Effects of High Pressure Coolant Jet on Grinding Temperature, Chip and Surface Roughness in Grinding Different Steels

A Project Thesis

By

Md. Abu Tarique Siddiqui

DEPARTMENT OF INDUSTRIAL & PRODUCTION ENGINEERING
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DHAKA-1000

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Submitted to the Department of Industrial & Production Engineering, Bangladesh University of Engineering & Technology, Dhaka, in partial fulfillment of the requirements for the degree of **Master of Industrial & Production Engineering** on September, 2006.

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BOARD OF EXAMINERS

1. Dr. Nikhil Ranjan Dhar — Chairman (Supervisor)
   Professor
   Industrial & Production Engineering Department
   BUET, Dhaka.

2. Dr. A K M Masud — Member
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   Industrial & Production Engineering Department
   BUET, Dhaka.

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DHAKA-1000

September, 2006

Declaration

It is hereby declared that this thesis or any part of its has not been submitted elsewhere for the award of any degree or diploma

Countersigned

Dr. Nikhil Ranjan Dhar
Supervisor & Professor
Industrial & Production Engineering Department
BUET, Dhaka

Md. Abu Tarique Siddiqui

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Abstract

Grinding can be described as a multi-tooth metal cutting operation in which material is generally removed by shearing and ploughing in the form of micro sized chips by the abrasive grits of the grinding wheel. As a result high temperature is produced in the grinding zone due to large negative rake and high cutting speed of the grinding wheel. Suitable cutting fluid is employed to reduce the temperature through cooling and lubrication in the cutting zone. As conventionally applied cutting fluid is unable to enter into the chip tool interface, the interface temperature is reduced to some extent. But HPC jet effectively reduces cutting zone temperature entering into chip tool interface maintaining a good surface integrity. This paper deals with grinding temperature, Chip morphology and surface roughness in grinding AISI-1040 steel while applying HPC jet from a tangential direction of the grinding wheel grits and compare the result with that of measured in completely dry grinding. Experimental results show that HPC jet application drastically reduces the cutting zone temperature resulting longer tool life and a better surface integrity for the finished work piece.

Contents

List of Figures

List of Tables

Chapter-1

Introduction

1.1 Introduction

Grinding is one of the oldest machining processes. Ancient human became the first grinding engineers when they discovered one could take two rocks and rub them together in order to form tools and weapons. Grinding engineers now employ the most modern techniques to remove material to form their work piece to obtain super finished product. In today's global market, there is the up to date task to make the machining process more efficient. These can be described as a multi-tooth operation in which a number of abrasive grains held by a bonding material perform the cutting operation. When only a small amount of metal must be removed, the finishing operation can be done on a grinding machine, using a rough and then a fine grind. In grinding, material is generally removed by shearing and ploughing in the form of micro sized chips by the abrasive grits distributed and held in position on the wheel by a non-metallic or metallic bond. Therefore, the grinding wheel must be porous and able to withstand high cutting loads that are placed on the abrasive grains during grinding and on the bonding bridges that hold the grains in position. The nature and the properties of the grinding wheel at the interface between the bonding bridge and the abrasive grains are very important when one considers how forces are transmitted into the bonding bridges through the interfacial layer. Vitrified bonds are typically used for high performance grinding processes and in comparison with other types of bonds, vitrified bonds permit easy dressing at the same time it possess high levels of resistance to wear [**Jackson et al. 1995, 2001**]. The bonding system that is used to hold abrasive grains in place reacts differently to forces that are placed on individual bonding bridges. The bond used in a grinding wheel has several functions:

- retain the abrasive grain during the process
- wear at a controlled rate with respect to the grain wear
- resist centrifugal forces, especially in high speed grinding
- readily exposes the grain to the work, where possible

Dull abrasive grains are caused by the generation of wear flats on active grains that leads to an increase in the area of contact and frictional interactions between abrasive grain and the workpiece. At the point of dulling of the abrasive grain, very high temperatures exist in the area of contact that greatly enhances adhesion and chemical reaction between two surfaces. If grain and bond bridge fracture does not occur during grinding then the plateau area on the grain widens and the rate of wear increases. If fracture is delayed further, as with hard grinding wheels, then the wheel becomes glazed and the workpiece is thermally damaged.

One of the major limiting factors of production rates in grinding is thermal damage. This damage can be reduced by the application of a cutting fluid that removes the heat produced due to shearing by cooling and heat generation due to friction or rubbing between the two surfaces by lubrication. The purpose of the fluid is to flush away chips from the grinding process **[Ebbrell et al., 2000]**.

Grinding process is characterized mainly by high specific energy requirement due to large negative rake and high cutting speed, which results in very high temperature. Such high temperature often leads to several problems like;

- A large heat affected zone
- Change in hardness and micro structure of the work piece
- Development of un-tempered and over tempered martensitic layer in heat treatable ferrous alloys
- Burning and its consequences
- Developments of high tensile residual stresses and micro cracks

The tensile residual stresses, if present in the ground sample, results in reduction in both the static and dynamic strength and corrosion resistance and leads to distortion just after machining and in service life. The tensile residual stress also induces surface and sub surface micro cracks especially in case of brittle materials.

Another distinct problem in grinding ductile and sticky materials is wheel loading mainly due to accumulation of chip particles in the inter grit spaces. This reduces the grinding efficiency and hence requires frequent redressing of the wheel. Thus, wheel loading also cuts down the total useful life of the wheel. Besides that wheel-loading also causes rise in forces, temperature and vibrations, poor surface finish, re-deposition of fine chips, poor surface integrity etc. It appears that the high temperature in grinding zone is the main problem and hence methods were tried out over the years to tackle this problem. Application of proper grinding fluids at times, reduced the above problems to some extent through cooling and lubrication of the grinding zone. The commonly used fluids are neat oil, soluble oil, semi synthetic and synthetic fluids with or without additives and inorganic salts. **Gong et al. [2004]** work of four major kinds of grinding fluids and confirm that there is no clear fluid that is perfect in all aspects. It would be ideal to combine the heat removal, filterability, cost and environmental properties of the synthetic fluids with the lubricity, maintenance and wheel life of the straight oils. There is a possible way to aspire to this goal since most cutting fluids are made from a concentrate mixed with water.

The application procedures of these fluids are generally by flood cooling or in the form of jet or even mist. Interrupted grinding technique by using grooved wheels or Dalmatian wheels, super abrasive wheels and electrochemical grinding with continuous cleaning or dressing by ultrasonic have also been investigated and tried out to reduce the grinding temperature.

High Pressure Coolant delivery is an emerging technology that uses up to 100 bar (1500 psi) to deliver a high velocity jet of coolant to the work center. The combination of fluid volume and high velocity provides a major improvement to the machining process over the traditional flooded delivery. Long stringy chips are broken up and rapidly flushed from the cutting edge so that they aren't re-cut by the tool, providing longer tool life and a better surface finish. Heat is reduced at the tool as a result tool life extend. Greater lubricity of the coolant is achieved by the high velocity jet between the chip and the cutting tool. Productivity and quality are maximized and coolant life is extended. The high pressure and high volume delivery of clean coolant to the cutting surface permit increased tool life and higher rotational speeds with reduced pecking and cycle times. Cutting fluids have the dual tasks of cooling the cutting surface and flushing chips. They also help control chip-tool interface temperatures and this can prolong tool life, improve cut quality, and positively influence part finish. For machining operations, high pressure is often recommended. A powerful stream of cutting fluid that can reach the cutting area provides strong chip removal and in some cases enough pressure to deburr.

Ample research has been done in various directions and is still going on aiming improvement in overall grinding efficiency through controlling the quality of the surface machined (roughness and accuracy), to reduce the cutting zone temperature dramatically and to increase tool life under the high pressure coolant jet.

1.2 Literature Review

1.2.1 Grinding Temperature

Outwater and Shaw [**1952**] noted that grinding is associated with much high specific energy requirement which may be an order higher than that required in conventional machining processes. The obvious consequence of this high specific energy is very high grinding zone temperature. They analytically found the mean and maximum surface temperature using Jaegar's model of semi-infinite body and insulated friction slider with uniform heat distribution.

Walter et al. [**1975**] measured the temperature of the grinding zone by embedded thermo-couple technique and correlated the grinding temperature with the structural changes in the ground workpiece.

Dex Ruisseaux and Zerkle [**1970**] reported that the heat generated due to chip formation in grinding at the shear plane results in high temperature near the cutting edges of the grits and in the material. But this temperature is not important as the material ahead of the grit is removed as chips. The quality of the ground surface would depend upon the surface and subsurface temperature and they analytically found the expressions for the same using Jeager's Model assuming uniform distribution of the heat source. If the chips are not removed, they could clog the wheel and essentially dull the wheel so that the only cutting operations occurring would be plowing and rubbing. If this clogging were to happen, the forces and energy input would greatly increase as would the heat input to the workpiece [**Ge et al., 2003**].

Malkin and Anderson [**1974**] in an experimental study derived an expression of the percentage of the total heat flowing into the work piece as;

$$R = \frac{U - 0.45U_{ch}}{U} X\,100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where,

R = partitioning coefficient

U = specific energy

U_{ch} = specific energy of chip formation (13.8 J/mm^3)

Malkin [**1974**] realized that the temperature on the surface of the work piece is governed by two temperature fields, namely, the local temperature field below a particular grit and the average temperature due to distributed heat source action over the whole contact length. The analytical solution was obtained assuming the material properties at a particular elevated temperature.

Yamamoto et al. [**1977**] noted that the average temperature at the work surface is dependent on the grinding wheel performance, work piece material characteristics and the grinding parameters.

Snoeys et al. [**1978**] indicated that the estimation of temperature by analytical or numerical techniques would be influenced by the type of heat source distribution. However, they pointed out that the use of rectangular distribution would suffice the purpose of evaluating the temperature field. The actual contact length greatly differs from the geometric contact length and they expressed the actual contact length as a function of the process parameters and geometric contact length.

Kops and Shaw [**1982**] identified the temperature at the grit, surface and subsurface of the work piece to be related to;

- Grinding wheel wear
- Surface finish
- Surface integrity and accuracy

Skalli et al. [**1982**] estimated temperature field and its history on the surface and subsurface of the work piece using finite element method. They considered the actual contact length to be twice the geometric contact length and the heat source to be uniformly distributed. The variation of thermal properties of the material with temperature was neglected.

In a similar work, Vansevenant [**1987**], however, assumed the heat source to be triangular in nature. The variation in the thermal properties of the work material with temperature was taken into account.

Shaw [**1990**] proposed a simpler analytical approach to evaluate surface temperature in fine grinding and finally arrived at an expression of partitioning coefficient.

Levine [1991] has modified a few previously developed models to account for the fact that some of the grinding energy is generated at the shear plane and not entirely at the wear flats as has been assumed previously. The modification did not affect the results for alumina wheels, but the errors of the previous models were considerable for CBN wheels.

Rowe et al. [1991] have also developed a thermal model for the grinding process at the grain zone. The only problem with the present model is assigning the grain wear in flat area.

