminium alloy in the industry especially in term of properties. Aluminium alloy has a high corrosion resistance and high electrical conductivity in some environments. It also has a high ductility and this made its alloy easily forged. Due to their high strength-to-weight ratio, aluminium alloys are used extensively in aircraft. It is because pure aluminium metal is much too soft for such uses, and it does not have higher tensile strength that is needed for airplanes and helicopters.

Aluminium and its alloys are invariably worked in the presence of lubricants that most often contain a boundary additive to minimize friction and metal transfer (T. J. Vickerstaff, 1973). Amongst the most machinable of the common metals, aluminium alloys are always used. The major machinability concerned with aluminium alloys includes tool life, chip characteristics, chip disposal and surface finish (J.F. Kellya, and M.G. Cotterell, 2002).

It can be either non-heat-treatable or heat-treatable. The composition of aluminium alloys is regulated by an internationally agreed classification system for each wrought and cast iron as summarized in Table 2.2 below. Aluminium alloy also can be subdivided into two categories which are heat-treatable and non- heat-treatable.

Table 2.2: Classification for wrought aluminium alloys

Wrought	Major Alloying Element
1XXX	Al of 90% minimum purity
2XXX	Al – Cu alloys
3XXX	Al – Mn alloys
4XXX	Al – Si alloys
5XXX	Al – Mg alloys
6XXX	Al – Mg – Si alloys
7XXX	Al – Zn – Mg alloys
8XXX	Miscellaneous alloys

Aluminium is a white silver fish metal and very strong resistance towards corrosion. It is often mixed with other metals like manganese, zinc, copper, magnesium or silicon to form alloys. Aluminium alloys carry the qualities of both the elements and thereby make the alloy better than the constituent elements in many regards. They resist corrosion far effectively and are lighter as well (J.F. Kellya, and M.G. Cotterell, 2002). The elements in alloying aluminium are copper, magnesium, manganese, silicon and zinc. It widely used in engineering structures and components where light weight or corrosion resistance is required.

Same principle requires preparing aluminium alloys such as must be carefully preserved fracture surfaces against abrasion or contamination. Carefully should be taken to cut the material along directions determined by the working process and by other interesting criteria if the part is difficult to handle and has to be sectioned. For example, it can be interesting to examine the evolution of microstructure along the rolling direction if the alloy has been rolled, and so the part must be cut in the same direction. Aluminium alloys are amongst the most machinable of the common metals (E.M. Trent, 1977). The major machinability concerned with aluminium alloys includes tool life, chip characteristics, chip disposal and surface finish (B. Chamberlain, 1979).

The harder and stronger the aluminium alloy will cause the shorter the chips. The machining of aluminium alloys can generate harmful metallic particle although it is easy to machine (V. Songmene et al., n.d).

2.7 NEURAL NETWORK

From the research, there are two different kinds of neural network to evaluate of optimal cutting forces. The neural network has three inputs and four outputs to simulate the machining process. It used as work on back propagation algorithm. The second network is used to calculate the optimal cutting parameters to achieve the goal of maximizing the material removal rate (S. T. Chiang et al., 1995).

The neural network is used to make corrections to the feed rate components with the parametric interpolation algorithm. So it can help to minimize the contour error caused by the dynamic lag of the closed-loop servo systems used to control the table feed drives (A. Mandal et al., 2011).

Generally, the neural network is one of the mathematical models used as prediction of surface roughness in a machining. Among of another mathematical model such as response surface methodology, multiple regression method and others, the neural network method can be more accuracy prediction result of surface finish with lesser computational time.

Figure 2.7 below shows the configuration of the neural network. The neural network can provide the result for any arbitrary value of input data set.

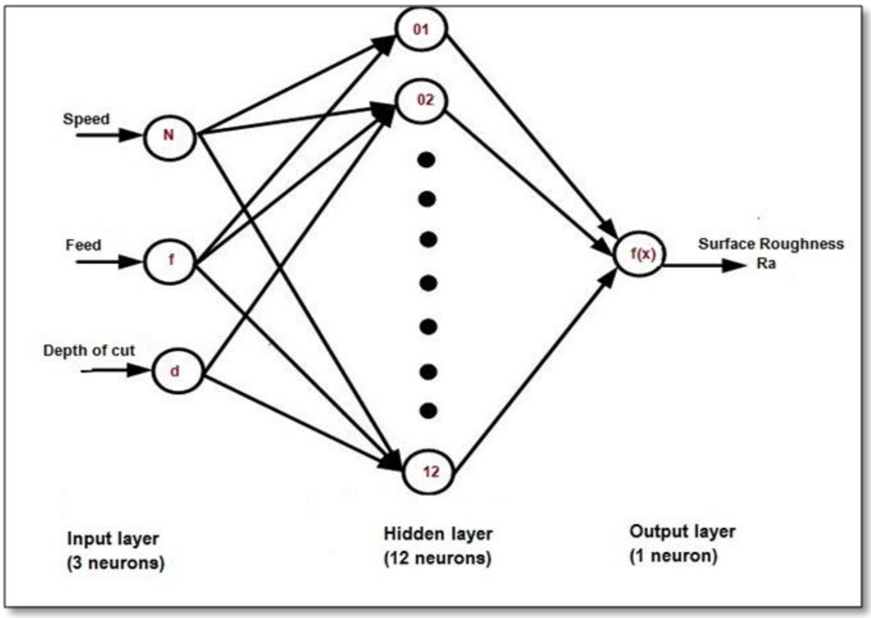


Figure 2.7: Classification of the neural network

Source: Anjan, K.Kakati, M. Chandrasekaran, A.Mandal,and A.K.Singh (2011)

CHAPTER 3

METHODOGY

3.1 INTRODUCTION

This chapter will discuss more details about the flow of this project by analyzing objectively and knowing the properties of material, the grinding machine, design of experiment and others.

3.2 EXPERIMENT SET-UP

The relationship between the surface roughness and wheel wear with the depth of cut of aluminium alloy will be investigated in the present study. The investigation will be conducted by using surface grinding machines. The surface grinding process used is similar to a grinding process as mentioned in the work of Vickerstaff (1973) and Kalpakjian (n.d). The composition for AA6061 T6 used in the present study is given in Table 3.1.

Table 3.1: Material composition of Aluminium Alloy 6061 used in the present study

Alloy Type	Aluminium Alloy 6061 T6							
Composition	**Si**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Fe**
Wt %	0.8	0.4	0.15	1.2	0.35	0.25	0.15	0.7

Four sets of depth of cut will be used to study the relation of surface roughness and wheel wear on aluminium alloy. Every two set of depth of cut will be used same abrasive material with different number of passes in grinding. The aluminium alloy used in the present study is shown in Figure 3.1. The measurements of surface roughness are dividing into three places (A, B and C) and different depth of cut (X, Y and Z) as we can see in the figure below. The averages of each place will be taken to ensure that more or better results were taken.

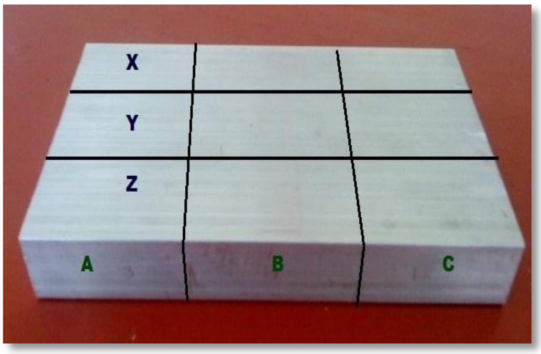


Figure 3.1: AA6061 T6 used in the present study

Aluminium alloys have excellent machining properties compared with other common engineering metals maybe because of aluminium and its alloys have one of the highest coefficients of thermal expansion among the base metals, along with relative softness and elasticity. The properties of aluminium alloys are highly resistant to non heat treatments, hardness, corrosion resistance and ductility. That is why aluminium alloys are perfect choice for different industrial applications. Mechanical properties of aluminium alloys are controlled by a number of principal microstructural features such as grain size and shape, constituent particles and others.

The present study involved the effective variable, which is cutting depth in plunge grinding by using water based coolant. The measured parameters also include surface roughness and wear produced. Nine different numbers of depth of cut will be taken. There are 36 kinds of experiments will be conducted to get the different results of variables and parameters.

3.3 EXPERIMENT PREPARATION

In the present study, a total of four sets of grinding process will run consisting of nine different depths of cut which are 5 μm until 21 μm for each type of abrasive materials and number of passes are required for the present study. For the present study, all experiments will be conducted by using surface grinding machine as seen in Figure

3.2 below to grind AA6061 T6. The reason is that because the geometry of the work piece material used for this project parallel and rectangular.

Figure 3.2: Surface grinding machine used in the present study.

Surface grinding machine has technical specification as shown in Table 3.2 below.

Table 3.2: Technical Specification of Surface Grinding Machine in the present study

Specification	
Working Surface of the table	300mm × 600mm
Maximum height from table to grinding wheel	275 mm
Vertical feed least count	0.01 mm
Cross feed least count	0.05 mm
Micro feed least count	0.002 mm
Spindle speed	2800 RPM
Size of grinding wheel	200 mm × 20 mm × 31.75 mm
Electric motor recommended	2 HP -2800RPM

Figure 3.3: (a) Silicon Carbide and (b) Aluminium Oxide used in the present study

The grinding wheel which was installed on a horizontal surface grinding machine was a silicon carbide type as seen in Figure 3.3 (a) above. Silicon carbide will change with aluminium oxide (Figure 3.3 (b)) after all experimental conducted done. Aluminium oxide is tougher, but silicon carbide is hardness and also can resistance to wear [1]. So aluminium oxide is better suited for grinding steel compared to silicon carbide. Silicon carbide tends to break into shape, so grinding users must be careful to run the experiment with silicon carbide.

In the present study, water based coolant (60% of water and 40% of ethylene glycol) was used as grinding fluid or lubrication because the heat produced during grinding process is critical in terms of work piece quality. Coolant system also separated from machine to eliminate vibration and dissipate heat. Water molecules are the only substance has three physical states of matter which are solid, liquid and gas. It also can absorb large amounts of heat energy because it has a high specific heat.

As we can see in Figure 3.4, Perthometer has a brilliant display and high resolution. Background lighting also can be switched on as needed. Besides that, it also had the integrated, high-resolution thermal printer enables an immediate logging of results, profile, curves and lists, as well as workpiece texts and time. This machine is common use in laboratories as well as can be running for a maximum of 200 measurements; 10 parameters per measuring program.

Figure 3.4: Mahr Perthometer S2 used in the present study

The surface roughness are obtained based on the observation using Mahr Perthometer S2. Roughness measurement by Mahr Perthometer is according to current standard of DIN EN ISO 3274. It's also easy to handle based on the automatic teller principle. Besides that, Mahr Perthometer S2 has a large high resolution graphic to indicate results.

3.4 EXPERIMENT PROCEDURES

In the present study, series of experiment will be conducted on aluminium alloy by using surface grinding machines. The first step of machining is determined the experimental condition for grinding process. Determinations of experimental condition are very important to make sure all experiments can be conducted easily and smoothly and also can eliminate error during the process. The machining process setup includes of two types of abrasives material and number of passes in grinding and had been done repeatedly according to their function.

