PREDICTION OF GRINDING MACHINABILITY WHEN GRIND P20 TOOL STEEL USING WATER BASED ZnO NANO-COOLANT

YOGESWARAN S/O MUTHUSAMY

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Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Grinding is often an important finishing process for many engineering components and for some components is even a major production process. The surface roughness, R_a is also an important factor affecting many manufacturing departments. In this study, a model have been developed to find the effect of grinding condition which is depth of cut, type of wheel and type of grinding coolant on the surface roughness on AISI P20 tool steel and wheel wear. Besides that, the objective of this study is to determine the effect of Zinc Oxide (ZnO) nano-coolant on the grinding surface quality and wheel wear for various axial depth. Precision surface grinding machine is used to grind the AISI P20 tool steel. The work table speed would be constant throughout the experiment which is 200 rpm. The experiment conducted with grinding depth in the range of 5 to 21µm. Besides, Aluminum Oxide wheel and Silicon Carbide wheel are used to grind the work piece in this experimental study. Next, the experiment will conduct using ZnO nano-coolant. Finally, the artificial intelligence model has been developed using ANN. From the result, it shows that the lower surface roughness and wheel wear obtain at the lowest cutting depth which is 5 µm. Besides that, grind using ZnO nano-coolant gives better surface roughness and minimum wheel wears compare to grind using water based coolant. From the prediction of ANN, it shows that the surface roughness became constant after cutting depth 21 µm. In conclusion, grind using ZnO nano-coolant with cutting depth 5 µm obtain a better surface roughness and lowest wheel wear. As a recommendation, various machining can be conducted using ZnO nano-coolant to emphasize better results.

ABSTRAK

Pengisaran adalah sering suatu proses yang penting untuk banyak komponen kejuruteraan dan untuk beberapa komponen lain. Kekasaran permukaan, adalah juga merupakan faktor penting yang mempengaruhi banyak jabatan pembuatan. Dalam kajian ini, satu model telah dihasilkan untuk mencari kesan keadaan pengisaran iaitu ketebalan potongan, jenis roda pengisar dan jenis bahan penyejuk yang memberi kesan kepada kekasaran permukaan keluli AISI P20 dan juga kehausan roda mesin pengisar. Selain itu, objektif utama kajian ini adalah untuk menentukan kesan nano-penyejuk ZnO pada kualiti permukaan pengisaran dan kehausan roda pengisar. Mesin pengisaran permukaan persis digunakan untuk mengisar alat kerja keluli AISI P20. Kelajuan mesin akan menjadi malar sepanjang eksperimen dijalankan iaitu 200 rpm. Eksperimen dijalankan dengan kedalaman pengisaran dalam lingkungan 5 hingga 21μm. Selain itu, roda Aluminium Oksida dan Silikon Karbida roda digunakan untuk mengisar bahan kerja dalam kajian ini. Seterusnya, eksperimen akan dijalankan menggunakan nano-penyejuk ZnO. Akhir sekali, satu model telah dibangunkan dengan menggunakan ANN. Kajian ini menunjukan bahawa kekasaran permukaan yang paling rendah diperolehi pada kedalaman pepotogan yang rendah iaitu 5 μm. Selain itu, eksperimen yang dijalankan menguna nano-penjejuk ZnO memperolehi kekasaran permukaan yang lebih baik dan kahausan roda yang minimum berbanding dengan mengisar mengunakan penjejuk berasaskan air. Dari ramalan ANN, ia menunjukkan bahawa kekasaran permukaan menjadi malar selepas pemotongan 21 μm. Kesimpulannya, kisar menggunakan nano-penyejuk ZnO dengan kedalaman pemotongan 5 μm mendapatkan kekasaran permukaan yang lebih baik dan kehausan roda paling rendah. Sebagai saranan, pelbagai mesin boleh dijalankan dengan menggunakan nano-penyejuk ZnO untuk memperolehi keputusan yang lebih baik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOL

µm	Micro Meter
%	Percentage
ºC	Degree Celcius
ø	Volume percentage of nano particle
$ø_2$	Volume percentage of nano-coolant after dilute
φ	Weight percentage of nano particle
ρ_w	Density of Water
ρ_p	Density of Nano particle
∆V	Total amount of distill water to be added
C_v	Specific Heat
Cm	Centimeter
g/cm^3	Gram per centimeter cubic
k	Thermal Conductivity
kg	Kilogram
kg/mm	Kilogram per milimeter
kg/m^3	Kilogram per meter cubic
K	Kelvin
l	Litre
mm	Milimeter
mm^3	Milimeter cubic
m/min	Meter per minutes
m/s	meter per second
rpm	Revolution per minute
W/m-K	Watt per meter Kelvin

LIST OF ABBREVIATION

ADC	Analog to Digital Converter
AE	Absolute Error
Al_2O_3	Aluminum Oxide
ANN	Artificial Neural Network
ARE	Absolute Relative Error
EG	Ethylene Glycol
EHT	Electron High Tension
EVO	Evolution
FKM	Fakulti Kejuruteraan Mekanical
GMDH	Group Method of Data Handling
HN	Hardness Number
Mag	Magnification
MSE	Mean Square Error
RSM	Response Surface Method
SiC	Silicon Carbide
WB	Water Based
WD	Working Distance
ZnO	Zinc Oxide
ZrO_2	Zirconium Oxide

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Brackground

The grinding machinability is widely used in the manufacturing of various materials (Samek et al., 1996). Grinding is often an important finishing process for many engineering components and for some components is even a major production process. There are many different types of grinding parameters. Different types of parameter in grinding process will be the effect of the characteristic of the work piece such as surface roughness, temperature, wheel wear, force and others. There are many types of parameters in the grinding process. Some of the parameters may be measured while the others may be calculated from those already known. Some of the parameters in grinding is needed for calculation of the others parameter (Midha et al., 1991). Parts such as automobile, aerospace, and medical component are some examples of grinding machinability. Therefore, grinding is one of most important and most complicated aspects of tool production and poor grinding will results in poor parts performance (Badger, 2003).

Xie and Huang (2008) has stated that P20 steels are extensively used as structural materials in modern manufacturing industries due to their excellent properties, such as high hardness at both ambient and elevated temperatures, low thermal expansion, good wear resistance and chemical inertness. Grinding with aluminum oxide abrasives is the most commonly used machining process for the fabrication of structural components made of those P20 steels. However, the superior properties of the P20 steel materials also render the grinding extremely difficult. The cost associated with the grinding process has been a major factor that has hindered the applications of the AISI

P20 steel. As a consequence, in the past several decades great research efforts were directed towards the development of efficient grinding processes for AISI P20 steel (Xie and Huang, 2008). Since P20 steel is a hard metal, correct grinding technique will require to avoid grinding cracks and improve tool life.

The surface roughness, R_a is also an important factor affecting many manufacturing departments. The main objective to obtain the optimum parameter in grinding is to reduce as much as possible manufacturing time and cost. Since P20 steel is wide used in manufacturing industry, the lowest surface roughness, R_a and optimum parameter get from this study will reduce the finishing operation such as final polishing. Since grinding is mostly used as finishing method, which determines the functional properties of the surface, the knowledge of the surface quality and its control are crucial. It is therefore an effort to achieve high levels of surface quality; conditionally improved by the grinding process, choosing the appropriate cutting conditions. The quality of the ground surface is generally defined as the sum of the properties under consideration upon demands. It is a complex of system factors. Surface quality includes physical, chemical and geometric properties (Madl et al., 2003). The geometric surface properties include roughness parameters as a characteristic of micro geometry in the cut plane perpendicular to the surface.