Wager and Wu [1991] studied the nature of temperature variation in up and down grinding. They notod that the temperature increases with the increase in infeed and work speed and the temperature difference between the up and down grinding follows the same pattern.

1.2.2 Control of Grinding Temperature

Grinding is basically a mechanical process, characterized by high temperature, which is generally controlled by a lower wheel speed, lower material removal rate, use of coolants, softer wheels and intermittent grinding. Duwell et al. [1966] postulated that the chemical reactions at the ground surface during grinding play a vital role due to high temperature and higher reactiveness of the freshly formed ground surface.

Malkin and Lenz [1978] suggested that proper grinding fluids should be used to lubricate and thus reduce the specific energy requirement, as the conventional grinding fluids are ineffective in controlling the high temperature. Snoey et al. [1978] also supported the idea that in grinding, lubrication should be given more importance as long as normal fluids are used. Nee [1979] studied the applicability of additives and solid lubricants in grinding tool steels with diamond wheels. Some of the additives, especially colloidal graphite, improved the wheel performance but solid lubricant failed to improve the tool performance. Yasui and Tsukuda [1983] reported that though the application of grinding fluids brings down the temperature but their film boiling temperature restricts their effectiveness.

Shaw [1985] suggested the following methods to control the grinding temperature:

- lower wheel speed
- lower material removal rate
- use of coolants
- softer wheels
- Intermittent grinding

Howes [1990] has reported that the lubricating and the cooling properties of the grinding fluids directly influence the surface integrity of the work piece. But the effectiveness of coolants are lost if the temperature exceeds the film boiling temperature of the fluids. One of the most important factors preventing or restricting the grinding fluid from penetrating into the grinding zone has been the thin but stiff layer of air around the rotating wheel. The rotating wheel sucks the air through the facial pores and due to the centrifugal action this air comes out through the periphery forming a stiff airflow.

Akiyama et al. [1984] and Aoyama and Inasaki [1984] studied the improvements in the grinding fluid action using painting and cardboard technique. The faces of the wheels are covered with silicon rubber paints, which prevent the wheels to draw in air from the surrounding. In card board technique a scrapper board made of soft card board is held against the wheel, which diverts the air strip away and facilitates the coolant delivery at the grinding zone. Nakayama et al. [1977], Snoeys et al. [1978] and Shaw [1985] advocated the use of slotted wheels to control the temperature. Nakayama et al. [1977] reported reduction in the forces and temperature by using grooved wheels due to intermittent cutting and better coolant delivery. Shaw [1985] reported that disk wheels provided with through holes randomly distributed over their faces are found to perform with less temperature in face grinding mode. This was attributed to intermittent cooling of the work piece. Shaw reported the use of 'Dalmatian' wheel to control the temperature.

Aoyama and Inasaki [1984] adopted on line ultrasonic cleaning method to continuously dress the wheel and remove any loaded particle. This helped in maintaining the wheel sharpness and provided less temperature. Graham and

Whitson **[1978]** delivered the coolants through the pores of the wheels and observed benefits like reduction in the forces, temperature and surface cracking and improvement in wheel life.

Eda et al. **[1985]** studied the effectiveness of the jet infusion technique of application of the grinding fluids. This technique brings out all the potentials of the grinding fluids. **Andrews [1985]** states that in creep feed grinding there must be sufficient fluid flow rate to maintain the grinding zone temperature below a critical value. However, in high efficiency deep grinding (HEDG) it has been shown that the specific grinding energy is much lower than creep feed grinding and the heat carried out by the chips is more significant than through the grinding fluid directly.

Pecher and Malkin **[1984]** reported that grinding with CBN wheels is almost free from thermal damages because of retention of its grit sharpness and chemical stability. Shaw [**1990]**, Levine **[1991]** and Rowe [**1991**] suggested that the partitioning coefficient is also very small in case of CBN wheels, which further reduces the thermal damages.

1.2.3 Mechanism of Chip Formation and its Characteristics

The study of grinding chip is required to understand the mechanism of chip formation and those of material removal. Early investigators **[Dall 1939, Ernst 1950 and Tarasovs 1950]** identified the mechanism of chip formation in grinding to be mainly shearing, like that in other conventional machining processes, by observing the shapes of the chips under optical microscope.

Wetton **[1969]**, while analyzing the composition of the grinding debris, found not only grinding chips but also fractured and pulled out grit and bond materials, which latter necessitated careful interpretation of optical and scanning electron microscope.

Cashion et al. **[1974]**, while studying Mossbauer spectrum from fine grinding chips, observed that the chips are mainly formed by shearing process. Doyle and Aghan **[1975]** supported the same observations while examining the grinding chips under transmission microscope. They also obtained clear lamella or segments, which clearly indicated the mechanism of chip formation to be shearing. Malkin **[1979]** also opined that the major mode of material removal in grinding is shearing. Doyle and Dean **[1980]**, classified different types of chips obtained in grinding as;

- chips of no particular shape
- spherical chips and
- lamellar chips.

Debris having no shapes is generally produced by rubbing of the wear flats of the grits with the work surface and by ploughing, and these kinds of chips are associated with poor surface finish and redeposition of chips on the ground surface. Spherical chips are generated by surface oxidation of other kinds of chips. Lamellar chips are usually produced by shear as in conventional metal cutting action.

Sakuma and Tado [1962] reported that the mode of chip formation changes with the change in the hardness and the heat treatment cycle of the work material and the wheel speed. They obtained leafy lamellar chips at low wheel speed, which became longer with the increase in wheel speed. With further increase in wheel speed follow spherical chips were obtained.

Ramanath et al. [1987] uttered that the spherical chips can form either by exothermic reaction of the chips with the oxygen present in the vicinity or due to sharp bending of the very thin platelets. These platelets are commonly formed due to elastic rubbing of the wear flats of the grits on the work piece. They suggested that high count of spherical chips indicate severe rubbing of the wheel with the work piece.

Pai et al. [1989], while grinding ductile materials, reported that long lamellar filament type chips, blocky particles and spherical chips were obtained. The length of the filament type chips and number of spherical chips were found to decrease on taking harder materials and / or using sharper wheels.

Profusion of spherical chips within the grinding debris hints that even melting may takes place in grinding. But Outwater [1952] and Shaw [1990], recommended that as melting is a time-temperature phenomenon the material never stays at very high temperature for sufficient time to melt.

Kumandari et al. [1983] investigated the mechanism of grinding by simulating it by turning and shaping with highly negative rake tool and found that side flow occurs instead of chip formation when the tool is provided with very large negative rake.

König Schmalt [1978] observed lamellar chips for ductile materials and less number of lamellar chips for harder materials. Chattopadhyay et al. [1991] similarly observed that mostly crushed type chips and lamellar chips are obtained while grinding harder and ductile materials respectively with brazed monolayer CBN and diamond wheels.

1.2.4 Characteristics of Ground Surface

The surface characteristics of engineering materials have a significant effect on the serviceability and life of a component thus it cannot be neglected in design. Surface engineering can be defined as the branch of science that deals with methods for achieving the desired surface requirements and their behavior in service for engineering components. The surface of any component may be selected based on texture and color, but engineering components generally demand a lot more than this. Engineering components must perform certain functions completely and effectively, under various conditions in aggressive environments.

Marshall and Shaw **[1952]** described burning as the appearance of the temper color on the ground surface due to high temperature. They observed burning to occur with loaded wheel. Outwater and Shaw **[1952]** found that the redeposition of chips on the ground surface increases in absence of oxygen and this may render a material almost ungrindable. The oxygen, even if present in traces, would from a thin oxide layer on the nascent ground surface and that hinder further redeposition rendering the material grindable.

Welton **[1969]** noted that redeposition increases with the increase in infeed due to higher temperature. Bond materials were found to exist along with the redeposit chip particles on the ground surface. Malkin and Cook **[1971]** observed a relation between burning and the forces. The normal and the tangential forces and their ratio suddenly increase at the onset of the burning. Malkin **[1974]** reported that in grinding hardened steels, burning is associated with a hardened zone at the subsurface followed by a soft tempered zone just beneath it. Burning would occur when the critical temperature for austenite formation has been reached on a sufficiently large portion of the grinding zone. Field and Koster **[1978]** suggested that the ground surface should not contain undesirable surface defects such as micro cracks, surface hardening or softening, overheating or burning, intemperate and /or over tempered martensites.

Malkin and Lenz **[1978]** described the burning to be characterized by the formation of oxide layers on the surface and transformation of austenitic structure. Burning is a critical average temperature phenomenon and the burning temperature is insensitive to normal grinding fluids.

Snoeys et al. **[1978]** suggested that the surface characteristics can be expressed as change in the physical and/or chemical characteristics of the upper layers of work piece, fatigue life, stress corrosion, appearance of tensile stresses, surface and subsurface cracks etc.

Burning causes change in color and Shimamune and Ono **[1983]** attributed this to optical interference. The color depends on the thickness of the oxide film, which develops due to temperature over a certain limit (500^0C). Grinding burn is accompanied by a color change and visible marks due to severe plastic deformation of the surface material **[Malkin 1988]**.

Prasad and Prasad [**1991**] studied the surface and the subsurface of abraded ferrous alloys by pin on disk method. For hardened steel, the abraded surfaces appear to be uniform and had a groovy structure, whereas in annealed specimens micro pitting is observed. In annealed steel subsurface cracks, microstructural changes and grain refinement occurs, but negligible microstructural changes takes place for the hardened steels.

The importance of surface integrity depends upon its impact on product performance **[Shaw 1996]** such as: fracture strength, fatigue strength, corrosion rate, stress corrosion cracking, wear, magnetic properties and dimensional stability.

1.2.5 Adverse Effects of Conventional Cutting Fluid Applications

Traditionally, manufacturers need to reduce the manufacturing cost has led to higher demand for increasing productivity. In real-world environmental regulations are being put in place, manufacturers are forced to re-evaluate their manufacturing processes and reduce or eliminate their waste streams. The waste streams present in machining include flow of cutting fluid, chip flow, and cutting tool usage.

The application of cutting fluid may not always reduce the cutting tool wear as is commonly believed. Rather some conditions like machining steels by carbide tools, the use of coolant may increase tool wear. It has been experienced [**Shaw et al. 1951**] that there was more tool wear when cutting with coolant than cutting dry in case of machining AISI 1020 and AISI 4340 steels by M-2 high speed steel tool cutting. Seah et al. [**1995**] also reported that at the first stage of machining (first 40 seconds or so), tool wear was faster in wet cutting than in dry cutting.

During machining, the cutting tool generally undergoes both flank wear and crater wear [**Trent 1983**]. Flank wear generally causes an increase in the cutting forces, dimensional inaccuracy and vibration. Crater wear takes place on the rake face of the tool where the chip slides over the tool surface. Another experimental investigation was conducted **[Cozzens et al. 1995]** on single point boring. This was aimed to study the role of cutting fluid, tool and workpiece material, tool geometry and cutting conditions on machinability. The results indicated that the cutting fluid conditions had no significant effect on surface texture, forces and built-up edge. Since boring is a high-speed operation and lubrication is ineffective, no effect was seen on the forces. However, the cutting fluid was found to have a significant effect on surface integrity.