For the first experiment, silicon carbide was installed into a grinding machine. Then, single-passes grinding was choice for the first setup machining. Single-passes grinding will change with multi-passes grinding after all different depths of cut were taken. Grinding machines actually is set up accordingly depending on their change of abrasive materials, number of passes and parameter in-depth of cut. The work piece is fixed to the machine table by using a machine vice. Machine vice was used in order to hold aluminium alloy tightly during grinding process. Then, the grinding wheel starts rotating with the help of an electric motor and removing material also starts. During the material removal, chip and built up edge has been formed by small cutting edges on abrasive particles and sticks with grinding wheel as seen in Figure 3.5. So it will lose their shape and geometry and affects the result of surface roughness. Dressing must be carried out before and after the grinding process to overcome this error. The coolant must be supplied for each running of the grinding processes to prevent heat generated and spark out between surface work piece and abrasive.

Figure 3.5: Built up edge occurs in grinding wheel after machining

After one passing grinding already done for 5 μm depths of cut, the surface roughness will be measured. Surface roughness were measured by Mahr Perthometer S2 machine as we can see in Figure 3.4. Table speed was constant for all experiments. Because of the grinding machine can't give an actual value of work speed, we decided to use a tachometer as measurement of work speed. The values obtained are analyzed and compared using tabulated data and graphs.

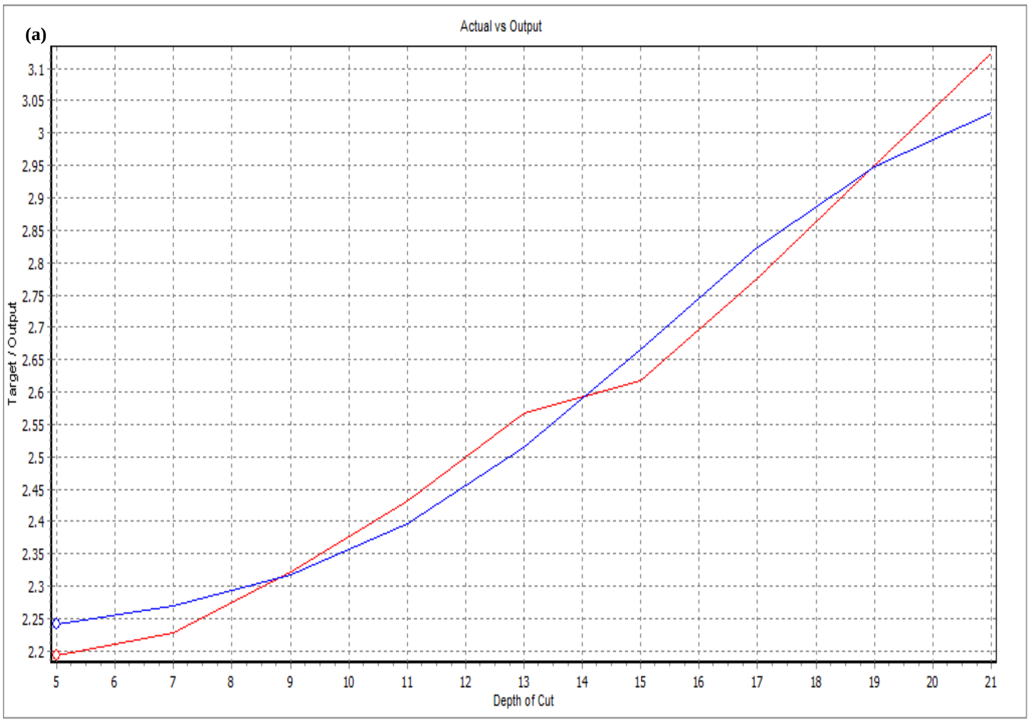
All the data obtained in the present study were recorded in Table 3.3 and Table 3.6 in Appendix A1 and Appendix A2 according to the number of passes in grinding and abrasives used in the present study. All the data obtained will be analyzed by using neural network analysis.

3.5 NEURAL NETWORK ANALYSIS

The neural network has ability to recognize the underlying relationship between input and output data. It is because it was trained to predict an output data based on input data.

In the present study, the analysis of surface roughness and wheel wear are based on the analysis generated by Alyuda NeuroIntelligence based on Quasi-Newton assumption. The analysis is based on information required which are correlations, R-squared, results summary and model graphs as shown in the figure below.

From all the graphs shown in below, increasing depth of cut cause the surface roughness and wheel wear also increases. The red lines represent actual values while the blue lines represent the predicted values. In the present study, the neural network has one input, two hidden layers and 1 output to simulate the machining process. The lower depth of cut gives the smooth surface finish of aluminium alloy.



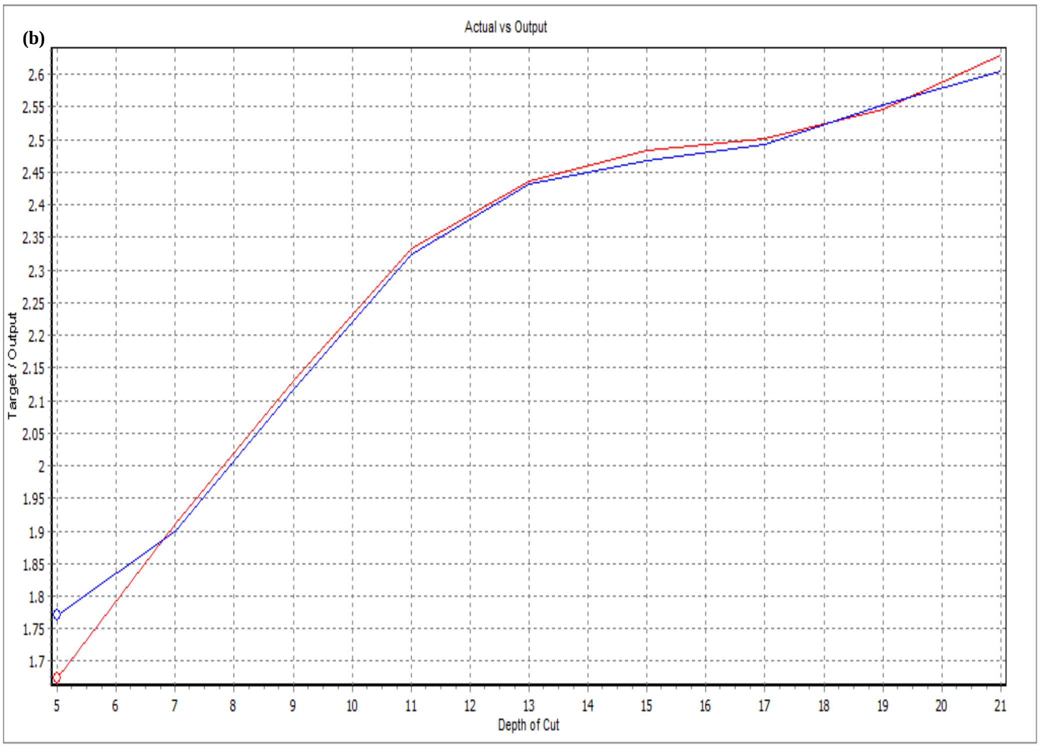
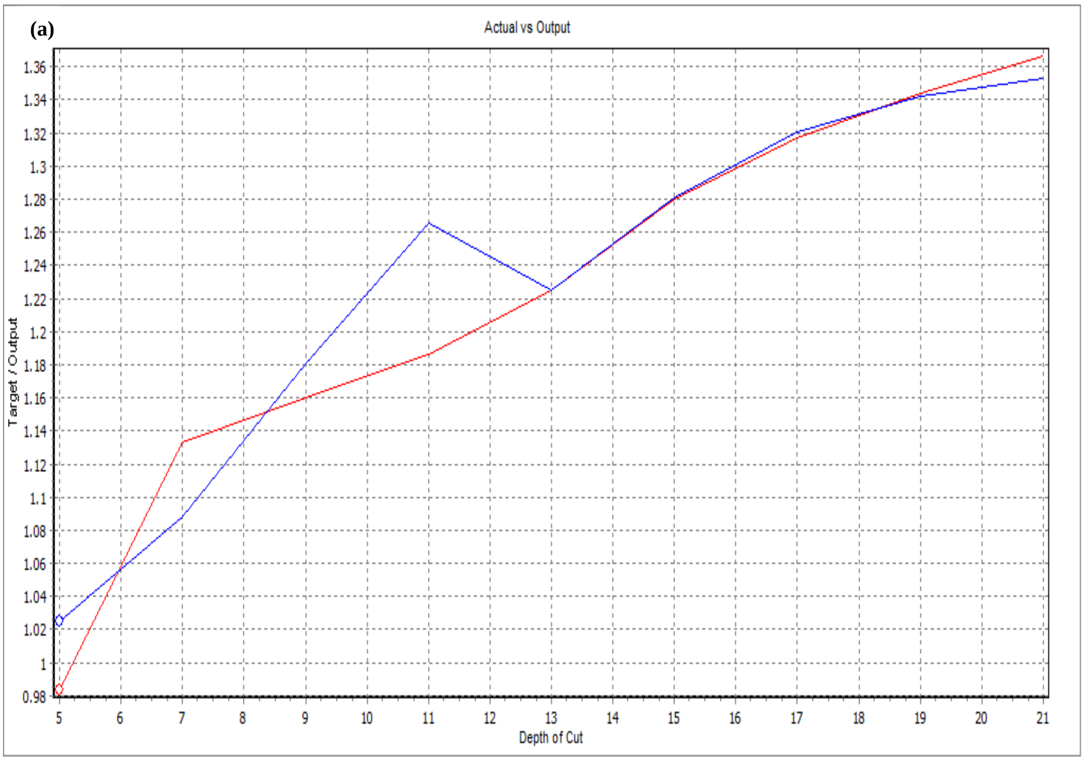


Figure 3.6: (a) single pass and (b) multi pass, Neural Network surface roughness results analysis for Silicon Carbide

The order of the training algorithm in a neural network is not seriously affected the training values. In the present study, the Quasi-Newton algorithm is used to predict the predicted value after the training procedures are finished. The target results as compared to the output values are listed in Table 3.7 until Table 3.10 in Appendix A3 according to the type of abrasives material and number of passes of surface roughness and wheel wear. The output values for both surface roughness and wheel wear are higher than the target value. The reasons for this could be due to compositional changes during the experiment.

In a neural network, the higher value used for iteration process is approximately to 10 000. In the present study, it difficult to training the smallest value of experimental results and needs the higher value of iterations in order to approach a desired target.