Grinding fluids are used to cool the work piece and the grinding wheel. It is also used to transport debris away from the grinding zone, and to provide lubrication at the contact between the wheel and the work piece (Hryniewicz et al., 1998). In this study, water based ZnO Nano-coolant is used as a grinding fluid. The grinding fluid may significantly affect the condition at these interfaces by changing the contact temperature, normal and shear stresses and the distribution along the interfaces of the tool and work piece (Safian et al., 1990). In this study, a model has been developed to find the effect of grinding condition which is depth of cut, type of wheel and type of grinding fluid on the surface roughness and wheel wear.

1.2 Problem Statement

There are two major problem encounters in this study. First will be the cost of the operation. Improper finishing in grinding process will contribute to further machining process such as polishing. Therefore, the cost of operation will increase due to addition machining process. Besides that, the excessive temperature of the work piece during the grinding is one of the problem encounters in this study. There is an increase in the temperature of the work piece during the grinding process. The high temperatures generated in the grinding zone can cause some types of thermal damages to the work piece, for example burning, excessive tempering of the superficial layer with possible re-hardening and increase of the brittleness (Malkin, 1989).

1.3 Objective Of The Study

The objectives of these studies are to identify:

- To determine the effect of variation axial depth and types of wheel on the grinding surface quality.
- To determine the effect of Water Based Coolant and Nano-coolant on the grinding surface quality and wheel wear.
- To develop an artificial intelligent model using Neural Network for prediction modelling.

1.4 Scope of Study

The major scope of this study is the work piece material. P20 tool steel is used as a work piece to conduct my experimental study. Besides that, in this study, the work table speed is one the parameter which maintain in the constant rate throughout this experimental study which is at 200 rpm. Furthermore, this experimental study is conducted with a single pass and also multi pass. For the multi pass, four passes are conducted for each experiment. Equally important, is the range of the grinding depth in this study. The experiment conducted with grinding depth in the range of 5 to 21 μm. Besides, Aluminum Oxide wheel and Silicon Carbide wheel are used to grind the work piece in this experimental study. Finally, the wheel dressing condition is similar after each of the experiments conducted.

1.5 Thesis Outline

This thesis contains five chapters which is every chapter have its own purpose. After viewing the entire chapter in this thesis hopefully viewer can understand the whole system design for this project.

Chapter one contains of the introduction or the overview of this project, the problem statement of this project, the objectives of the project, the scopes of the project and the outline of this thesis for every chapter.

Chapter two contains all the literature review. This chapter will explain the information about the article that related to the project that is done by other research. This chapter also describes the journals and other important information regarding this project.

Chapter three is a chapter for the methodology of this project. This chapter will explain about the detail of the project. It also includes the project progress that has blocked diagram, flowchart and also the explanation in detail about the project.

Chapter four discusses the result and the analysis for this project. This chapter will explain on the results and analysis of the project. The analysis includes the comparable results between project using water based coolant and Nano coolant. Both values will be compared to justify the theory.

Chapter five will explain the conclusion of the project. It also includes the future recommendation of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to Samek et al. (2011) grinding is the finishing machining operation to ensure the final surface quality. Compared with the operation methods of defined tool geometry, a tool for grinding consists of a number of statistically oriented grinding grains of random shapes. During the grinding process, small chips are removed along with high rates of material removal. Therefore grinding operations are used for machining difficult-to and hardened materials. The resulting surface quality depends on input factors such as principally cutting conditions are, followed by grinding material and accompanying phenomena. Generally, materials hard to machine are ground with finer grit wheels and a soft material are ground by coarse grained wheels. Cutting speed strongly influences the selection of a suitable grinding wheel degree. It is known that the higher cutting speed is, the finer the grinding wheel should be. The choice of optimal cutting conditions for grinding is not as strongly influenced by the requirement of keeping the optimum tool life, as is the case with other machining methods. Since grinding is mostly used as finishing method, which determines the functional properties of the surface, the knowledge of the surface quality and its control are crucial. It is therefore an effort to achieve high levels of surface quality, conditionally improved by the grinding process, choosing the appropriate cutting conditions. The quality of grinded surface is generally defined as the sum of the properties under consideration upon demands. It is a complex of system factors. Surface quality includes physical, chemical and geometric properties. The geometric surface properties include roughness parameters as a characteristic of micro geometry in the cut plane perpendicular to the surface (Samek et al., 2011).