Proper selection and application of cutting fluid generally improves tool life. At low cutting speed almost four times longer tool life was obtained [**Satoshi et al. 1997**] by such cutting fluid. But surface finish did not improve significantly. Wearing of cutting tools not only causes loss of the cutting edges or tips of the inserts but loss of the entire insert after wear of all the corners. From an environmental perspective, therefore, the significant waste is not the portion of the tool worn away by the tool-work contact, but the remaining portion of the tool that is disposed after its useful life **[Sheng and Munoz 1993**].

Manufacturing by machining constitutes major industrial activities in global perspective. Like other manufacturing activities, machining also leads to environmental pollution **[Ding and Hong 1998]** mainly because of use of cutting fluids. These fluids often contain sulfur (S), phosphorus (P), chlorine (Cl) or other extreme-pressure additives to improve the lubricating performance. These chemicals present health hazards. Furthermore, the cost of treating the waste liquid is high and the treatment itself is a source of air pollution. The major problems that arise due to use of cutting fluids are [**Aronson 1995**]:

- environmental pollution due to breakdown of the cutting fluids into harmful gases at high cutting temperature
- biological hazards to the operators from the bacterial growth in the cutting fluids
- requirements of additional systems for pumping, local storage, filtration, temporary recycling, cooling and large space requirement
- disposal of the spent cutting fluids which also offer high risk of water pollution and soil contamination

Since beginning of twentieth century people [**Peter et al.1996**] were concerned with possible harmful effects of various cutting fluid application. It has been estimated [**Bennett 1983**] that about one million workers are exposed to cutting fluids in the United States alone. Since cutting fluids are complex in composition, they may be more toxic than their constituents may be irritant or allergenic. In addition, both bacteria and fungi can effectively colonize the cutting fluids and serve as source of microbial toxins. Hence, significant negative effects, in terms of environmental, health, and safety consequences, are associated with the use of cutting fluids. The effects of exposure to the fluids on health have been studied for over 50 years; beginning with the concern that cutting fluid (oil) is a potential etiologic factor for occupational skin cancer (Epidemiological studies indicate that long-term exposure to metal working fluids can lead to increased incidence of several types of cancer). The

International Agency for Research on Cancer has concluded that there is "sufficient evidence" that mineral oils used in the workplace is carcinogenic **[Peter et al.1996]**. Workers are exposed to metal cutting fluids via three routes **[Bennett et al. 1985]**; skin exposure, aerial exposure and ingestion. Skin exposure is the dominant route of exposure, and it is believed that about 80 percent of all occupational diseases are caused by skin contact with fluids **[Bennett et al.1985]**. Cutting fluids are important causes of occupational contact dermatitis, which may involve either irritant or allergic mechanisms. Water mixed fluids generally determine irritant contact dermatitis and allergic contact dermatitis when they are in touch with workers skin. Non-water-miscible fluids usually cause skin disorders such as foliculitis, oil acne, keratoses and carcinomas.

Iowa Waste Reduction Center **[1996]** reported that besides potential skin and eye contact, inhalation is also a way to occupational exposure. Mists are aerosols comprised of liquid particles (less than 20 µm). During machining process, a considerable amount of heat is generated for which the cutting fluid may attain a temperature sufficiently higher than the saturation temperature. The vapor is produced at the solid-liquid interface as a result of boiling. Vapor may be generated also at the liquid-air interface when the fluid vapor pressure is less than the saturation pressure, namely as evaporation phenomena. Vapor generated then may condense to form mist. The non-aqueous components of the cutting fluid, such as the biocide additives, appear as fine aerosol that can enter the workroom air. Additionally, the cutting fluids impact with both stationary and rotating elements within the machine tool system, which leads to mechanical energy being transmitted to the fluid. Thus, the cutting fluid has higher surface energy and becomes less stable and disintegrates into drops (atomization). The spray from the fluid application also may generate mist. A total fluid loss of 5 to 20 percent may occur due to evaporation, atomization, splashing and drag out processes. Whether formed by atomization or evaporation/ condensation, small droplets may be suspended in the air for several hours even several days in the workers breathing zones. These drifting droplets tend evaporate furlher. Inhaled particles (with aerodynamic diameters less than 10 µm) deposit in the various regions of the respiratory system by the complex action of the different deposition mechanisms. The particulate is below 2.5 µm aerodynamic diameter deposit primarily in the alveolar regions which is the most sensitive region of lung. The parliculate in size ranges from 2.5 µm to 10-µm deposits primarily in the airways. The potential health effects of exposure to cutting fluid mists have been the subjects of epidemiological studies in the automotive industry. The mist droplets can cause throat, pancreas, rectum, and prostate cancers, as well as breathing problems and respiratory illnesses. One acute effect observed is mild and reversible narrowing of airways during exposure to cutting fluid mist **[Kennedy 1989]**.

Several other epidemiological studies have also suggested that exposure to fluid mist may be associated with increased risk of airway irritation, chronic bronchitis, asthma and even laryngeal cancer **[Bennett et al. 1985 and Eisen et al. 1994]**. The Occupational Safety and Health Administrations (OSHA) standard for airborne particulate (largely due to fluid mist) is 5 mg/m^3, and the United Auto workers (UAW) has proposed a reduction in the standard to 0.5 mg/m^3. The oil mist level in a plant ranged from 4.2 to 15.6 mg/m^3 but fell to between 0.47 to 1.68 mg/m^3 when a different cutting fluid was substituted in the system [**Welter 1978**].

Anti misting compounds, such as a polymetha-acrylate polymer, poly-isobutylene and poly-n-butane in concentrations of 0.2% as well as poly (1, 2-butene oxide) have been suggested for addition into cutting fluids [**Bennett et al. 1985**]. But, consideration must be given to the effects of these chemicals upon humans. The most effective way to control mist exposure is to use mist collector to prevent mist from entering plant air [**Leith et al. 1996**]. Many collectors use several stages of filters in series for the purpose. Other collectors use centrifugal cells or electrostatic precipitators as intermediate stages. Any collector using a 95% Di-Octyl Phthalate (DOP) or High-Efficiency Particulate Air (HEPA) filter as a final collection stage has been tested as high efficiency when new. However, its efficiency will decrease with time. Moreover, the oil droplets may undergo partial or complete evaporation as they travel to collector [**Raynor et al. 1996**]. The generated organic vapors may return to the room and affect work health, and may re-condense on the cool surface causing safety and maintenance problems.

Pollution free manufacturing is increasingly gaining interest due to recent development of pollution-prevention legislation, European initiatives on product take-back or recycling, which affect many export industries in the US, and a growing consumer, demand for green products and production processes. Concern for the environment, health and safety of the operators, as well as the requirements to enforce the environmental protection laws and occupational safety and health regulations are compelling the industry to consider a high-pressure coolant jet machining process as one of the viable alternative instead of using conventional cutting fluids.

Cutting fluids are widely used in machining operations to obtain accuracy of part dimensions, longer tool life and in some cases better surface finish. The research literature identifies two primary functions of cutting fluids in machining operations: lubrication to reduce process friction and cooling to remove process generated heat. A secondary function of the cutting fluid is to transport the chips from the cutting zone. Cutting fluid systems are used in industry to deliver fluid to the cutting process, re-circulate fluid, separate chips, and collect fluid mists. The machining costs (labor and overhead) in the US alone are estimated to be $300 billion/year [**Komanduri and Desai 1983**]. The costs associated with the use of cutting fluids is estimated to be about 16% of the manufacturing costs [**Byrne and Scholta 1993**] which is many more times than the labor and overhead figures quoted above. A recent study in Germany found that 16% of machining cost in the high volume manufacturing industries is associated with the use of cutting fluids (procurement, maintenance and disposal) while only 4% of the cost was associated with cutting tools [**Aronson 1995**]. It is well documented that 7–17% of machining cost of a work-piece is due to coolant-lubricant deployment **[Klock, 1997]**. The use of cutting fluids also requires additional equipment for plant housekeeping.

2.2 Summary of the Review

A review of the literature on grindability of different steels highlights the huge potential of the control of grinding temperature and its detrimental effects on surface integrity of the finished product. It is realized that the grinding temperature has a critical influence on surface integrity of the product, tool wear and tool life. All these responses are very important in deciding the overall performance of the grinding wheel. The dimensional accuracy and surface integrity of the workpiece also deteriorate due to high temperature. The conventional cutting fluids are not that effective in high speed machining like grinding particularly in continuous cutting of materials likes steels. Further, the conventional cutting fluids are not environment friendly. The disposal of the cutting fluids often leads to local water pollution and soil contamination. Recycling and reuse of conventional cutting fluids creates further problems.

Metal cutting fluids changes the performance of machining operations because of their lubrication, cooling and chip flushing functions. Typically, in the machining of hardened steel materials, no cutting fluid is applied in the interest of low cutting forces and low environmental impacts. High pressure cooling presents itself as a viable alternative for hard machining with respect to tool wear, heat dissertation and machined surface quality.

High-pressure coolant may be a credible route in the manufacturing industry for achieving maximum performance from the available cutting tools for high speed machining with efficient cooling and lubrication techniques in order to minimize heat generated at the primary shear zone, chip–tool and tool–workpiece interfaces achieving slow tool wear while maintaining cutting forces/power at reasonable levels, if the high pressure cooling parameters can be strategically tuned. . This cooling technology may be perfected by the provision of efficient high-pressure cooling systems and tooling which may be appealing to industry in terms of costs.

The advantages of high cooling technology include

- significant improvement to tool life,
- effective chip segmentation and
- efficient cooling and lubrication.

Mazurkiewicz et al. [1989] reported that a coolant applied at the cutting zone through a high-pressure jet nozzle could reduce the contact length and coefficient of friction at chip-tool interface and thus could reduce cutting forces and increase tool life to some extent. It has been reported that the cooling and lubrication is improved in high speed machining of difficult-to-machine materials by the use of high-pressurized coolant/lubricant jet [**Wrethin et al. 1992**].

Alaxender et al. [1998] reported that coolant injection offered better cutting performance in terms of surface finish, tool force and tool wear when compared to flood cooling.

Kovacevic et al. **[1995]** suggested that the application of high-pressure water jet through the tool rake face, friction is reduced at the tool-chip interface due to formation of a cushion layer, which prevents intimate contact at the tool-chip interface, consequently leading to bending and self-breakage of chips.
From all these investigations, it evident that applying cutting fluid in the form of a jet at higher pressure into the cutting zone is more beneficial than conventional cooling techniques.

It has been reported **[Rahman et al. 2000]** that the machining characteristics were found to be effective by using high pressure coolant at 17 bar with a feed rate of 0.05 mm tooth^{-1}, depth of cut 0.35 mm and cutting speed 150 m min^{-1}. Hence, further experiments were conducted with the observed cutting conditions and varying the hardness of the workpiece. For each workpiece hardness samples with dry cut, conventional coolant and high pressure coolant are analyzed and found that High pressure coolant is more effective than dry and flood cutting of steel.