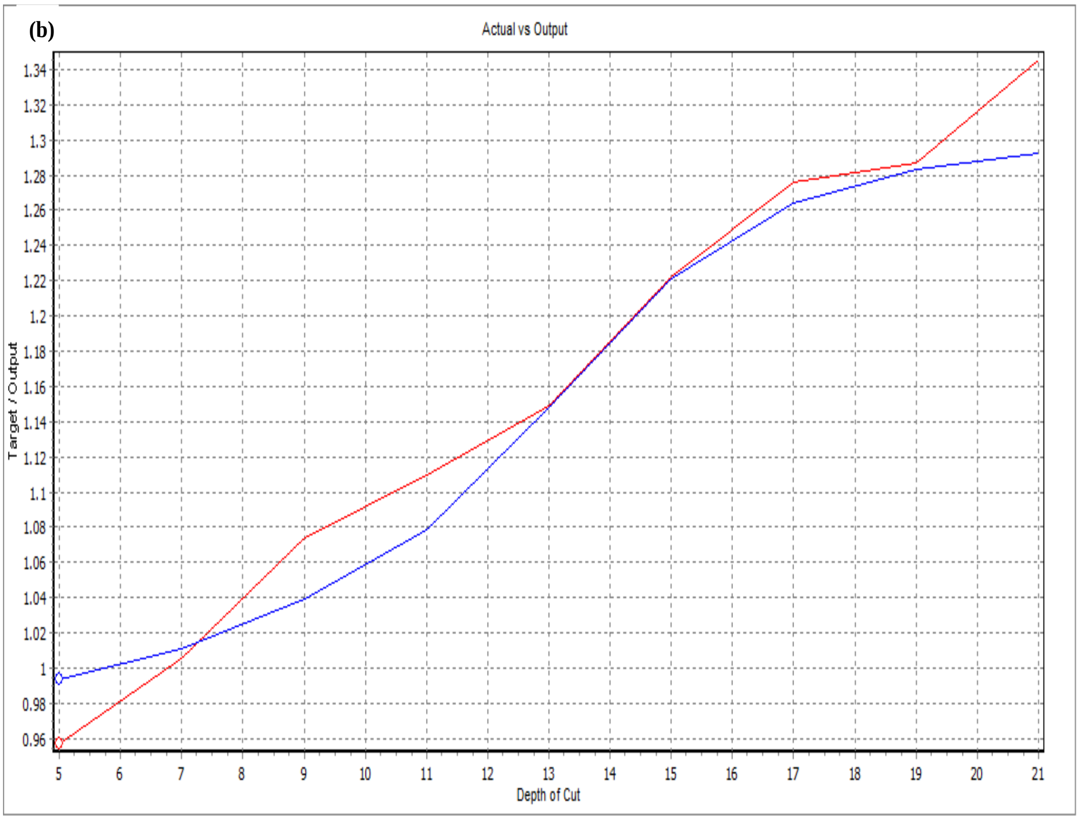
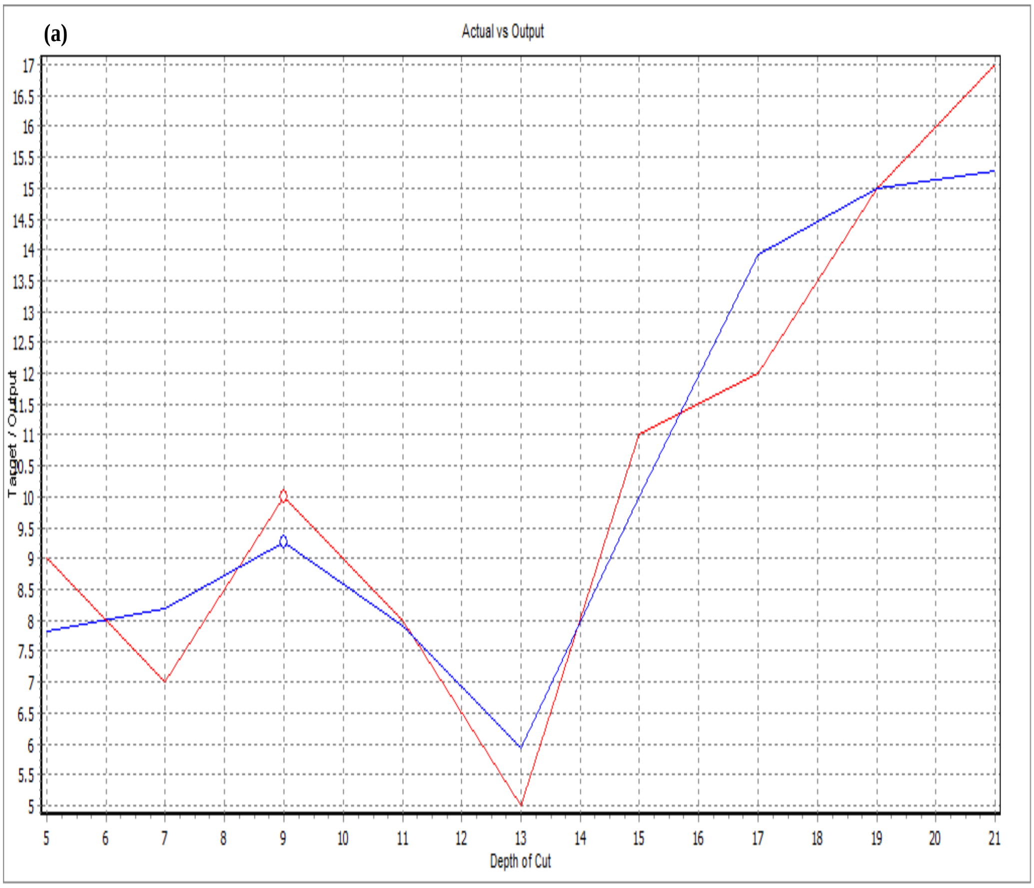


Figure 3.7: (a) single pass and (b) multi pass, Neural Network surface roughness results analysis for Aluminium Oxide

Table 3.11 and Table 3.12 below shows the summary of surface roughness and wheel wear analysis, respectively.

Table 3.11: Summary of surface roughness analysis

Abrasive Material	Number of passes	Correlation	R-squared
Silicon Carbide	Single-pass	0.991339	0.981664
	Multi-pass	0.996335	0.991969
Aluminium Oxide	Single-pass	0.955644	0.894217
	Multi-pass	0.995216	0.987428



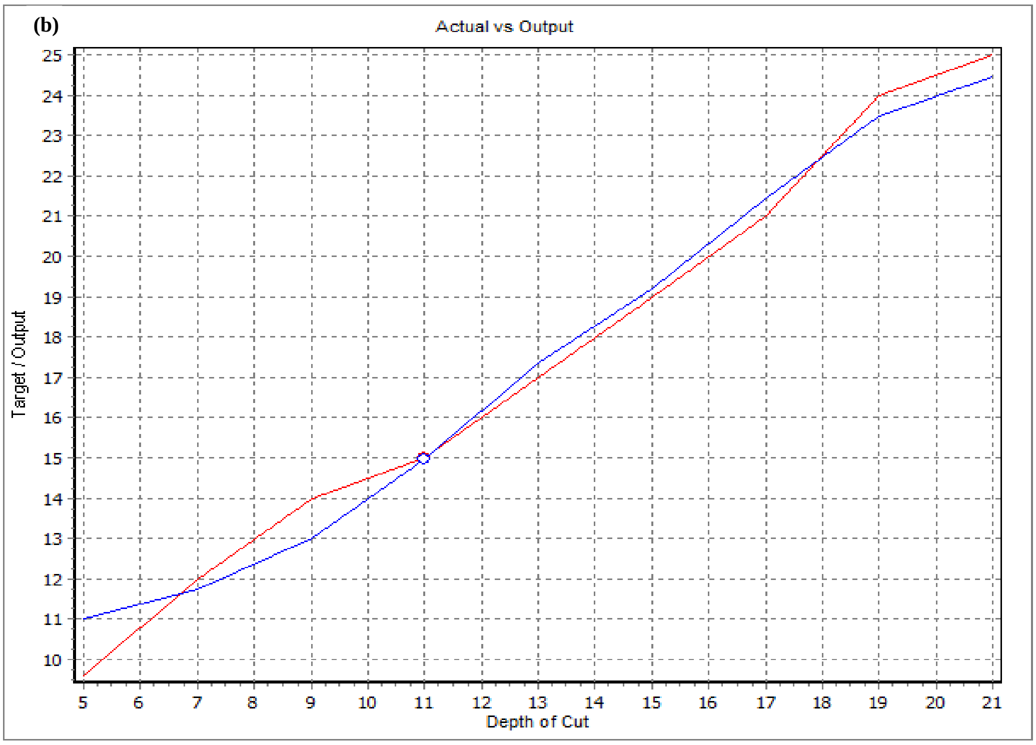
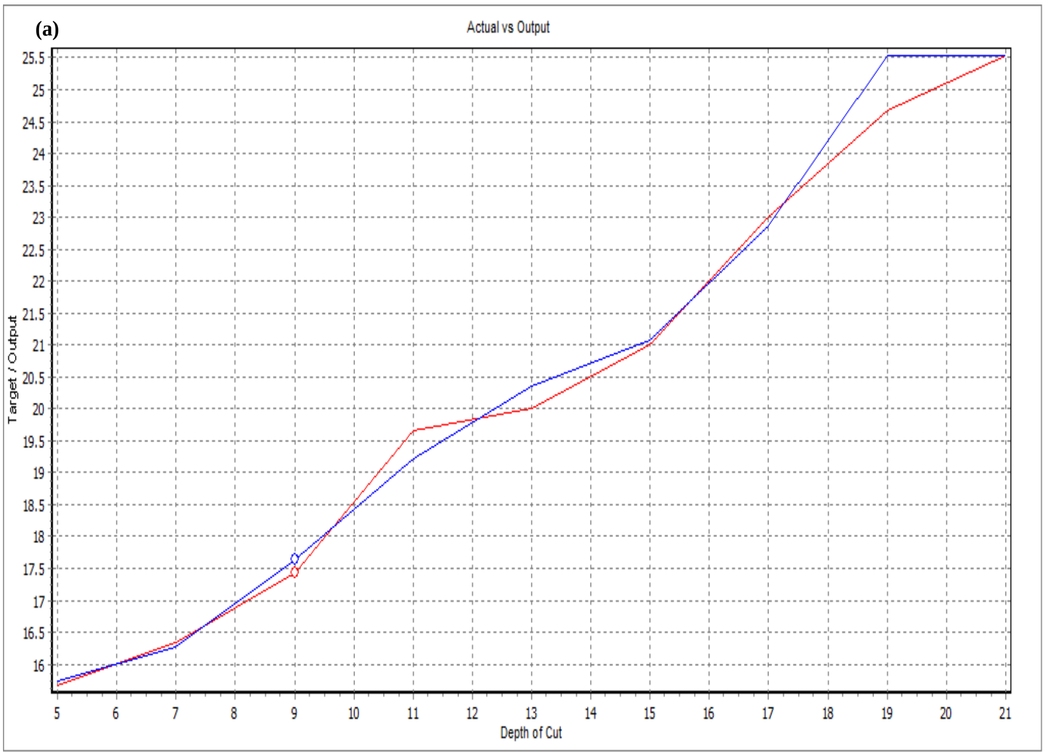


Figure 3.8: (a) single pass and (b) multi pass, Neural Network wheel wear results analysis for Silicon Carbide