2.2 Theory of Grinding

2.2.1 Mechanics of the Grinding Process

In the grinding process, the kinematic relationship between the grinding wheel and the work piece motions applies to each cutting grain. Some aspects of the process by which a grain grind can be illustrated by the geometrical relationship between a grain and the work piece during the grinding process. The geometry of the undeformed chip is shown in Figure 2.1

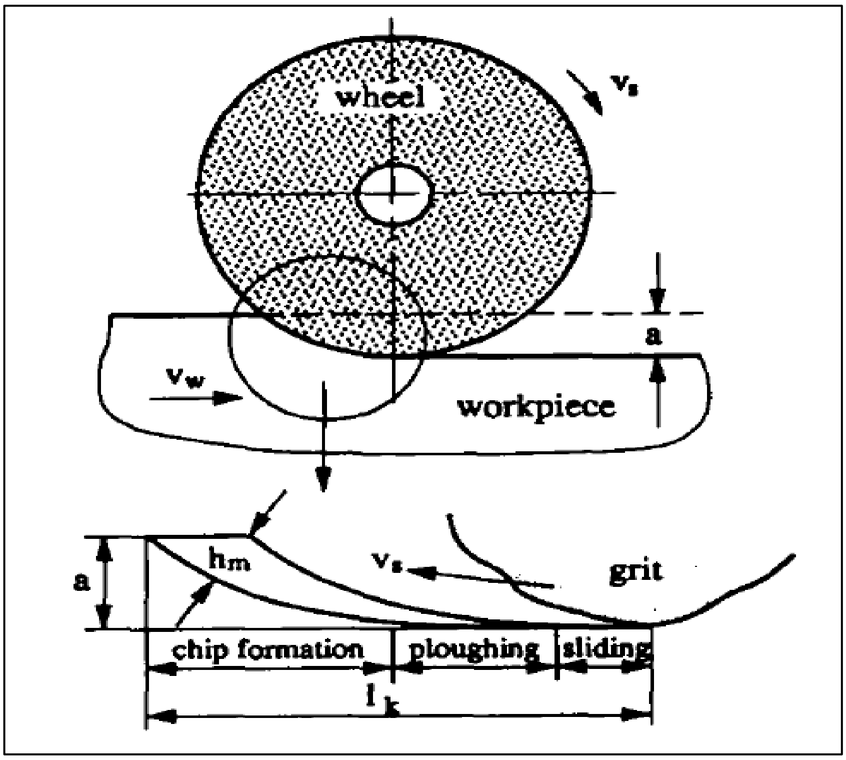

Figure 2.1: Three stages of chip generation

Source: Chen and Rowe (1995)

Based on the Figure 2.1 the undeformed chip shape is characterized by the cutting path length of the grain and the maximum undeformed chip thickness hm. The grinding process can be distinguished into three phases, including rubbing, ploughing and cutting. When the grain engages with the work piece up-cut grinding, the grain slides without cutting on the work piece surface due to the elastic deformation of the system. This is the rubbing phase. As the stress between the grain and work piece increases beyond the elastic limit, plastic deformation occurs. This is the ploughing phase. The work piece material is piled up to the front and to the sides of the grain to form a groove. A chip is formed when the work piece material can no longer withstand the tearing stress. The chip formation stage is the cutting phase. From the point of view of the energy required to remove material, cutting is the most efficient phase. Rubbing and ploughing is inefficient, since the energy is wasted in deformation and friction with a negligible contribution to material removal. Furthermore a high temperature may result, producing an excessive rate of wheel wear and the work piece surface may suffer metallurgical damage (Chen and Rowe, 1995).