Senthil kumar et al.[**2002**] opined that improvement in tool life and surface finish is found by applying high-pressure coolant while machining with uncoated insert having different hardness. However, there is no significant difference in surface roughness with workpiece hardness for different types of inserts, with the application of high-pressure coolant. Generally, the values of surface roughness are well below 1.0 μm, which is even better than for grinding or EDM. It can be concluded that high pressure coolant is effective under the specified cutting conditions. For both coated and uncoated tools, the use of high-pressure coolant below the optimal hardness is found to be detrimental to the flank wear and hence tool life. This is due to the wear mechanism, and may be prompted by the ductility of the material, resulting in edge chipping that causes large tool wear and thus shortens tool life.

1.3 Objectives of the Present Work

Literature survey reveals that application of high pressure coolant may improve the machinability characteristics in high speed machining and grinding which are inherently characterized by high temperature and responsible for several detrimental effects. But it appears that research in this direction has not been done yet systematically and thoroughly to have clear understanding of the behavior and extent of benefits of high pressure coolant jet in grinding different work materials including various steels.

The main objectives of the present work is to experimentally investigate the mechanism of metal removal and grindability characteristics in surface grinding of two steels of common use at different infeed rates;

i. under dry condition
ii. under high pressure coolant condition

Mainly in respect of

i. mode of chip formation
ii. actual grinding zone temperature and

iii. surface topography

The present research work provided the scopes of development and use of

i. design of a suitable nozzle for applying high pressure coolant jet
ii. Measuring grinding zone temperature by embedded thermocouple technique

Chapter-2

Design and Development of High Pressure Coolant System

2.1 Introduction

The major characteristic, which distinguishes grinding from other methods of machining, is a large contact area between the grinding wheel and the work piece and strong friction between abrasive grains, bond and work surfaces. Such a contact area and high rotational speed of a grinding wheel prevent the high pressure coolant (HPC) jet to reach the grinding zone. This can lead to thermal cracks of sub-superficial layers **[Brinksmeier et. al. 1999]**. A considerable amount of heat generated while feed is raised for higher MRR at same wheel speed. Secretion of heat results in substantial stresses in the workpiece and in the grinding wheel. In order to avoid these outmoded effects, an "optimal" cooling is required. The optimal cooling is associated with delivering a necessary amount of HPC jet to the grinding zone. **Hryniewicz et al.[2001]** experimentally examined that bulk porosity and nozzle position were the main parameters influencing the flow rate through the grinding zone. The researchers collected measurements for the useful flow rate and supplied flow rate while the work speed, depth of cut, nozzle distance, wheel porosity, dressing depth and dressing leads were varied and used to measure the amount of fluid passing through the grinding zone for straight surface grinding. This brings about an extensive reduction of the consumption of high pressure coolant which at the same time enables us to obtain economical and ecological advantages. But the use of conventional cutting fluids methods are major problem associated with oil based, are:

i. Ineffectiveness in desired cooling and lubrication
ii. Health hazards due to generation of obnoxious gases and bacterial growth
iii. cause inconvenience to no cleanliness of the grinding zone
iv. Corrosion and contamination of the lubricating system of the machine tools
v. Need of storage, additional floor space, pumping system, recycling and disposal
vi. Environmental pollution and contamination of soil and water.

In this view, it has already been observed throughout previous research that proper application of high pressure cooling may play vital role by providing not only environment benign but also significant in technological and economical benefits. In order to take advantage of HPC jet system should be properly designed and fabricated on grinding to lessen temperature of different steels. The following factors are important from the subject point of view:

i. Effective cooling by enabling HPC jet reach as close to the actual heat zones as possible

ii. Avoidance of bulk cooling of the tool and the job, which may cause unfavorable metallurgical changes

iii. Minimum consumption of HPC by pin-pointed nozzle impingement during chip formation

2.2 Design and Fabrication of HPC Jet Delivery System

The cutting fluid is collected from the reservoir of coolant tank, which needs to be strained at high pressure and impinged at high speed through the nozzle. Considering the conditions continual supply at 6 liter/min and pressure around 40 bar over a reasonably long time grinding of coolant required for the present research work, a coolant tank has been designed, fabricated and used at large capacity (200 liter). The photographic and schematic view of the coolant tank along with motor-pump assembly, flow control valve, relief valve and directional control valve is shown in Fig.2.1.

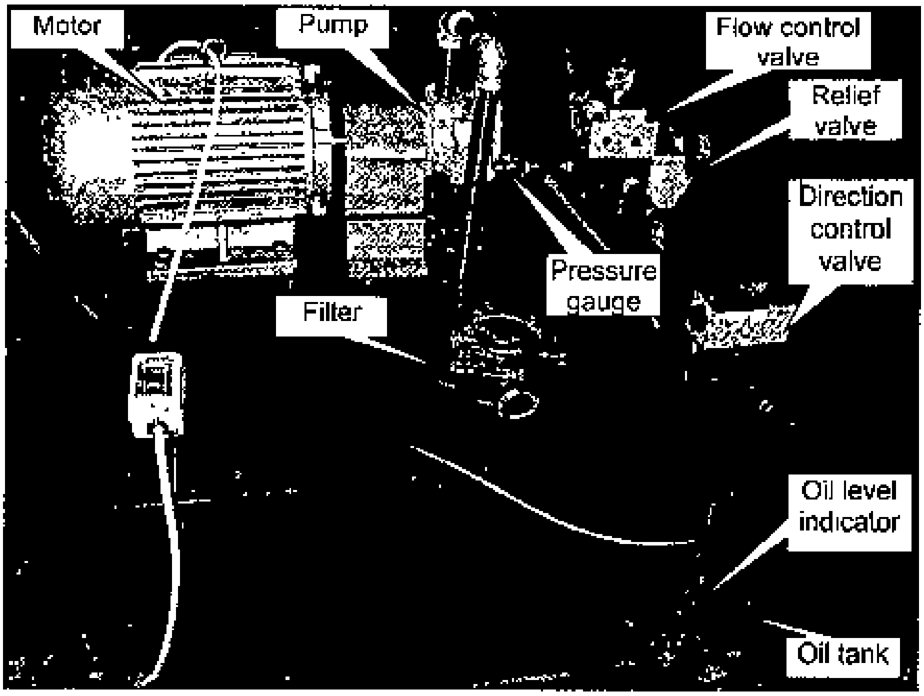


Fig.2.1 Photographic view of coolant delivery system

The coolant is contained in the coolant tank and a pump is used to ensure desired high driving pressure during the high withdrawal periods. This is accomplished by controlling relief valve through flow control valve that creates a high pressure. When the flow control valve is open, coolant taken from the tank at normal pressure is pressurized at a required pressure controlling by relief valve. A relief valve is installed one end in the discharge line of the flow control valve other end a return line back to the supply tank is to provide complete protection against an unexpected over pressure situation. The flow control valve is pressure and temperature compensating type valve and maintain a constant flow rate independent of change in system pressure (load) and temperature (viscosity of the fluid). The valve with an integral check valve allows a controlled flow and reverses free flow. The high-pressure coolant is impinged through a nozzle at the interface of the workpiece-grinding wheel. A direction control valve is used to control the flow direction of the jet during grinding.

2.3 Design and Fabrication of the Nozzle

The purpose of a nozzle is to achieve maximum fluid at optimal position under direct cutting fluid flow to interface between at the tip of the grits of the wheel and work surface. The nozzle also fulfills the purpose of increasing the fluid velocity by contracting the cross-sectional area of the jet stream.

Webster et al. [**2002**] developed the coherent jet for grinding operations due to the reduction of air entrainment in the cutting fluid, more accurate velocity matching to the wheel periphery, and accurate focusing into the cutting. Silva et al. [**2003**] have used them due to their high performance to compare different cutting fluids when grinding martensitic steel.

Ninomiya et al. [**2004**] found that by using a floating nozzle on a CBN wheel, the wheel wear was reduced in half for shallow depths of cut and low workpiece speeds. It was also found that the surface finish was enhanced under these conditions. When compared with traditional coolant application, the floating nozzle improves the grinding performance with an impressive one twelfth of the cutting fluid. The reason for this reduction is that the necessary amount of coolant reaches the grinding zone through the floating nozzle.

The nozzle has been designed and fabricated so that the nozzle spray pattern, covering area and coolant flow rate can be controlled. A schematically view of the nozzle developed and used as shown in Fig.2.2. The nozzle length and tip bore diameter are 128.9mmX0.5 mm respectively. It was fixed to the stand incorporated with the grinding wheel cover and connected with direction control valve through hydraulic pipe to supply coolant in the form of jet to the cutting zone. A flow control valve is used to control the flow of coolant as required. The jet should impinge at the cutting zone in liquid state only and setting of the nozzle is linear as coolant jet flow tangentially with the grinding wheel grits. The result of this arrangement is expected to be effective cooling with economical coolant dispensing. It is important to properly position coolant delivery nozzle to achieve the following:

- Getting the fluid to the tool/workpiece interface
- Minimizing mist and odor problems
- Controlling thermal shock

This is one of the most important functions of the fluid, and may require positioning fluid lines just to move chips out of the cutting zone. Nozzle is placed 30.0 mm away from the tool tip to minimize the interterence of the nozzle with the flowing chips and to reach quite close to the chip tool contact zone with out avoiding of bulk cooling of the tool and the workpiece, which may cause unfavorable metallurgical changes.

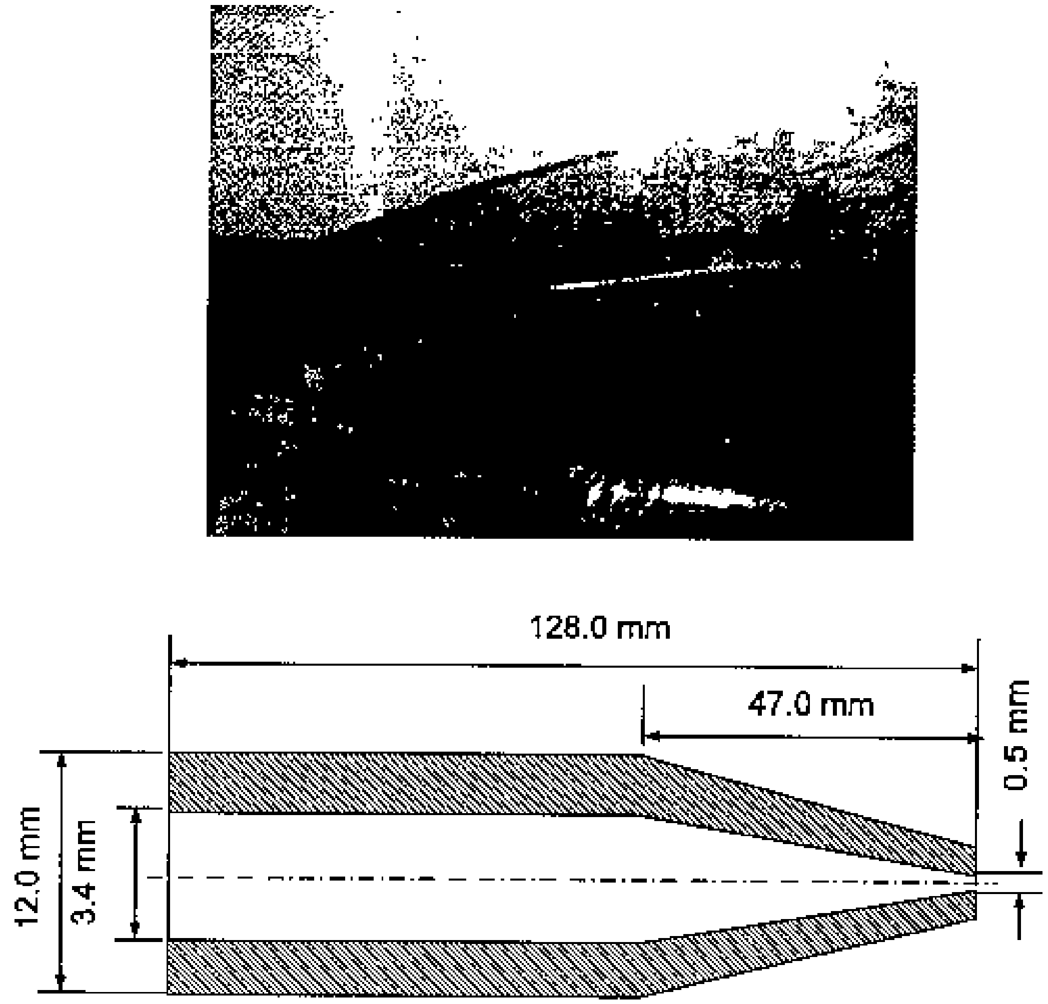


Fig.2.2 Photographic and schematic view of the nozzle used for coolant delivery at the cutting zone