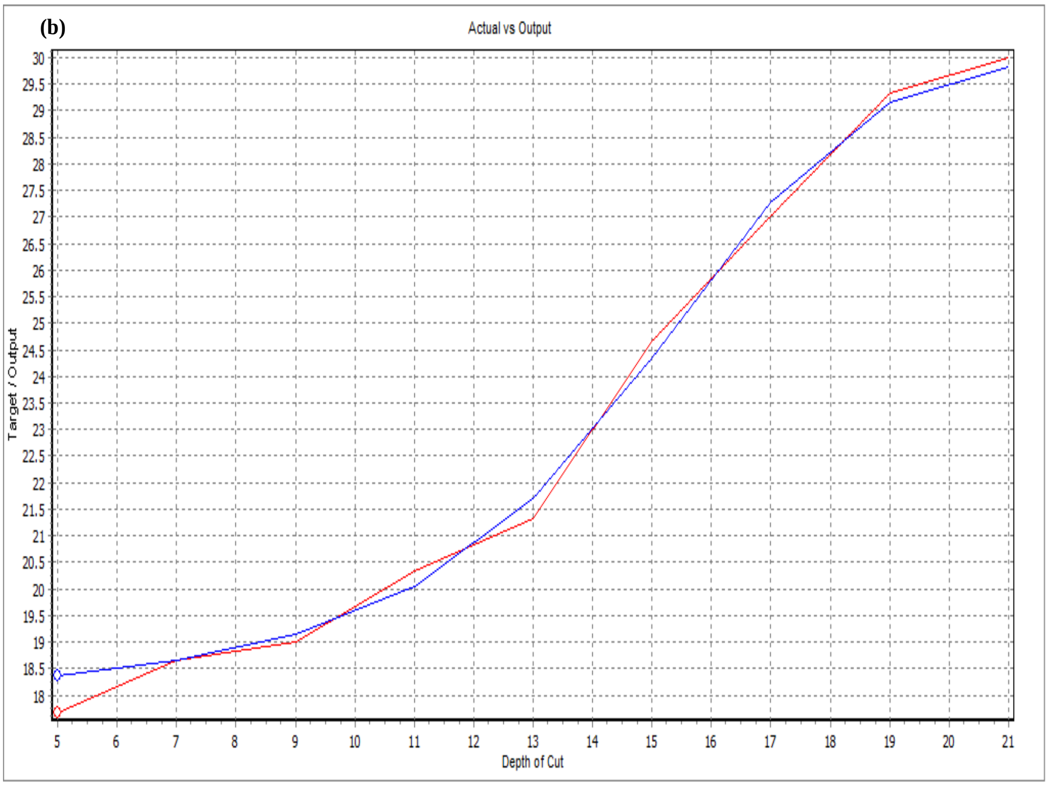


Figure 3.9: (a) single pass and (b) multi pass, Neural Network wheel wear results analysis for Aluminium Oxide

Table 3.12: Summary of wheel wear analysis

Abrasive Material	Number of passes	Correlation	R-squared
Silicon Carbide	Single-pass	0.943341	0.864814
	Multi-pass	0.99779	0.993913
Aluminium Oxide	Single-pass	0.961849	0.886748
	Multi-pass	0.991754	0.87508

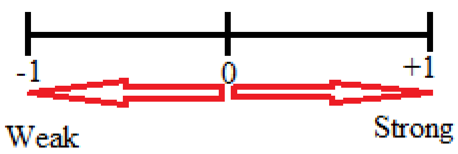


Figure 3.10: Correlation values used in present study

In the present study, the variable depths of cut with surface roughness and wheel wear become stronger if the greater correlation values approach to one as seen in Figure 3.10 above. Higher values of R-squared or if R- squared equal to one means that better predict one term from another. The smallest percentage error means that values are better.From the summary obtained in both tables above, it is proven that the ANN model obtained from predicted value is accurate and effective in predicting. It is because all the value R-squared results shown in Table 3.12 are approaches to 1. The highest percentage error in surface roughness is 10.6 % while in wheel wear is 13.5%.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The major impact of surface roughness on applications involving fluid dynamics, heat transfer, thermal resistance, abrasive process and others are influenced by some parameters such as workpiece material mechanical properties, number of passes and the types of coolant. In the present work, the effect of these parameters on finishing characteristics like material removal and surface roughness are studied.

4.2 EXPERIMENTAL RESULTS

4.2.1 Surface Roughness

The observations of the results are analyzed by using neural network software, perthometer and metallurgical microscope. The number of experiments generated by Surface Grinding Machine which produced 36 runs of experimentation with different number of passes and grinder. Therefore, this experiment divided into four studied which are using Aluminium oxide and Silicon Carbide with two different numbers of passes for each grinder. The table speed for all experiments was constant that is 200 RPM.

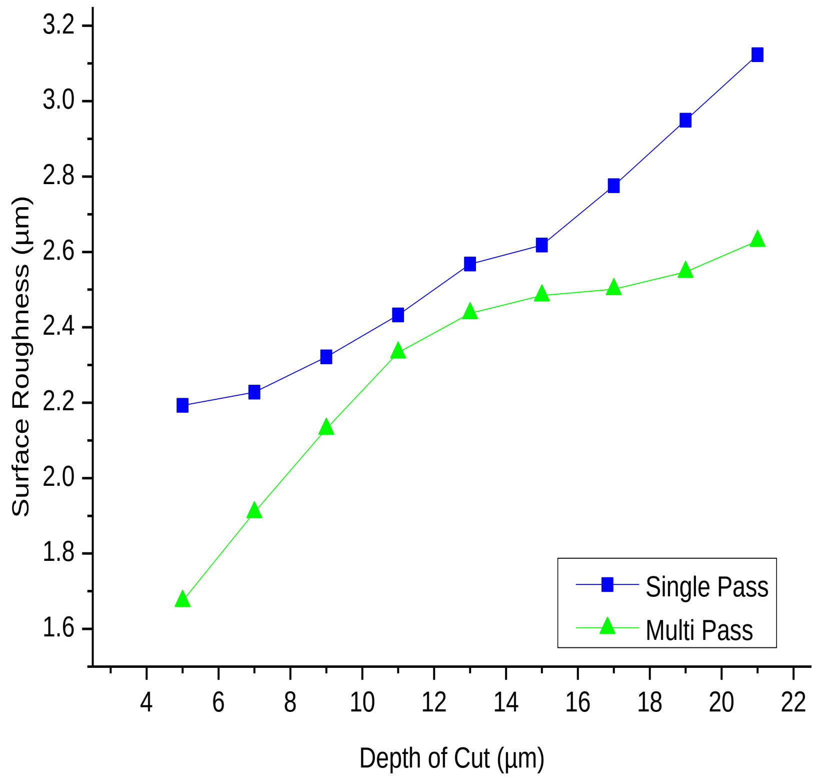


Figure 4.1: Relation between surface roughness and depth of cut of grinding Silicon Carbide

Figure 4.1 is drawn between surface roughness and depth of cut by using the abrasive of silicon carbide. Regarding to graph above, noticed that the surface roughness increased with the increased depth of cut. Increase depths of cut will slightly increasing the surface roughness values from 0.983 µm until 1.367 µm.

From the Figure 4.2 below, one can be noted that increasing depth of cut will slightly increasing the surface roughness values from 2.193 µm until 3.123 µm. Increases depth of cut will affect the increasing surface roughness results for both single pass and multi pass. The surface roughness gives 1.674 µm when grinding machine has grind by 5µm of depth of cut. But the surface roughness for aluminum oxide is less rough compared to silicon carbide. When 5 µm depth of cut was grind, it gives 0.957 µm value of surface roughness. The entire figure showed an agreement between experimental result with the literature review by A. Mandal et al. (n.d) which is increased feed rate and depth of cut the value of surface roughness increases.

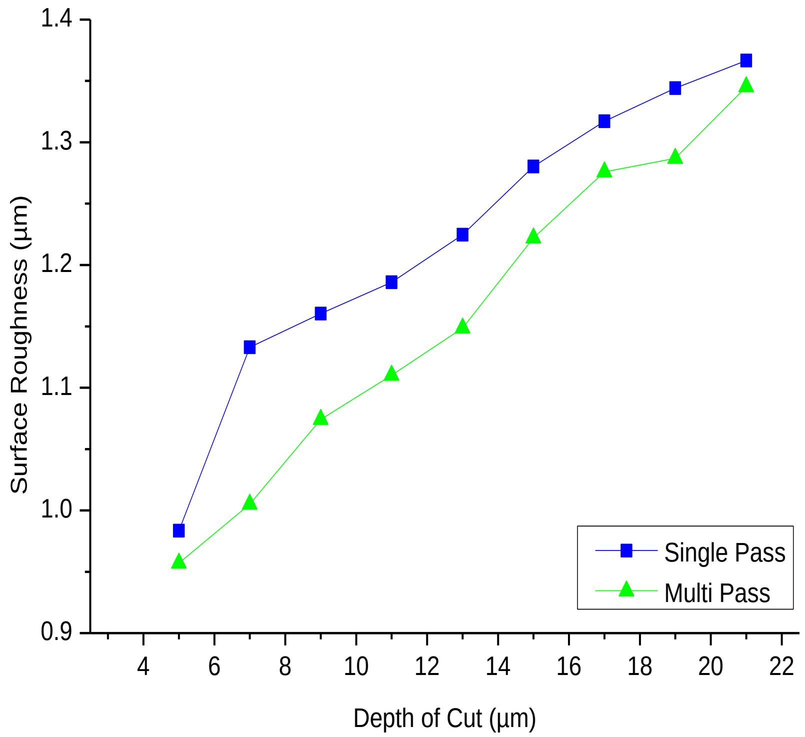


Figure 4.2: Relation between surface roughness and depth of cut of grinding Aluminium Oxide

Comparisons of the measured surface roughness of aluminium alloy using water based coolant with the different abrasive material are shown as Figure 4.1 and Figure 4.2. The measured data give the effect of different parameters to the values of surface roughness of aluminium alloy. Aluminium Oxide is chosen as the best results and conditions for surface roughness of Aluminium alloy. Generally, from both results of single pass and multi pass, it can be seen clearly that Aluminium Oxide gives the best surface finish compared to Silicon Carbide for Aluminium alloy. The image of surface roughness of aluminium alloy for both grinding wheels can be referred from Figure 4.3 and 4.4. The higher depth of cut will cause surface roughness of aluminium alloy rougher.

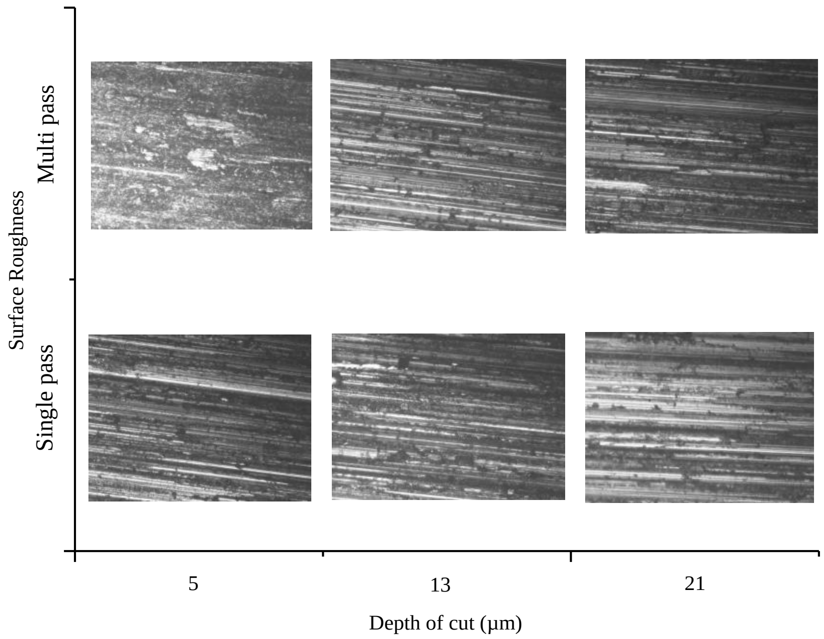


Figure 4.3: Microscope metallurgical result of surface roughness of aluminium alloy using Silicon Carbide