2.2.2 Thermal Analysis of Grinding

Malkin and Gou (2007) stated that the grinding process requires high energy expenditure per unit volume of material removed. Virtually all of this energy is dissipated as heat at the grinding zone where the wheel interacts with the work piece. This leads to the generation of high temperatures which can cause various types of thermal damage to the work piece, such as burning, metallurgical phase transformations, softening (tempering) of the surface layer with possible re-hardening, unfavourable residual tensile stresses, cracks, and reduced fatigue strength of the work piece.. Thermal damage is one of the main factors which affects work piece quality and limits the production rates which can be achieved by grinding, so it is especially important to understand the underlying factors which affect the grinding temperatures.

In earlier research in 1950, it was conclusively shown that most grinding damage is thermal in origin. The first attempt to correlate actual grinding temperatures with structural metallurgical changes in the work piece was reported five years later. For this purpose, an embedded thermocouple was used to measure temperatures in the work piece subsurface during grinding of a hardened bearing steel. Numerous other methods have also been developed to measure grinding temperatures using either thermocouples or radiation sensors. While considerable difficulties may arise in interpreting such measurements due to the extreme temperature gradients in time and space near to the surface, embedded thermocouples and infrared radiation sensors utilizing fibre optics have been shown to provide a reasonably good indication of the work piece temperature near the ground surface. Both of these temperature-measuring techniques have been found to give results which are consistent with each other, and also with measurements of the surface temperature using a thin foil thermocouple.

Besides that, Malkin and Gou (2007) also mention that, temperatures are generated during grinding as a consequence of the energy expended in the process. In general, the energy or power consumption is an uncontrolled output of the grinding process. Temperature measuring methods do not provide a practical means to identify and control grinding temperatures in a production environment, as their use is generally restricted to the laboratory. In-process monitoring of the grinding power, when coupled with a thermal analysis of the grinding process, can provide a much more feasible approach to estimating grinding temperatures and controlling thermal damage. Thermal analyses of grinding processes are usually based upon the application of moving heat source theory. For this purpose, the grinding zone is modelled as a source of heat which moves along the surface of the work piece. All the grinding energy expended is considered to be converted to heat at the grinding zone where the wheel interacts with the work piece. A critical parameter needed for calculating the temperature response is the energy partition to the work piece, which is the fraction of the total grinding energy transported to the work piece as heat at the grinding zone. The energy partition depends on the type of grinding, the wheel and work piece materials, and the operating conditions (Malkin and Gou, 2007).

2.3 Analysis of Grinding Wheel Surfaces

2.3.1 Grinding Wheel

In grinding wheels, the cutting edges produced from the abrasive grains are arranged in a random fashion. Randomly arranged grains produce, in turn, a surface which profile could be considered as random. Raman et al. (2002) detailed the study of grinding wheel surfaces and have been reported on the measurement and analysis of the working surface of grinding wheels**.** Since the grinding wheel has a high surface speed compared with the work piece surface, the surface of the grinding wheel which contributes to the cutting could well be taken as the effective profiles of the wheel comprising all the high points on the individual sections of the wheel. Attempts have been made to obtain this effective profile by superimposing individual section profiles, but it is an elaborate and time consuming approach (Raman et al., 2002).

2.3.2 Wheel Dressing Process

Vickerstaff (1975) have shown that a grinding wheel produces features on the work piece surface which can be directly attributed to the wheel dressing process. The traverse rate and shape of the single-point dressing diamond is particularly important.

Pahlitzsch (1954) suggest that the diamond actually cuts through the abrasive grit to produce what is effectively a form tool. The dimensions of this form are determined by the combination of diamond traverse rate, shape and in the feed. When the wheel is used for grinding the abrasive grits transfer their profile to the work piece surface.