Chapter-3

Experimental Investigations

3.1 Experimental Procedure and Conditions

High Speed grinding, like the cutting of hard materials, at higher speeds are those technologies, which are recently being increasingly applied in the production industries especially in mould producing. These machining process are characterized by their productivity, good surface finish quality and higher dimensional tolerances. This high speed causes the high cutting temperature.

The high cutting temperature generated during grinding not only reduces tool life but also impairs the product quality. The temperature becomes more intensive when cutting velocity and feed are increased for higher MRR (Material Removal Rate) and the work materials are relatively difficult to machine for their high strength, hardenability and lesser thermal conductivity are characterized by their productivity, good surface finish quality and higher dimensional tolerances.

The concept of high pressure coolant presents itself as a possible solution for high speed machining in achieving slow tool wear while maintaining cutting forces/power at reasonable levels, provided that the high pressure cooling parameters can be strategically tuned. It has the benefits of a powerful stream that can reach the cutting area, it provides strong chip removal, and in some cases enough pressure to deburr. High-pressure coolant injection technique not only provided reduction in cutting forces and temperature but also reduced the consumption of cutting fluid. The beneficial role of high pressure coolant on environment friendliness has already been established.

The aim of the present work is primarily to explore and evaluate the role of such high pressure coolant on grindability characteristics of some commonly used steels mainly in terms of chip formation modes, cutting zone temperature and surface topography, which govern productivity, product quality and overall economy.

The present experiments were conducted in a surface grinder in plunge surface grinding mode. The grinding experiments have been carried out under dry and high pressure coolant (HPC) jet conditions. High pressure coolant jet impinged at the grinding zone for removing temperature through the nozzle at an angle from a suitable distance is shown in Fig.3.1

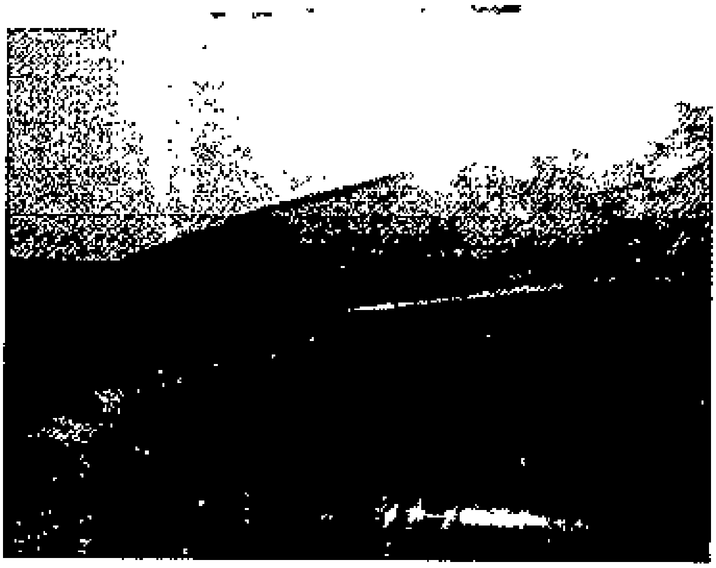
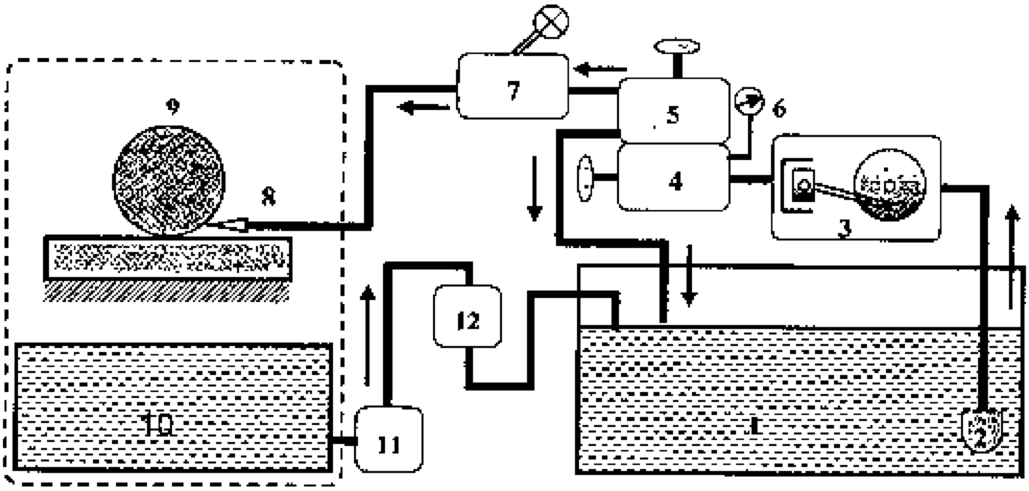


Fig.3.1 Photographic view of HPC jet delivery nozzle injecting cutting oil

The schematic and the photographic view of the experimental set up are shown in the Fig 3.2 and Fig3.3 respectively. The present experimental conditions are given in Table-3.1.



1.	Coolant Tank	5.	Relief valve	9.	Grinding wheel
2.	Foot Valve	6.	Pressure Gauge	10.	Coolant Tank
3.	High Pressure Pump	7.	Direction Control Valve	11	Supply Pump
4.	Flow Control Valve	8	Nozzle	12.	Filter

Fig.3.2 Schematic layout of the experimental set-up

Fig.3.3 Photographic view of the experimental set-up

Table-3.1 Experimental conditions

Machine	Horizontal Spindle Surface Grinding Machine (model: M7120A), 2.8 kW
Material (Steel)	AISI- 1040 Steel AISI- 4140 Steel
Size	40mm X 25mm X 8mm
Wheel	A60P5V99
Process Parameters	
Spindle speed	3000 rpm
Wheel speed	39.89 m/sec
Table speed	6 m/min
In feed (μm)	10 ,20,30 and 40
Environment	Dry and High pressure coolant Jet condition

Grinding of steels involves more heat generation for their ductility and production of continuous chips having more intimate and wide wheel and surface contact area. Again, the cutting temperature increases further with the increase in feed and hardness of the steels for more specific energy requirement. Keeping these facts in view the commonly used steel like AISI-1040 steel and AISI-4140 steel have been undertaken for the present investigations. The compositions, strength, and hardness of these steel are given in Table 3.2.

Table-3.2 Chemical Compositions of Materials (wt%)

Work material	BHN	C%	Si%	Mn%	Cr%	Mo%	Ni%	P%	S%
AISI-1040	86	0.45	.15-0.4	0.5-0.8	0.9–1.2	.15-0.3	0.6	0.0351	0.0351
AISI-4140	252	0.450	0.3	0.75	1.02	0.3	0.6	0.035	0.035

The positioning of the nozzle tip with respect to the grinding wheel has been settled after a number of trials. The final arrangement made and used has been shown in Fig.3.4. The high pressure coolant jet is directed in such a way that it reaches at the grinding wheel and workpiece interface.

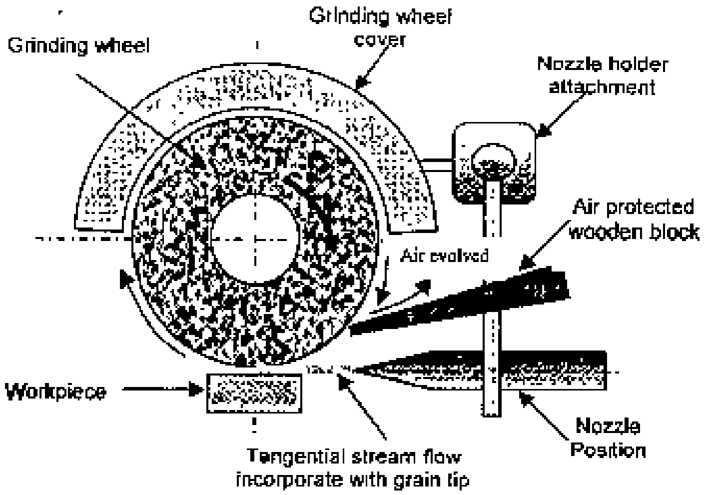


Fig. 3.4 Schematic view of the nozzle positioning of the grinding wheel

3.2 Experimental Results

3.2.1 Temperature Calibration

Electric current flows in a closed circuit of two dissimilar metals if their two junctions are at different temperatures; the thermoelectric voltage produced depends on the metals used and on the temperature relationship between the junctions. If the same temperature exists at the two junctions, the voltages produced at each junction cancel each other out and no current flows in the circuit. With different temperatures at junctions, different voltages are produced and current flows in the circuit. A thermocouple can therefore only measure temperature differences between the two junctions.

Thermocouples essentially comprise a thermo-element (a junction of two specified dissimilar metals) and two appropriate wire extension lead. A thermocouple operates on the basis of the junction located in the process producing a small voltage which increases with temperature. It does on a reasonably stable and repeatable basis.

A thermocouple probe and a junction of the constantan wire and AISI-1040 steel is embedded in a slot within two copper plates and isolation is done by mica sheet placing around it. The placement of two junctions are nearly close to each other at the middle of the plate and junction is heated gas welding torch at the middle of the two junctions as shown in Fig: 3.5. When the conductors of thermo-element are joined to the terminals, thermal voltages can be generated at the transition. In this case, the second junction is located at the connection point of the millivolt meter. The temperature of this connection point (**terminal temperature**) if known, allows computation of the temperature at the measuring junction. The thermal voltage resulting from the terminal temperature is added to the measured voltage and their sum corresponds to the thermal voltage against a 0°C reference.