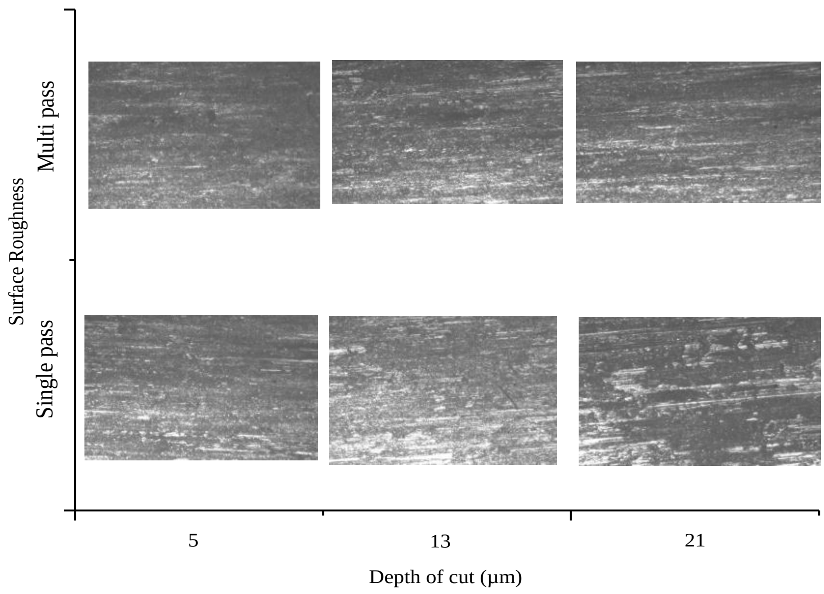


Figure 4.4: Microscope metallurgical result of surface roughness of aluminium alloy using Aluminium Oxide

According to the figures above, more silver lines shown in surface means it has a rough surface finish. This will cause the data become increasing as seen in Figure 4.3. When compared both single pass and multi pass, multi pass gives the best results because less silver lines occur in surface finish. But when comparing the results between aluminium oxide and silicon carbide (Figure 4.3 and Figure 4.4), it can see that less silver lines occur in surface finish by using abrasive aluminium oxide. It can prove that using aluminium oxide as grinder can give the best results as long as coolant supplied during grinding process.

4.2.2 Wheel Wear

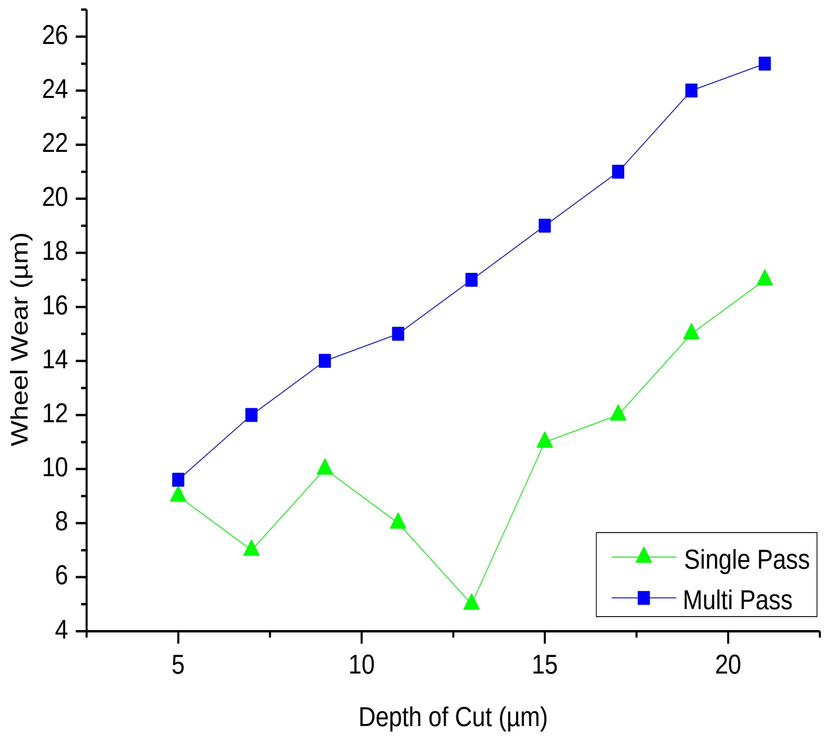


Figure 4.5: Relation between wheel wear and depth of cut of grinding Silicon Carbide

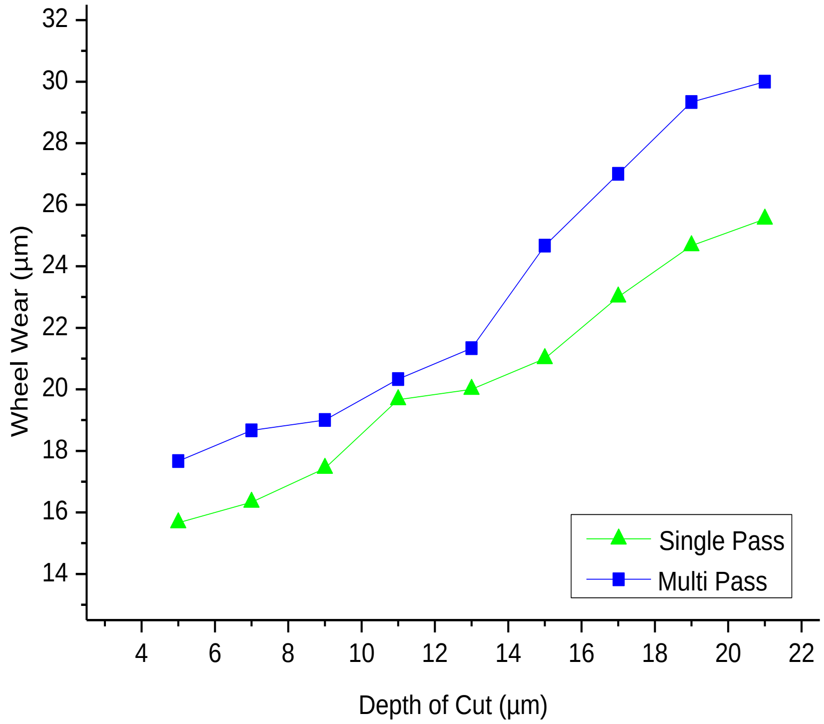


Figure 4.6: Relation between wheel wear and depth of cut of grinding Aluminium Oxide

Based on Figure 4.5 and 4.6, wheel wear is proportional to the depth of cut. From Figure 4.4, the wheels wear of single pass was decreased at point 11 µm until 13 µm depths of cut. Reducing the wheel wear gives the best surface finish. The wheel wears increased with the depth of cut at different number of passes and abrasive materials with a constant type of coolant. This result is consistent with experimental findings in the textbook by Ichiro I et al. (2006). The wheel wear will increase because of punctual impact stresses linked between workpiece and material. The abrasive grain must be suitable to influence stresses and the nanofluids must be capable to work well together with workpiece and abrasive grain in order to reduce wheel wear as well as good surface quality will occur on the surface finish.

Figure 4.7: Built up edge stick in a grinding wheel

It also should be noted at this point that surface of aluminium alloy has been rough because of built up edge occur during grinding wheel as seen in Figure 4.7.

4.3 PREDICTION RESULT FROM NEURAL NETWORK

Figure 4.8 until Figure 4.11 represents the predicted results for surface roughness and wheel wear as a function of depth of cuts for aluminium alloy with different abrasive material, constant type of coolant and table speed.

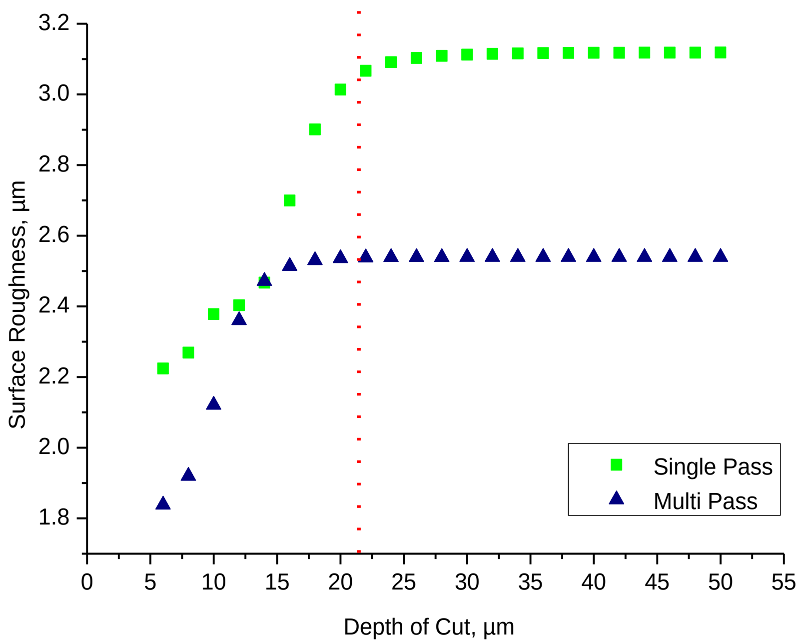


Figure 4.8: Predicted surface roughness of Silicon Carbide by using neural network software

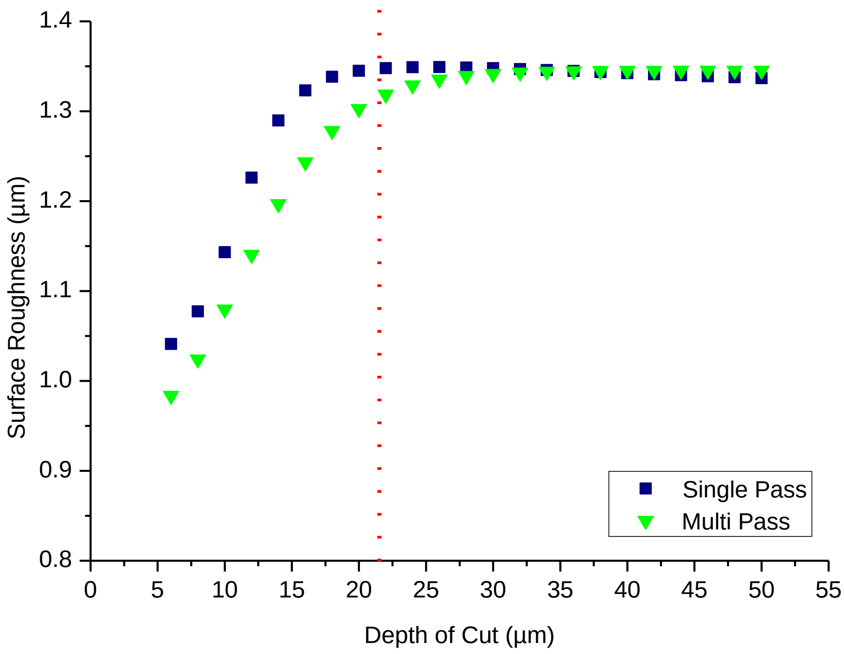


Figure 4.9: Predicted surface roughness of Aluminium Oxide by using neural network software