Bhateja et al. (1972) recorded both wheel and work piece profiles by stylus measurement. Dressing features clearly appeared on the work piece surface, but could not be detected on the surface of the wheel. They suggest that this is probably because any grooves produced in the grid by the dressing process would be very small compared to the total roughness of the wheel.

According to Malkin and Cook (1971) the wheel was dressed with a single-point pyramidal diamond and the debris collected on grease covered glass slide. After dissolving away the grease and the metal chips the dressing particles were sieved and weighed to determine their size distribution. The original grit size and the wheel hardness were found to influence the size distribution of the dressing particles. Generally smaller grits and harder wheels gave smaller dressing particles. More significantly however, the dressing particles for all the wheels used were not much smaller than the grits which went into the wheels, indicating that the dressing diamond actually fractures grits to' produce relatively large fragments or, possibly, dislodges them from the bond.

2.4 Grinding Parameter

2.4.1 Grinding Wheel Life

A wheel life model is developed in terms of the Group Method of Data Handling (GMDH) for studies of identification and prediction problems in complex systems in which wheel speed, feed, depth of cut, grain size, grade and hardness of work material are taken into consideration. In this method an accurate model of wheel life is obtained with the factors affecting it is chosen from a small number of input and output data. A mathematical model for grinding wheel redress life is identified by the polynomial theory of complex systems. Wheel speed, feed, grain size and grade are chosen as the independent variables from among the factors considered having an effect on wheel wear through the identification of the model. The model obtained enables the redress life to be predicted for all combinations of grinding wheel, work material and grinding conditions, and serves as an aid in the optimization of the grinding process (Nagasaka et al., 1979).

2.4.2 Surface Roughness on Work Piece

A grinding wheel has roughness in the axial and circumferential directions. The grinding grits flake, chip and fracture as well as is pulled out of the binder. Furthermore, when materials lying to high adhesion are ground the grit is capped by adherent lumps. The roughness of the wheel therefore changes continuously with the length and the number of passes.

The magnitude of the roughness is influenced by the hardness of the material ground as well as the elastic properties of the work piece, grit and binder materials. The elastic deflection of the grid at contact is generally found to be small.

Besides that, Vengkatesh et al. (1998) also proposed that another contributor to surface roughness which has received rather less attention than attrition and grinding mechanics is the wear and surface damage. The issue of wear has been addressed primarily for materials prone to high adhesion. The chemical and metallurgical mechanism of adhesion of metal to grit has been studied with a view to look at the blunting and attrition of the wheel. In terms of surface damage it has been suggested that the adhered material acts as a tool of large nose radius to tear and plough out large grooves on the surface. Grinding is a process which transmits power and generates traction. We are of the opinion that it is important to treat the rubbing regime in the contact zone of grinding as a general tribosystem which transmits traction by sliding or rolling and therefore may give rise to a variety of modes of metal removal. Such modes including the one by plastic grooving, collectively contribute to the generation of surface roughness. These modes are clearly sensitive to material properties such as hardness, toughness and fatigue strength, the operative values of which being dependent on the strain, strain rate and temperature generated in the contact zone. As stated in above, the localization of heat influenced by the thermal conductivity of material is a factor which is likely to affect wear and surface roughness. Under 'no wear' conditions material hardness is the primary factor which influences roughness. Under more severe operating conditions when the generated strain, strain rate and temperatures are high wear modes influenced by thermo-physical and fracture properties as well as microstructural stability under these conditions, come into play and add to the 'no wear' roughness. In this paper they have addressed the issue of material response to grinding, in generating surface roughness. We neglect attrition which has an interactive relation to material response by undertaking single pass operations only. Examinations of the wheel after single pass showed minimal attrition and after each roughness due to workpiece wear generated in surface grinding of metals pass the wheel is dressed afresh.