Continuous data in millivolt is taken using a milli-voltmeter while heating and standard thermocouple thermometer measures temperature in degree centigrade. For getting maximum accuracy of thermocouple calibration reading is carefully taken sequentially and at regular interval of temperature increment. Calibration of the thermocouples is shown in fig. 3.6.

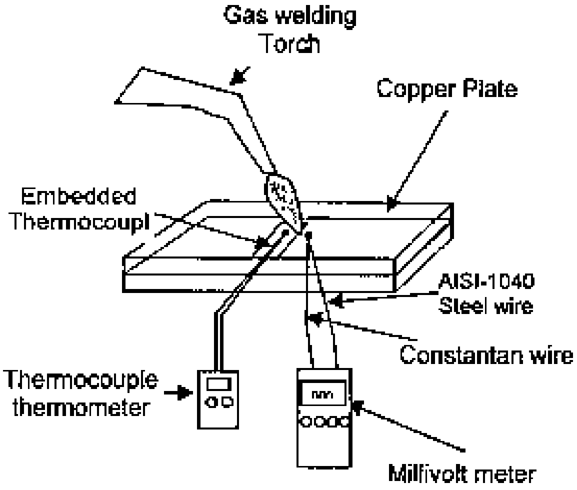
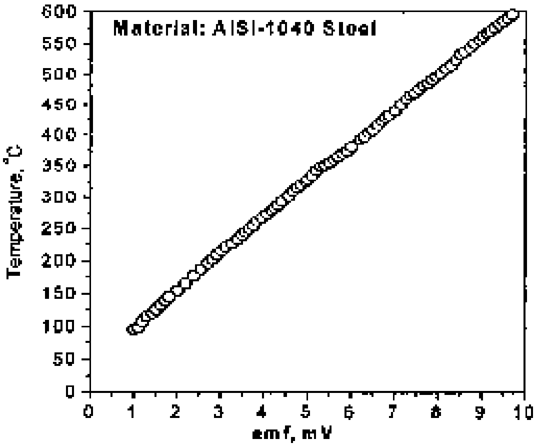
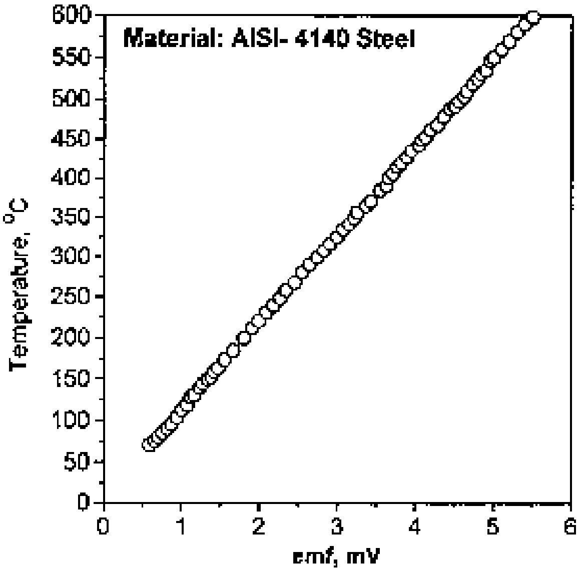


Fig.3.5 Schematic view of Temperature calibration of AISI- 1040 Steel



(a) AISI-1040 steel



(b) AISI-4140 steel

Fig.3.6 Tool-work thermocouple calibration curves for (a) AISI-1040 steel and (b) AISI-4140 steel

3.2.2 Grinding temperature

The temperature of the grinding surface has been measured by using a simple and reliable tool-work thermocouple technique, a constantan wire fitted into a thin slot in the work material produced by EDM at the middle portion of the work specimens as indicated in Fig.3.7. The constantan wire has been properly secured and insulated in the slot. During grinding operation the wire tip made contact with the work surface and formed the hot junction of the iron-constantan thermocouple pair. The voltage signals from the thermocouple were monitored using a suitable digital milli-voltmeter (RISH Multi 15S, India). Fig.3.8and Fig.3.9 show the variation of the grinding zone temperature observed in different environments at various infeeds.

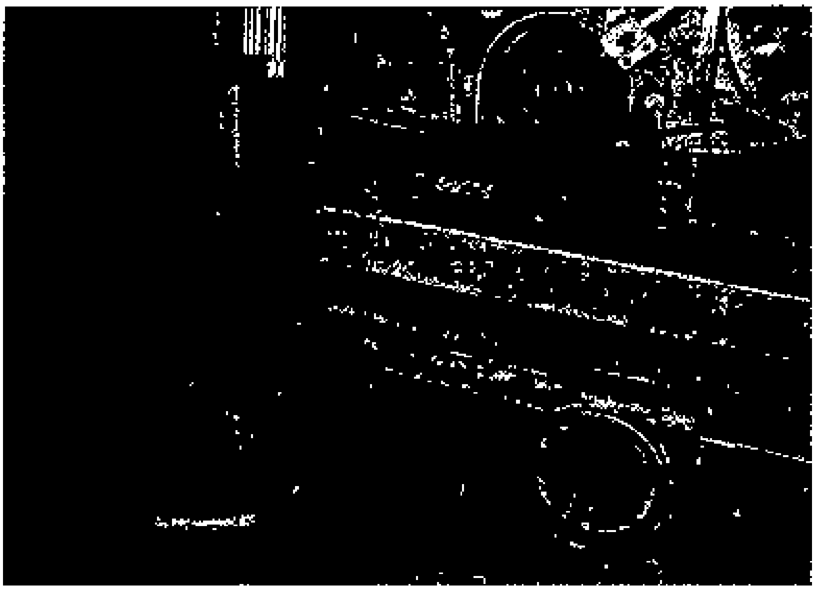


Fig.3.7 Methods of measuring the grinding zone temperature

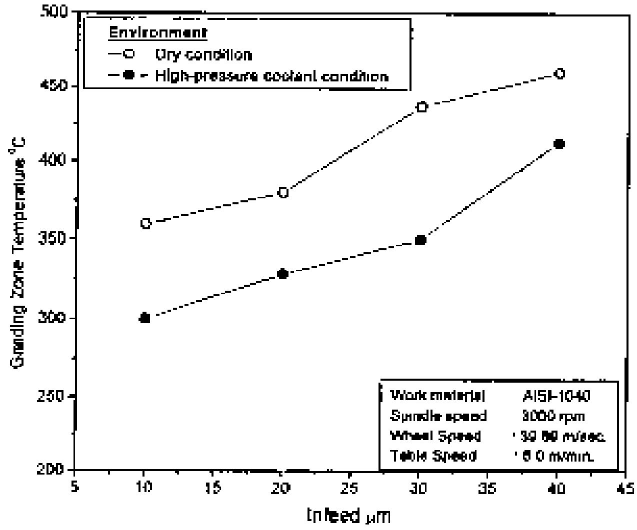


Fig.3.8 Variation of grinding zone temperature with infeeds while grinding AISI-1040 steel under dry and high-pressure coolant condition

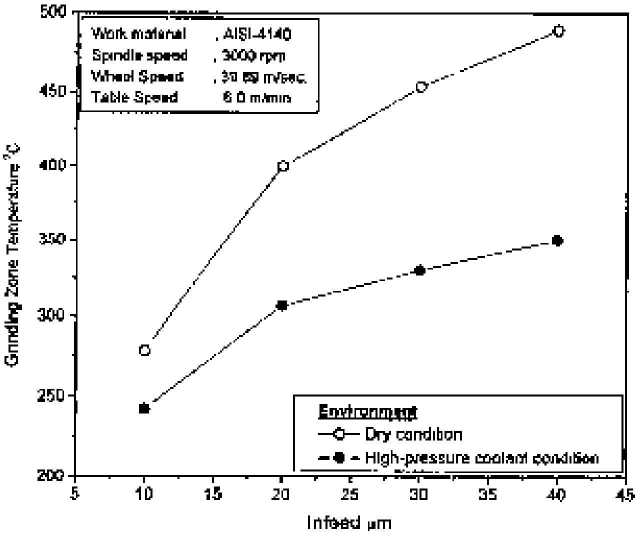
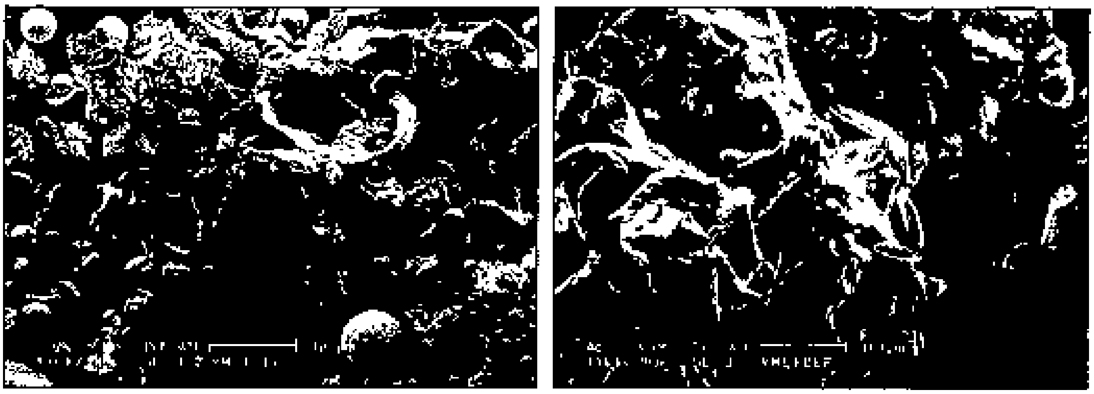


Fig.3.9 Variation of grinding zone temperature with infeeds while grinding AISI-4140 steel under dry and high-pressure coolant condition

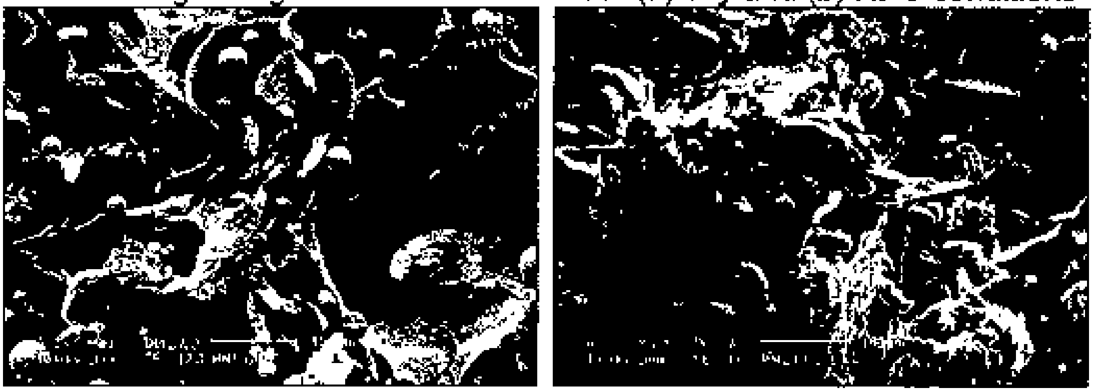
3.2.3 Microscopic study of the chips

The chips were collected by placing a white paper on the spark stream during grinding in dry environment. The collection of the chips were carried out only after the grinding has reached the steady state indicated by almost no vibration in the magnitude of the grinding forces with the number of passes. Those dried chips were preserved by covering with aluminum foil. In High pressure coolant jet condition, the chips were collected in a long plastic cup placing it on the spark stream during grinding; chips were separated from the liquid after sedimentation and on a piece of tissue paper. Finally oil over chips were washed thoroughly by acetone and dried in natural air. For studying the nature of interaction and chip morphology dried chips were observed under scanning electron microscope (HITACHI, S-2600N Scanning Electron Microscope, Japan). The photographs of the chips obtained under the different environments and at different infeeds have been shown in Fig.3.10 to and Fig.3.17 respectively.