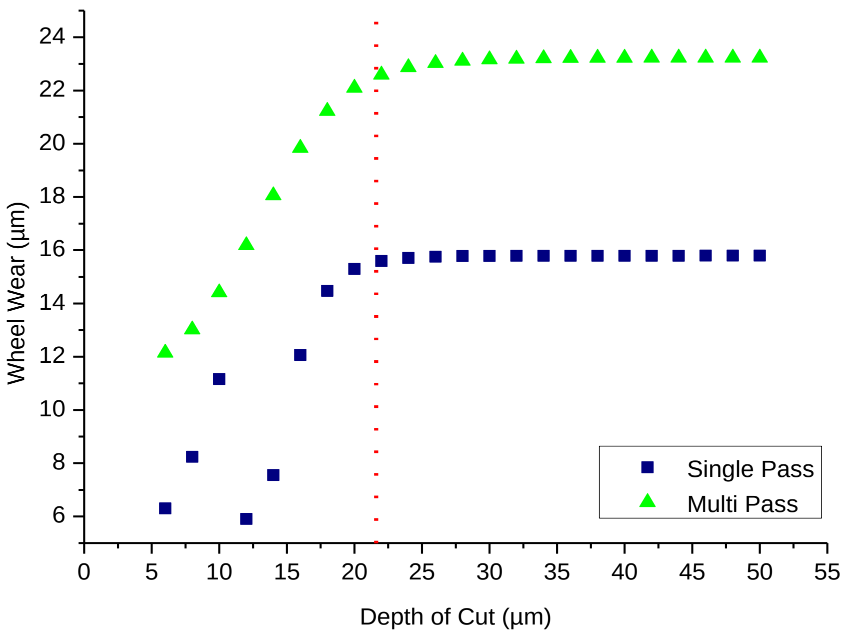


Figure 4.10: Predicted wheel wear of Silicon Carbide by using neural network software

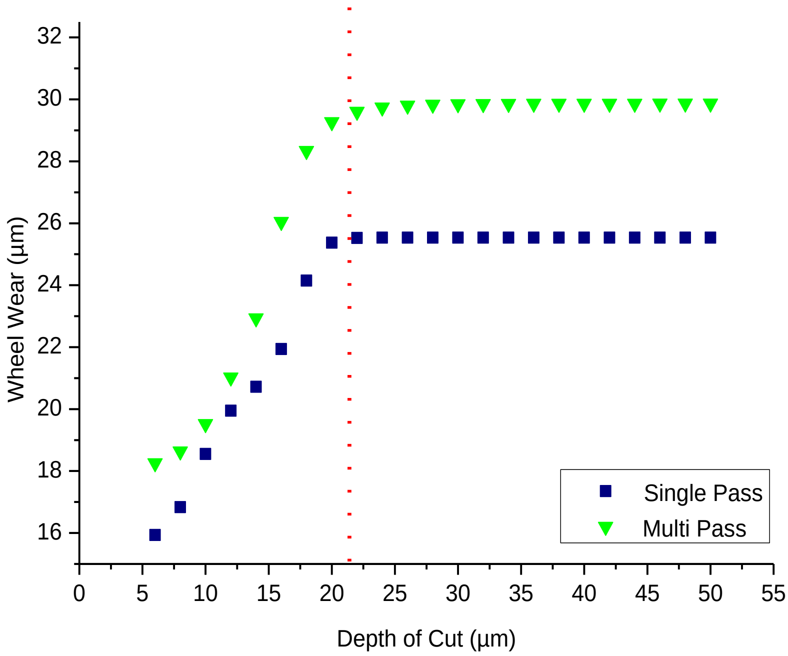


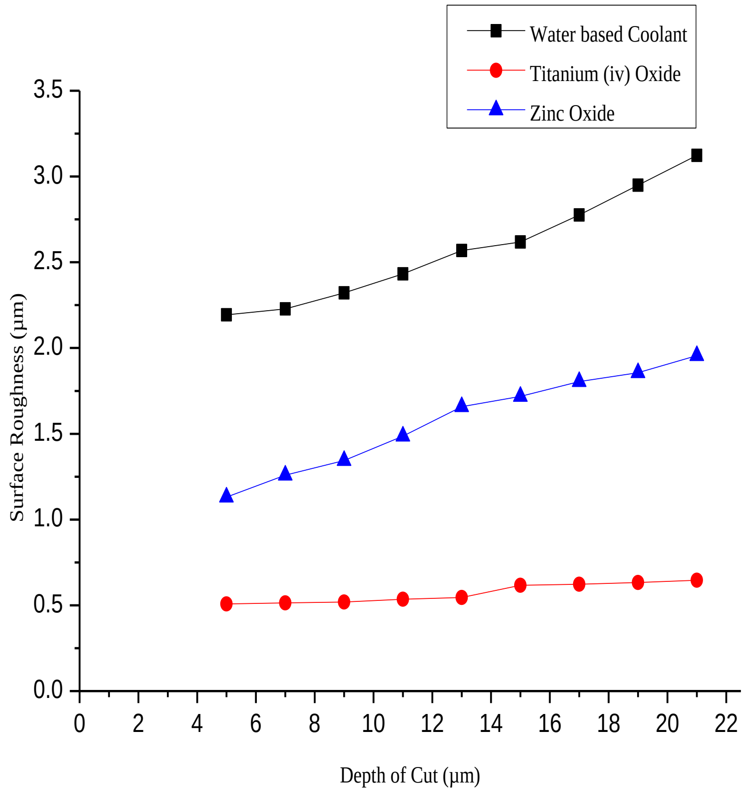
Figure 4.11: Predicted wheel wear of Aluminium Oxide by using neural network software

The predicted results were taken from 22 µm to 50 µm of depths of cut as surface grinding machine only can take maximum 21µm depth of cut in laboratory. So, this application of neural network can help engineers determine the results easily without exhaustive more experiments. These results show good agreement with experimental data and the proposed model results. As seen in Table 3.7 to Table 3.10, the output and target values are fairly close, which indicates that developed model can be effectively used to predict the surface roughness as well as wheel wear on the machining of aluminium alloy using water based coolant. There are smallest increment between the surface roughness and wheel wear results for both abrasives and number of passes after the red lines as seen in all figures above.

4.4 EFFECTS OF OTHER NANOFLUIDS ON ALUMINIUM ALLOY

The higher grinding forces in high-performance grinding processes can be reduced by using the friendly lubricant such as water based coolant. High total machining times are disadvantages for the work piece as well as the higher surface roughness of the work piece. But it can improve by considering the type of nanofluids that are most suitable for grinding aluminium alloy so that can get a better surface finish as well as very economical. Coolant used to avoid residual stress and surface friction during grinding process. Water based coolant is most friendly cooling lubricant, but it may be suitable for certain material only.

(a)



(b)

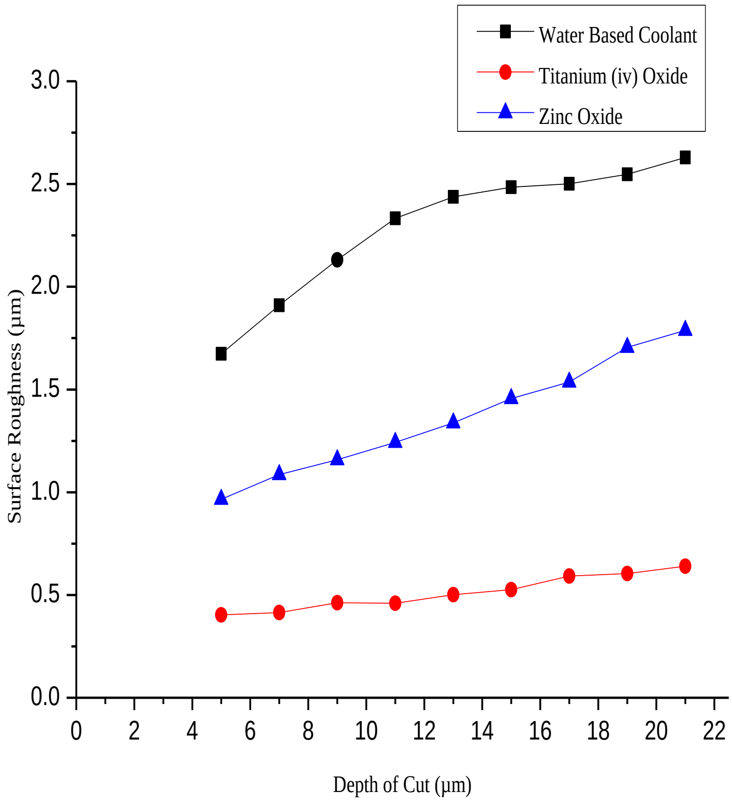


Figure 4.12: Relation between (a) single pass and (b) multi pass of other nanofluids on aluminium alloy

The average results for different type of coolant when grind aluminium alloy is presented in Figure 4.12. Based on the graph obtained, it can be seen that only Titanium (iv) is most suitable nanofluid to grind aluminium alloy although all surface roughness increased when the depth of cut increased. Comparing between the effect of nanofluids, it showed that the higher depth of cut, the higher of surface roughness. When 5 µm depth of cut was run, the water based coolant, Titanium (iv) Oxide and Zinc Oxide gives different result that is 1.674 µm, 0.508 µm and 1.131 µm respectively. The higher surface roughness for this nanofluids is 3.123 µm followed by 1.956 µm and 0.646 µm. The reason aluminium alloy becomes rough when using water based coolant could be more heat generated maybe because of less coolant supplied during grinding process.

Water based coolant being used in this present study to remove heat. This is because water with higher specific heat capacity, density and thermal conductivity can make the system stay cool. But its properties still less than other nanofluids. The heat generated between grinding wheel and workpiece can remove by supplying the cooling system and enhancing surface quality and reducing wheel wear.

4.5 RESULTS COMPARISON AND ANALYSIS

4.5.1 Comparison Results between Silicon Carbide and Aluminium Oxide

Aluminium alloy is one of material is difficult to grind because it has a low melting point (1090^{o}F) and soft nature. When using a regular grinding wheel, it will cause the surface finish becoming rough. It can generate harmful metallic particles during the grinding process. [36]

The selection of abrasive in grinding process is based on two conditions which are the properties of the material and the type of lubricant cooling. From the figure below, aluminium oxide can give a better surface finish of aluminium alloy compared to silicon carbide. Figure 4.13 and Figure 4.14 below had showed the comparison results between both grinders and number of passes in the grinding process.