Vengkatesh et al. (1998) commence the study by recording the roughness generated under conditions of very low depth of cut from a variety of materials possessing a range of hardness. The analytical method used is power spectral analysis. The depth of cut is increased to generate conditions where the grinding force and traction also increase commensurately and wear and surface damage ensue. Using the 'no wear' roughness power spectrum generated by the method described in a previous paper as a datum, we study the shift in this power spectra due to such damage as a function of depth of cut and material response. Grinding is done on the flats of aluminium, copper, titanium and a hard steel.

2.5 Grinding Fluid

2.5.1 Effectiveness of Grinding Fluid

The benefits of cutting fluids are generally recognized throughout the industry. Despite this, cutting fluids are often treated as an afterthought and given insufficient attention. Ebbrell et al. (1999) found that the boundary layer of air around the grinding wheel deflects most of the grinding fluid away from the grinding zone. A better understanding is required of the hydrodynamics of cutting fluid delivery and ways to optimize it.

A cutting fluid has three main functions when applied to the grinding process. There are, bulk cooling of the work piece, the flushing away of the chips and dislodged wheel grits and lubrication. Bulk cooling and flushing are reasonably understood but the lubrication effects of the cutting fluid are less clear. It is generally accepted that cutting fluids lower the grinding zone temperature due to lubrication, which reduces wheel dullest, rather than by removing heat from the grinding zone. By reducing wheel dulling, friction and hence power is reduced so that the heat generated is limited. Bulk cooling and flushing can be achieved even though very little fluid enters the contact region between the grinding wheel and work piece. Lubrication depends on fluid entering the contact region and although a large volume may not be necessary to achieve this purpose, fluid delivery will be ineffective if no fluid enters the grinding zone. This investigation was aimed at achieving a better understanding of the effect the boundary layer has on fluid delivery (Ebbrell et al., 1999).

2.5.2 Cutting Fluid Delivery

With regard to the grinding process particular problems exist due to the high surface speeds of the wheel, which causes a boundary layer of air around the wheel periphery. The boundary layer restricts the flow of cutting fluid into the grinding zone. In example, flood delivery via a shoe or jet delivery tangential to the wheel via a nozzle, are not believed to fully penetrate this boundary layer and, thus, the majority of the cutting fluid is deflected away from the grinding zone. According to Ebbrell at el., flood delivery of a cutting fluid is usually delivered from a shoe which is fitted around the wheel surface. This method typically delivers large volumes of cutting fluid at low velocity. Therefore, earlier it was suggested this method was ineffective, especially under high speed grinding conditions where the energy of the fluid is not sufficient to penetrate the boundary layer of air surrounding the wheel. Delivery of cutting fluid via a nozzle in the form of a jet can have two benefits. Firstly the fluid can be delivered with a velocity great enough to penetrate the boundary layer of air and secondly, if applied at a high enough velocity, it may be used to clean the wheel mechanically by removing adhered metal.

The angle at which the cutting fluid is delivered has been the subject of much research in recent years. Delivering the cutting fluid as near to tangential to the grinding wheel as possible, is a common approach with the cutting fluid directed straight towards the grinding zone. However, this is contrary to investigations which have suggested the nozzle be positioned at an angle to the wheel periphery (Ebbrell et al., 1999).

Unfortunately different investigations have offered conflicting optimum angles at which to position the nozzle. This disparity may be due to the viscosity of the cutting fluid and its velocity at the nozzle exit. As stated by Trmal and Kaliszer (1976) the benefits of using scraper plates. Using a pitot tube to measure the velocity of the boundary layer, a decrease in air velocity occurred as the scraper plate was moved towards the wheel periphery. This is supported by Campbell who investigated the hydrodynamic pressure at the wheel or work piece interface caused by the passage of cutting fluid beneath the wheel. At a critical wheel speed this pressure measured zero Introducing a scraper plate allowed the grinding wheel speed to be increased by 20 % before the hydrodynamic pressure again measured zero. The need for high fluid velocities to penetrate the air boundary layer make the application of water based cutting fluids much more difficult in terms of a coherent jet.