(a) Dry grinding (b) HPC grinding

Fig.3.10 SEM photographs of grinding chips at 10 μm infeed while grinding **AISI- 1040 Steel** under (a) **dry** and (b) **HPC** conditions



(a) Dry grinding (b) HPC grinding

Fig.3.11 SEM photographs of grinding chips at 20 µm infeed while grinding **AISI- 1040 Steel** under (a) **dry** and (b) **HPC** conditions

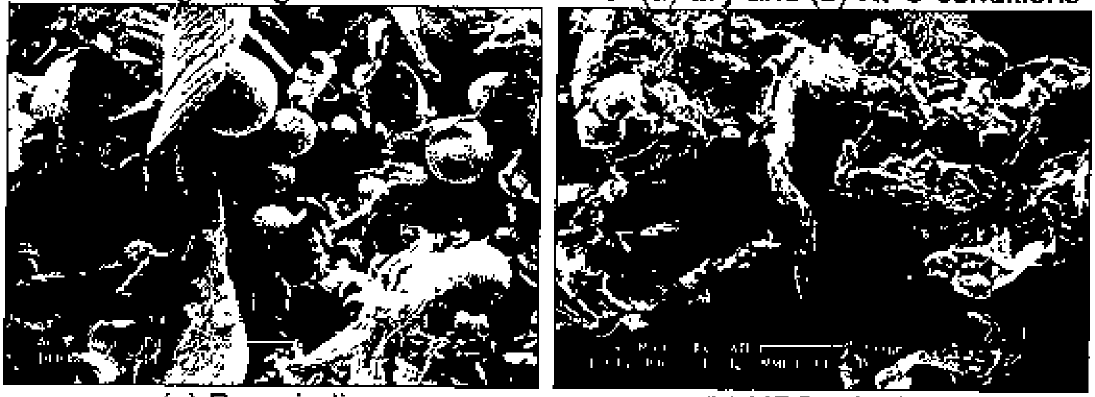

(a) Dry grinding (b) HPC grinding

Fig.3.12 SEM photographs of grinding chips at 30µm infeed while grinding **AISI- 1040 Steel** under (a) **dry** and (b) **HPC** conditions

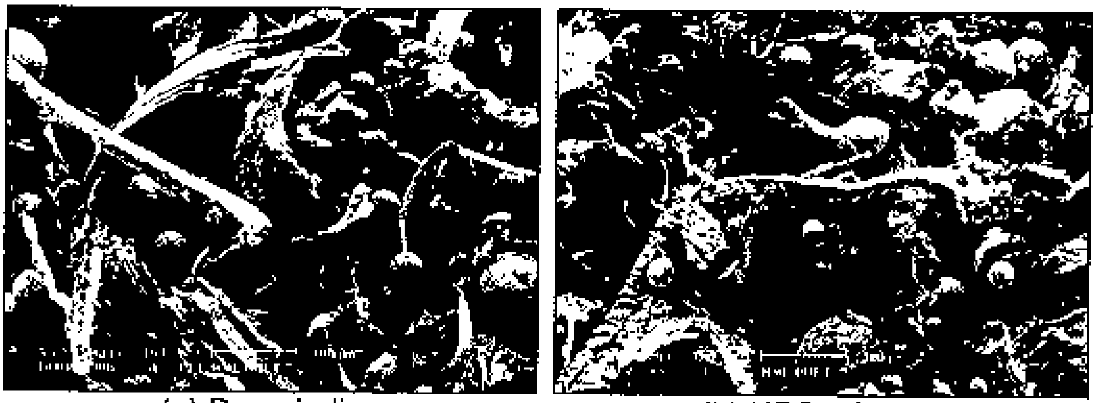

(a) Dry grinding (b) HPC grinding

Fig.3.13 SEM photographs of grinding chips at 40 µm infeed while grinding **AISI- 1040 Steel** under (a) **dry** and (b) **HPC** conditions

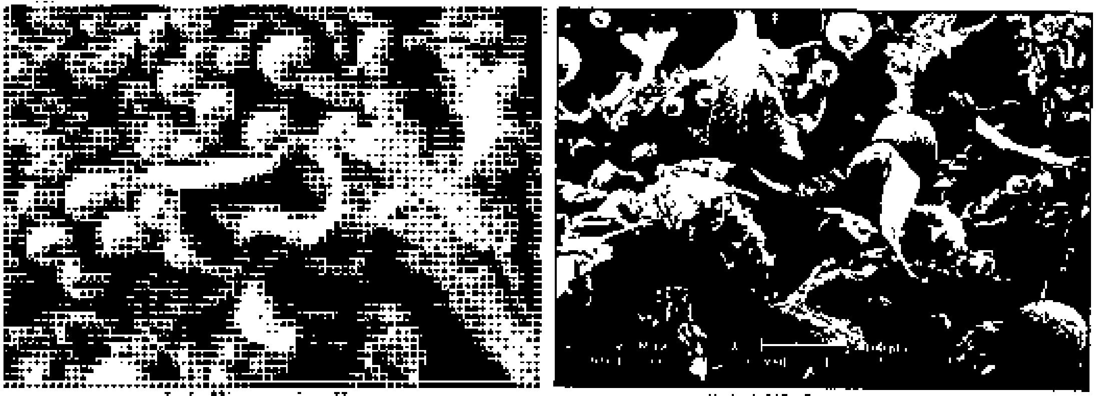

(a) Dry grinding (b) HPC grinding

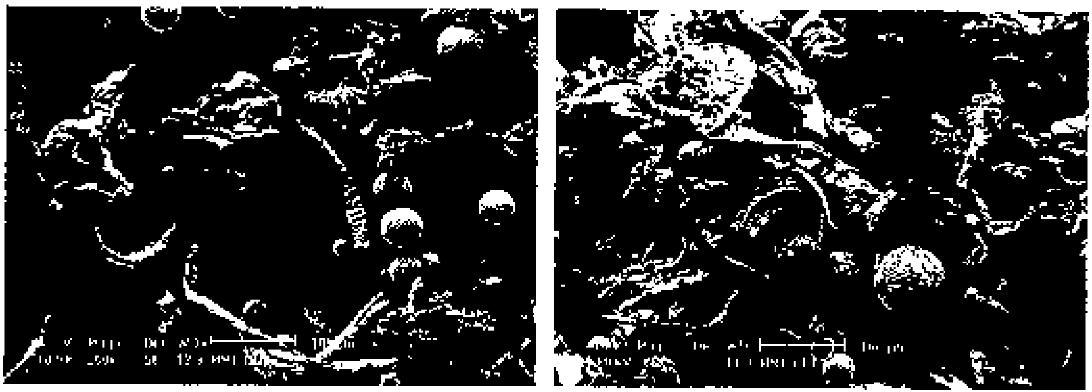
Fig.3.14 SEM photographs of grinding chips at 10 µm infeed while grinding **AISI- 4140 Steel** under (a) **dry** and (b) **HPC** conditions

(a) Dry grinding (b) HPC grinding

Fig.3.15 SEM photographs of grinding chips at 20 μm infeed while grinding **AISI- 4140 Steel** under (a) **dry** and (b) **HPC** conditions

(a) Dry grinding (b) HPC grinding

Fig.3.16 SEM photographs of grinding chips at 30 μm infeed while grinding **AISI- 4140 Steel** under (a) **dry** and (b) **HPC** conditions



(a) Dry grinding (b) HPC grinding

Fig.3.17 SEM photographs of grinding chips at 40 μm infeed while grinding **AISI- 4140 Steel** under (a) **dry** and (b) **HPC** conditions

3.2.4 Surface Roughness

The grinding characteristics of any material for any given conditions of the wheel and the grinding process are judged also by the topography of the ground surface. The surface features include general textures, plastic deformation of the asperities, oxidations, etc. all of which are more or less governed by the high grinding temperature. The surface roughness of the ground specimens has been measured in transverse directions by a Talysurf (Surtronic 3+ roughness checker, Rank Taylor Hobson, UK) as shown in Fig.3.18. The variation in surface roughness observed in different environments at various infeeds shown in Fig.3.19 and Fig.3.20.

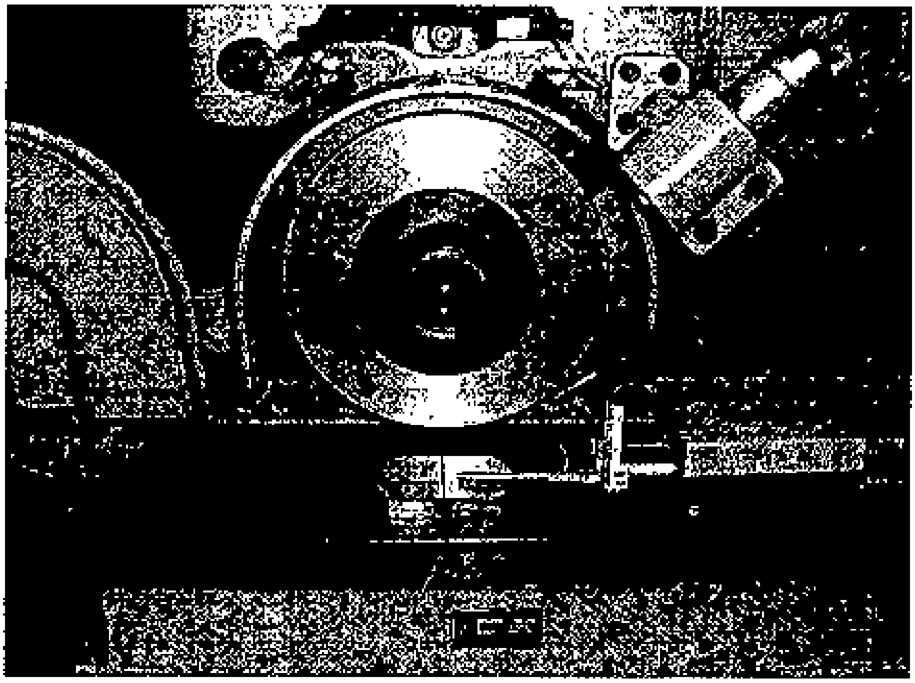


Fig.3.18 Photographic view of measuring surface roughness

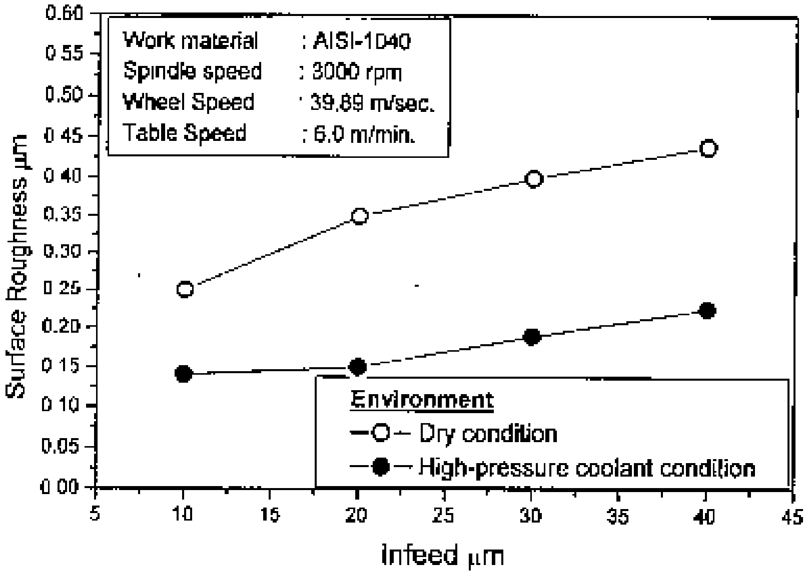


Fig.3.19 Variation of surface roughness with infeeds while grinding AISI-1040 steel under dry and high-pressure coolant condition