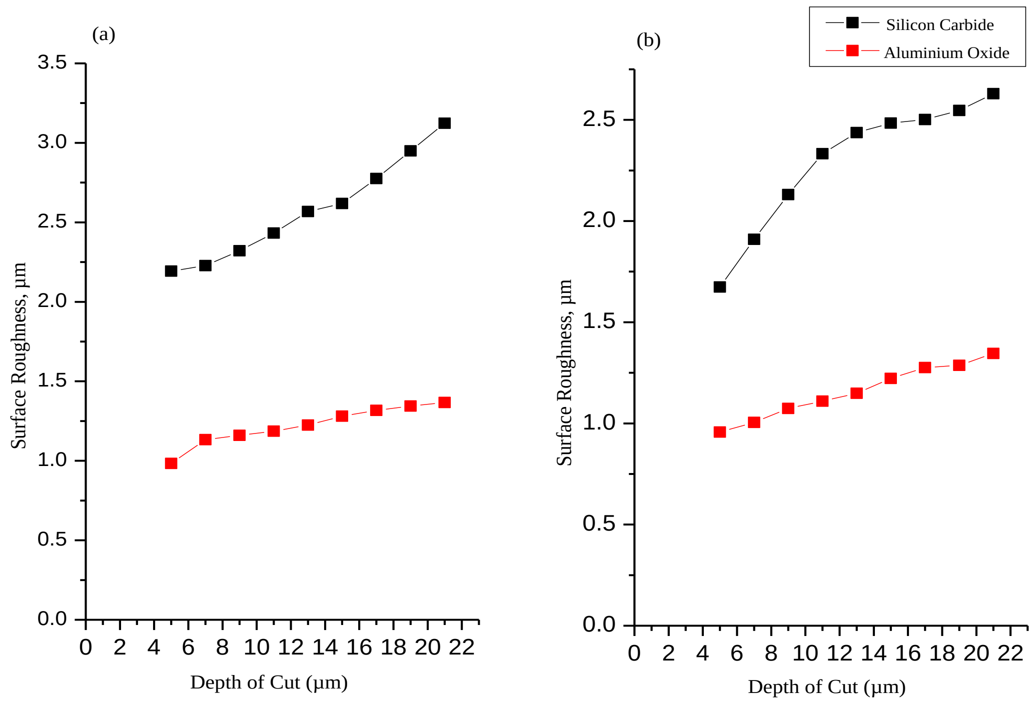


Figure 4.13: Comparison result of surface roughness between Aluminum Oxide and Silicon Carbide for (a) single pass and (b) multi pass

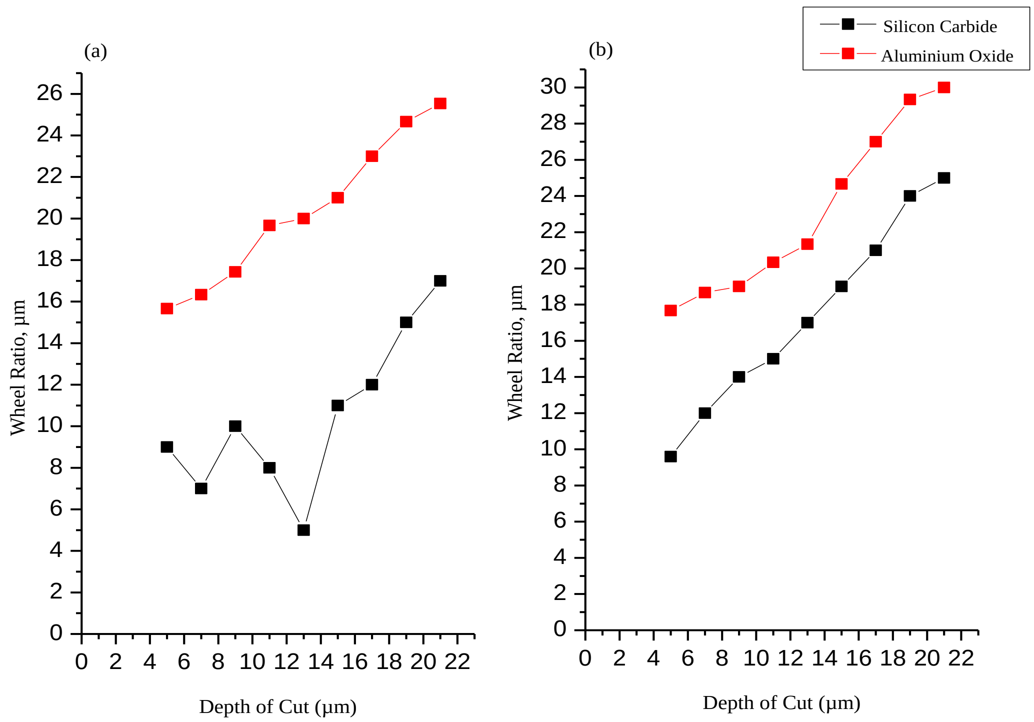


Figure 4.14: Comparison result of wheel wear between Aluminum Oxide and Silicon Carbide for (a) single pass and (b) multi pass

Increasing results of wheel wear maybe due to repeatedly run of grinding wheel to the workpiece and the impact stressed linked with it. Reducing the number of wheel wears can give a better surface finish of aluminium alloy.

4.5.2 Comparison between Calculation Value and Neural Network Analysis

Table 4.1 and Table 4.2 shows a summary of statistical results for the ANN model and multiple linear regression model.

Table 4.1: Neural network analysis and calculation value for surface roughness

Abrasive Material	Number of passes	Surface Roughness			
		Correlation		R-Squared	
		Neural Network	Calculation	Neural Network	Calculation
Silicon Carbide	Single-pass	0.991339	0.986	0.981664	0.972
	Multi-pass	0.996335	0.9353	0.991969	0.8748
Aluminium Oxide	Single-pass	0.955644	0.965	0.894217	0.931
	Multi-pass	0.995216	0.9996	0.987428	0.9992

Table 4.2: Neural network analysis and calculation value for wheel wear

Abrasive Material	Number of passes	Wheel Ratio			
		Correlation		R-Squared	
		Neural Network	Calculation	Neural Network	Calculation
Silicon Carbide	Single-pass	0.943341	0.754	0.864814	0.569
	Multi-pass	0.99779	0.996	0.993913	0.993
Aluminium Oxide	Single-pass	0.961849	0.999	0.886748	0.998
	Multi-pass	0.991754	0.976	0.87508	0.952

The correlation and R-squared values for calculation and using neural network analysis are fairly close. These results indicated surface roughness and wheel wear errors measurement based on the difference between observed and predicted values. The statistics for both models in term of correlation and R-squared revealed that ANN produced a more efficient prediction compared to the regression model.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

In the present study, Artifial Neural Network model is developed to predict the surface roughness and wheel wear in grinding process based on the experimental setup. The surface roughness and wheel wear obtained from all experiments and neural network analysis are consistences in-depth of cut. The output parameters are observed increase with increasing depth of cut with an optimum parameter that is 5µm. Aluminium oxide is suitable as a grinder wheel for grinding aluminium alloy because it has minimum number of surface roughness that is 0.957 µm compared to silicon carbide only has 1.674 µm. The minimum number of wheel wear in silicon is 9 µm while aluminium oxide gives 15.67 µm of wheel wear.

Artificial Neural Network model obtained from predicted value is accurate and effective in predicting, which is giving 10.6% error of surface roughness and 13.5% error of wheel wear.

5.2 RECOMMENDATIONS

From the present study, there are several recommendations which may be used to improve the results for a similar study in the future. The recommendations are listed below.

(1) Consider several factors in surface grinding such as grinding wheel and the material of the piece being worked on especially the properties of both materials and fluids. This is because poor combinations of properties give poor final results and far from accuracy results.

(2) The machine used to analyze the surface roughness has very sensitive, when the surrounding factors vary such as temperature and wind, it will affect the roughness of the surface and the readings will differ from actual one.

(3) Get different parameters such as table speed, temperature, differing depth of cut and others to compare the results.

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APPENDIX A1

SURFACE ROUGHNESS TABLE

Table 3.3 (a): Surface roughness results during single pass Silicon Carbide

Depth of Cut (µm)	Surface Roughness (µm)									
	Initial			Medium			Final			Average
	1	2	3	1	2	3	1	2	3	
5	2.47	1.151	1.579	3.193	1.626	5.311	1.713	1.42	1.274	2.193
7	2.896	2.600	2.839	2.348	3.162	2.222	0.706	2.405	0.875	2.228
9	3.842	2.473	2.18	1.076	1.9	1.462	3.564	1.278	3.117	2.321
11	2.194	2.139	1.277	3.724	2.488	1.559	2.62	3.006	3.000	2.432
13	3.165	3.040	3.526	3.357	2.761	1.408	1.947	1.954	1.954	2.568
15	3.101	3.529	2.335	2.121	2.977	2.211	2.510	2.311	2.469	2.618
17	3.508	4.711	3.428	1.799	1.401	3.278	3.096	1.487	2.270	2.775
19	3.853	3.011	3.841	3.318	3.408	3.054	2.421	1.994	1.645	2.949
21	3.765	4.048	3.604	1.924	3.327	3.567	2.235	3.667	1.972	3.123

Table 3.3 (b): Surface roughness results during multi pass Silicon Carbide

Depth of Cut (µm)	Surface Roughness (µm)									
	Initial			Medium			Final			Average
	1	2	3	1	2	3	1	2	3	
5	2.270	1.228	1.238	1.793	1.390	1.680	2.149	2.019	1.300	1.674
7	1.428	2.046	1.282	1.517	2.060	1.646	2.179	2.886	2.142	1.909
9	2.867	2.920	2.853	2.735	1.035	1.304	1.388	2.104	1.970	2.131
11	2.525	2.517	2.801	1.976	1.983	2.147	1.996	2.485	2.568	2.333
13	2.209	2.207	2.351	3.756	2.582	2.626	1.387	2.362	2.455	2.437
15	2.109	2.620	2.525	2.424	2.450	2.859	2.325	2.139	2.908	2.484
17	2.118	2.776	2.953	2.791	2.169	2.416	2.156	2.940	2.194	2.501
19	2.807	2.581	2.668	2.357	2.267	2.140	2.051	2.311	3.739	2.547
21	2.450	2.248	2.338	2.326	2.960	3.305	2.724	2.351	2.963	2.629

Table 3.4 (a): Surface roughness results during single pass Aluminium Oxide

Depth of Cut (µm)	Surface Roughness (µm)									
	Initial			Medium			Final			
	1	2	3	1	2	3	1	2	3	Average
5	0.997	0.622	1.285	1.118	0.894	1.300	1.119	0.781	0.735	0.983
7	0.916	0.942	0.965	1.204	1.318	1.313	1.021	1.328	1.190	1.133
9	1.053	1.007	1.601	1.404	1.307	1.222	0.914	0.958	0.978	1.160
11	0.867	1.702	1.062	1.186	1.062	1.399	1.358	1.259	0.778	1.186
13	1.219	1.233	0.989	1.049	1.392	1.389	1.213	1.237	1.301	1.225
15	1.324	1.222	1.221	1.361	1.364	.1.556	0.847	1.665	1.238	1.280
17	1.297	1.540	1.007	1.264	1.328	1.161	1.429	1.167	1.661	1.317
19	1.259	1.143	1.533	1.539	1.302	1.378	1.213	1.262	1.182	1.344
21	1.969	1.352	1.957	1.175	1.450	1.133	1.045	1.198	1.020	1.367

Table 3.4 (b): Surface roughness results during multi pass Aluminium Oxide

Depth of Cut (µm)	Surface Roughness (µm)									
	Initial			Medium			Final			
	1	2	3	1	2	3	1	2	3	Average
5	1.041	0.899	1.032	1.051	1.064	1.054	0.980	0.756	0.737	0.957
7	0.993	0.979	1.090	1.056	0.994	1.043	1.000	1.066	0.825	1.005
9	1.102	1.104	0.890	0.915	1.352	1.006	1.078	1.105	1.115	1.074
11	1.079	1.224	1.241	1.094	0.938	1.134	0.902	1.143	1.236	1.110
13	1.163	1.207	1.205	1.310	1.164	1.058	1.033	0.999	1.199	1.149
15	1.188	1.206	1.212	1.518	1.239	1.244	1.255	1.084	1.053	1.222
17	1.375	1.425	1.409	0.984	1.507	1.382	1.174	1.010	1.217	1.276
19	1.147	1.282	1.325	1.442	1.458	1.431	1.132	1.181	1.185	1.287
21	1.183	1.182	1.073	1.814	1.328	1.290	1.379	1.491	1.368	1.345

APPENDIX A2

WHEEL WEAR TABLE

Table 3.5 (a): Wheel wear produced during single pass Silicon Carbide

Depth of cut (µm)	Wheel Diameter (mm)								
	Before				After				Wheel Wear
	1	2	3	Average	1	2	3	Average	
5	16.521	16.523	16.521	16.522	16.514	16.512	16.513	16.513	0.009
7	16.510	16.509	16.507	16.509	16.503	16.503	16.501	16.502	0.007
9	16.501	16.495	16.495	16.497	16.489	16.490	16.488	16.487	0.010
11	16.484	16.486	16.484	16.485	16.476	16.477	16.477	16.477	0.008
13	16.472	16.472	16.473	16.472	16.466	16.469	16.466	16.467	0.005
15	16.461	16.460	16.463	16.461	16.450	16.450	16.449	16.450	0.011
17	16.407	16.404	16.405	16.405	16.391	16.392	16.396	16.393	0.012
19	16.389	16.389	16.390	16.389	16.376	16.373	16.374	16.374	0.015
21	16.368	16.365	16.370	16.368	16.352	16.351	16.349	16.351	0.017

Table 3.5 (b): Wheel wear produced during multi pass Silicon Carbide

Depth of cut (µm)	Wheel Diameter (mm)								
	Before				After				Wheel Wear
	1	2	3	Average	1	2	3	Average	
5	16.799	16.798	16.798	16.798	16.789	16.789	16.788	16.789	0.0097
7	16.31	16.312	16.312	16.3113	16.299	16.298	16.300	16.299	0.012
9	15.671	15.671	15.672	15.6713	15.657	15.656	15.659	15.6573	0.014
11	15.376	15.372	15.371	15.373	15.360	15.357	15.358	15.3583	0.015
13	15.35	15.349	15.351	15.35	15.333	15.332	15.333	15.3327	0.017
15	15.311	15.311	15.310	15.3107	15.291	15.291	15.293	15.2917	0.019
17	15.274	15.277	15.273	15.2747	15.253	15.253	15.255	15.2537	0.021
19	15.243	15.244	15.243	15.2433	15.220	15.219	15.219	15.2193	0.024
21	15.215	15.215	15.215	15.215	15.191	15.191	15.189	15.1903	0.025

Table 3.6 (a): Wheel wear produced during single pass Aluminium Oxide

Depth of cut (µm)	Wheel Diameter (mm)								
	Before				After				Wheel Wear
	1	2	3	Average	1	2	3	Average	
5	21.810	21.812	21.811	21.811	21.797	21.794	21.795	21.795	0.016
7	21.773	21.774	21.772	21.773	21.753	21.758	21.759	21.757	0.016
9	21.734	21.733	21.731	21.733	21.713	21.714	21.719	21.715	0.017
11	21.588	21.589	21.589	21.589	21.571	21.567	21.569	21.569	0.019
13	21.543	21.541	21.542	21.542	21.521	21.525	21.520	21.522	0.020
15	21.514	21.514	21.514	21.514	21.496	21.491	21.492	21.493	0.021
17	21.174	21.173	21.174	21.174	21.150	21.152	21.150	21.151	0.023
19	21.127	21.125	21.126	21.126	21.103	21.100	21.101	21.101	0.025
21	21.082	21.082	21.082	21.082	21.058	21.057	21.055	21.057	0.026

Table 3.6 (b): Wheel wear produced during multi pass Aluminium Oxide

Depth of cut (µm)	Wheel Diameter (mm)								
	Before				After				Wheel Wear
	1	2	3	Average	1	2	3	Average	
5	19.868	19.867	19.869	19.868	19.851	19.849	19.851	19.850	0.017
7	19.834	19.832	19.831	19.832	19.813	19.814	19.814	19.814	0.018
9	19.799	19.798	19.796	19.798	19.776	19.780	19.780	19.779	0.019
11	19.747	19.745	19.749	19.747	19.727	19.726	19.727	19.727	0.020
13	19.708	19.708	19.709	19.708	19.688	19.685	19.688	19.687	0.021
15	19.663	19.664	19.665	19.664	19.639	19.641	19.638	19.639	0.0247
17	19.490	19.493	19.499	19.494	19.467	19.467	19.467	19.467	0.027
19	19.445	19.447	19.448	19.447	19.416	19.419	19.417	19.417	0.029
21	19.400	19.405	19.403	19.403	19.371	19.373	19.374	19.373	0.030

APPENDIX A3

NEURAL NETWORK ANALYSIS TABLE

Table 3.7: (a) Output and target value of surface roughness using single pass Silicon Carbide

	Row	Depth of Cut	Target	Output	AE	ARE
TRN	0	5	2.193	2.24153	0.04853	2.2127
TRN	1	7	2.22811	2.25298	0.02487	1.11595
TRN	2	9	2.32133	2.27113	0.0502	2.1625
VLD	3	11	2.43244	2.43494	0.0025	0.10269
TRN	4	13	2.568	2.53081	0.03719	1.44829
TRN	5	15	2.61822	2.66305	0.04483	1.71207
TST	6	17	2.77533	2.82678	0.05145	1.85373
TRN	7	19	2.94944	2.97891	0.02947	0.99912
TRN	8	21	3.12322	3.07365	0.04957	1.58718

Table 3.7: (b) Output and target value of surface roughness using multi pass Silicon Carbide

	Row	Depth of Cut	Target	Output	AE	ARE
TRN	0	5	1.67411	1.70149	0.02738	1.6354
TRN	1	7	1.90956	1.89306	0.0165	0.8641
TRN	2	9	2.13067	2.15023	0.01956	0.91799
TST	3	11	2.33311	2.30502	0.0281	1.20424
TRN	4	13	2.43722	2.40893	0.02829	1.16093
VLD	5	15	2.48433	2.48421	0.00012	0.00481
TRN	6	17	2.50144	2.53524	0.0338	1.3511
TRN	7	19	2.54678	2.56712	0.02035	0.79884
TRN	8	21	2.62944	2.58614	0.04331	1.64696

Table 3.8: (a) Output and target value of surface roughness using single pass Aluminium Oxide

	Row	Depth of Cut	Target	Output	AE	ARE
TRN	0	5	0.98344	1.0234	0.03996	4.06296
TRN	1	7	1.133	1.08729	0.04571	4.03448
TRN	2	9	1.16044	1.18243	0.02199	1.89496
TST	3	11	1.18589	1.26726	0.08137	6.86123
VLD	4	13	1.22467	1.22439	0.00028	0.02285
TRN	5	15	1.28025	1.28222	0.00197	0.15409
TRN	6	17	1.31711	1.32001	0.0029	0.21995
TRN	7	19	1.34414	1.34044	0.00371	0.27578
TRN	8	21	1.36656	1.35127	0.01528	1.1183

Table 3.8: (b) Output and target value of surface roughness using multi pass Aluminium Oxide

	Row	Depth of Cut	Target	Output	AE	ARE
VLD	0	5	0.95711	0.95712	7E-06	0.00072
TRN	1	7	1.00511	1.00631	0.0012	0.11917
TRN	2	9	1.07411	1.06339	0.01072	0.99795
TRN	3	11	1.11011	1.11272	0.00261	0.23487
TRN	4	13	1.14867	1.16658	0.01792	1.55971
TRN	5	15	1.22211	1.21852	0.00359	0.29402
TRN	6	17	1.27589	1.26173	0.01416	1.10958
TRN	7	19	1.287	1.29338	0.00638	0.49596
TST	8	21	1.34533	1.31442	0.03092	2.29818

Table 3.9: (a) Output and target value of wheel wear using single pass Silicon Carbide

	Row	Depth of Cut	Target	Output	AE	ARE
TRN	0	5	9	7.25469	1.74531	19.3923
TRN	1	7	7	7.25469	0.25469	3.63844
VLD	2	9	10	7.25469	2.74531	27.4531
TRN	3	11	8	7.25469	0.74531	9.31636
TRN	4	13	5	7.25471	2.25471	45.0943
TRN	5	15	11	10.9999	0.00014	0.00131
TST	6	17	12	11.8362	0.1638	1.36499
TRN	7	19	15	14.9991	0.00093	0.00623
TRN	8	21	17	16.9994	0.00059	0.00346

Table 3.9: (b) Output and target value of wheel wear using multi pass Silicon Carbide

	Row	Depth of Cut	Target	Output	AE	ARE
TRN	0	5	9.6	10.2531	0.65307	6.80277
TRN	1	7	12	11.7391	0.26091	2.17424
TRN	2	9	14	13.9035	0.09655	0.68962
TST	3	11	15	15.742	0.74202	4.94678
TRN	4	13	17	17.1569	0.15686	0.9227
VLD	5	15	19	18.735	0.26501	1.3948
TRN	6	17	21	21.1335	0.13352	0.63581
TRN	7	19	24	23.736	0.26398	1.09992
TRN	8	21	25	24.8129	0.18711	0.74842

Table 3.10: (a) Output and target value of wheel wear using single pass Aluminium Oxide

	Row	Depth of Cut	Target	Output	AE	ARE
TRN	0	5	15.667	15.7418	0.07479	0.4774
VLD	1	7	16.333	16.3152	0.01779	0.1089
TRN	2	9	17.433	17.7255	0.2925	1.67784
TRN	3	11	19.667	19.1551	0.51186	2.60263
TRN	4	13	20	20.1891	0.18913	0.94563
TRN	5	15	21	21.1642	0.16417	0.78176
TST	6	17	23	22.6598	0.3402	1.47913
TRN	7	19	24.667	24.6432	0.02383	0.09659
TRN	8	21	25.533	25.477	0.05598	0.21926

Table 3.10: (b) Output and target value of wheel wear using multi pass Aluminium Oxide

	Row	Depth of Cut	Target	Output	AE	ARE
TST	0	5	0.01767	0.01913	0.00146	8.26783
TRN	1	7	0.01867	0.01947	0.0008	4.30344
VLD	2	9	0.019	0.02011	0.00111	5.81484
TRN	3	11	0.02033	0.02123	0.0009	4.42649
TRN	4	13	0.02133	0.02297	0.00164	7.66629
TRN	5	15	0.02467	0.02499	0.00032	1.30313
TRN	6	17	0.027	0.02666	0.00034	1.25897
TRN	7	19	0.02933	0.02772	0.00161	5.49875
TRN	8	21	0.03	0.02831	0.00169	5.63409

APPENDIX B

CALCULATION OF CORRELATION AND R-SQUARED BY USING MULTIPLE LINEAR REGRESSION MODEL

x	**y**	**x^2**	**y^2**	**xy**
5	0.983	25	0.996	4.915
7	1.133	49	1.284	7.931
9	1.160	81	1.346	10.440
11	1.186	121	1.407	13.046
13	1.225	169	1.501	15.925
15	1.280	225	1.638	19.200
17	1.317	289	1.734	22.389
19	1.344	361	1.806	25.536
21	1.367	441	1.869	28.707
117	**10.995**	**1761**	**13.551**	**148.089**

$$r = \frac{n\Sigma XY - \Sigma X \Sigma Y}{\sqrt{[n\Sigma X^2 - (\Sigma X)^2][n\Sigma Y^2 - (\Sigma Y)^2]}}$$

$$r = \frac{9(148.089) - (117)(10.995)}{\sqrt{[9(1761) - (117)^2][9(13.551) - (10.995)^2]}}$$

$$r = \frac{46.386}{\sqrt{[2160][1.069]}}$$

$$r = 0.965$$

$$r^2 = 0.931$$