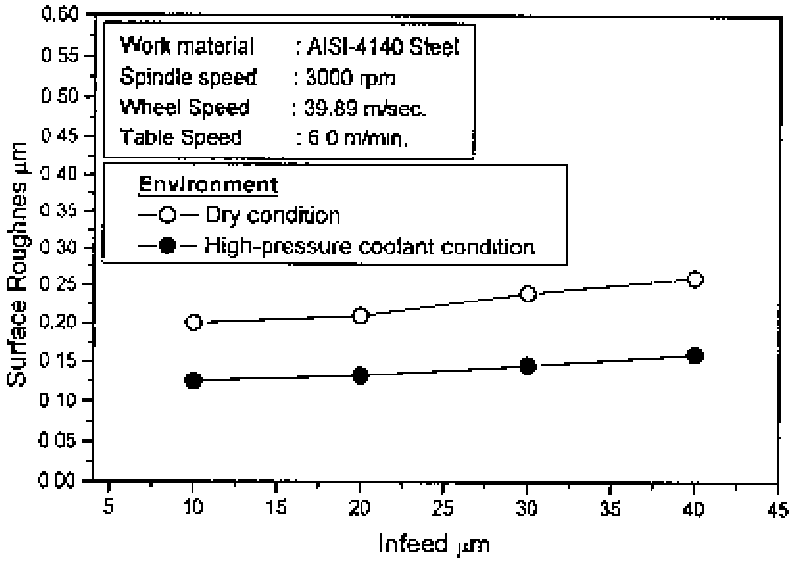


Fig.3.20 Variation of surface roughness with infeeds while grinding AISI-4140 steel under dry and high-pressure coolant condition

Chapter-4

Discussion on Experimental Results

In this experiment, three parameters are to be considered in grinding such as cutting zone temperature, chip morphology, and roughness. Cutting temperature is the most important controlling factor for any kind of manufacturing. Chip morphology and surface roughness are valuable index for measuring the grindability of the product.

4.1 Cutting Temperature

Grinding is associated with high temperature which is responsible for aggravating several problems like wheel loading, thermal damages of the ground surfaces, poor grindability etc. in the present work, the benefits expected out of high pressure coolant (HPC) jet over dry conditions are also based mainly on the reduction in the grinding zone temperature. Therefore, to evaluate the major effects of HPC jet in grinding different steels and to explore the main causes of such effects it is essential to determine the grinding temperature under various conditions. The magnitude and distribution of grinding temperature depends on many factors and their relations are quite complex for which it is difficult to evaluate the grinding temperature analytically. A simple technique by using a constantan wire fitted into a thin slot provided by wire cutting at the middle portion of the work specimens was used to measure the grinding zone temperature.

In Fig.3.8 and Fig.3.9 shows that how grinding zone temperature increases with the increases in feed. In both case such as dry and high pressure coolant jet, temperature increases with the increases in feed. But by using high pressure coolant jet temperature is less than in comparison to dry condition. When feed is increased it created more friction as well as increase the temperature in both case. Due to increase in feed, wheel grid elements were also fractured which is another reason for increasing the temperature. It has been shown that the cooling efficiency was more effective change in the hardness and the heat treatment cycle of the work material due to HPC jet system.

4.2 Grinding Chips

The study of grinding chip is required to understand the mechanism of chip formation and those of material removal. The chips produced during grinding AISI- 1040 steel at different infeeds have been shown in the figures from Fig.3.10 to Fig.3.13 respectively under the different environments. Dry grinding at both 10 μm and 20 μm infeeds provided different types of chips such as lamellar, spherical, irregular shaped and blocky particles. The clear lamellar structure of the chip indicates shearing to be one of the mechanisms of chip formation. Some small and medium size chips have taken up spherical shape possible due to excessive heating and exothermic oxidation. Higher grinding zone temperature and ductility of this steel specimen are expected to yield larger number of spherical chips. Chips produced under high pressure coolant jet condition at both 10 μm and 20 μm infeeds are mainly shear long thin lamellar chips indicating the mechanism of chip formation to be predominantly by shearing. At higher infeeds of 30 μm and 40 μm, dry grinding yielded small number of long spiral chips, most of the lamillar and leaty lamillar types of chips suggesting similar mechanism of chip formation. The leafy lamellar chips were obtained due to fracture of the wheel grits, which became rubbing with the workpiece of the material. On the contrary, high pressure grinding provided small fragment crushed chips also along with long lamellar chips, which indicate that, the shearing and fracturing are the main mechanisms of the chip formation under such HPC jet condition. By studying the chip characteristics, it is evident that in dry grinding the mechanism of chip formation is primarily shearing, ploughing and rubbing. Substantially, the mechanism of material removal is changed to predominantly shearing and fracturing under HPC jet condition. However, no indication was obtained regarding the change in chip formation mechanism with the increase in infeed.

The chips obtained while grinding AISI-4140 steel at different infeeds under different environments are shown in the figures from Fig.3.14 to Fig.3.17. In case of AISI-4140 steel spherical chips have been almost absent under all the environments, though all other kinds of chips have been obtained particularly under dry grinding. This indicates that the mechanism of chip formation is prepared by particularly shearing, ploughing and rubbing. However, significantly the chip formation is sheared fracturing under HPC jet system which is shown in Fig.3.10 to Fig.3.13. Reveal that HPC grinding yielded much lesser lamellar chips compared with dry grinding and it has been more pronounced when infeed was raised to 40 µm, no substantial variation in length and shape of the chips could be found due to change in infeed though. However, it appears that the size of the long lamellar chips have increased, which can be attributed to higher hardness of AISI- 4140 steel as compare to AISI- 1040 steel. Also the number of fractured chips has significantly increased in case of AISI- 4140 steel with respect to AISI- 1040 steel under HPC jet condition. It indicates that the mechanism of chip formation under high pressure of coolant jet shifts from shearing to fracturing with increase in hardness of metal. The sizes of the long lamellar chips have also been observed to be larger under HPC jet condition than those obtained under dry grinding.

The chips obtained while grinding AISI-4140 steel at different infeeds under different environments are shown in the figures from Fig.3.14 to Fig.3.17. In case of AISI-4140 steel spherical chips have been almost absent under all the environments, though all other kinds of chips have been obtained particularly under dry grinding. This indicates that the mechanism of chip formation is prepared by particularly shearing and rubbing. However, significantly the chip formation is sheared fracturing under HPC jet system which is shown in Fig.3.10 to Fig.3.13. Figures reveal that HPC grinding yielded much lesser lamellar chips compared with dry grinding and it has been more pronounced when infeed was raised to 40 µm, no substantial variation in length and shape of the chips could be found due to change in infeed. However, it appears that the size of the long lamellar chips have increased, which can be attributed to higher hardness of AISI- 4140 steel as compare to AISI- 1040 steel. Also the number of fractured chips has significantly increased in case of AISI- 4140 steel with respect to AISI- 1040 steel under HPC jet condition. It indicates that the mechanism of chip formation under high pressure of coolant jet shifts from shearing to fracturing with increase in hardness of metal. The sizes of the long lamellar chips have also been observed to be larger under HPC jet condition than those obtained under dry grinding.

4.3 Surface Roughness

In respect of surface finish, Fig.3.19 and Fig.3.20 show that HPC grinding has all along provided extensively less surface roughness in compare to dry grinding. It has already been stated that in high pressure coolant jet grinding worked as efficient cooling, reduce friction between the tool-workpiece, flashing the chips from the grinding zone, remove the adhesive chips between the grits space of the wheel and hence retained grit sharpness enable metal removal mainly by shearing, and partly by ploughing and fracturing, producing sufficiently less surface roughness in compare to dry grinding. Plastic deformation and oxidation occurred in dry grinding smoothens the surface irregularities. Hence, HPCJ grinding provided apparently considerably fewer surface roughnesses. The aspect of surface burning observed, which indicates that unlike dry grinding, HPC grinding has expectedly always been free from burning. This can obviously be attributed to lower temperature, retained grit sharpness and less rubbing and ploughing in HPC grinding.

In comparison two materials such as AISI-1040 and AISI-4140, surface roughness is gradually decreases with the increases in feed by using High pressure coolant jet. But, by using AISI-4140 roughness is higher than AISI-1040 because of hardness of the material. When grinding the hard material, it reduces the sharpness of the wheel grits as well as the performance of the cutting efficiency.

In Fig. 3.20 shows that, roughness suddenly decreases when feed is increase 10 to 20 micron due to rubbing of the wheel grit under dry condition. After dressing the wheel roughness becomes increases with the increases in feed. So, roughness is dependent to tool sharpness.

Comparison two metals (AISI-1040 and AISI-4140) surface roughness is gradually decreases with the increases in infeed while applying high pressure coolant jet. But roughness is higher in case of AISI-4140 than AISI-1040 because of hardness of the material. Grinding of hard material reduces the sharpness of the wheel grits as well as the performance of the cutting efficiency.

Fig.5 shows that under dry condition roughness suddenly decreases when feed is increase from 10 to 20 micron due to rubbing of the wheel grit with the work material. After dressing the wheel roughness increases with the increases in feed. Therefore, roughness is dependent on tool sharpness.

Chapter-5

Conclusions

The following conclusions can be drawn the nature of effective performance of high pressure coolant jet on grinding of different materials based on the experimental results:

- High pressure coolant jet reduces grinding zone temperature significantly due to effective cooling and lubrication at the chip- tool and work-tool contact area.

- HPC grinding yields to a less significant lamellar chips compared with dry grinding and marked no substantial variation in length and shape of the chips can be found due to change in infeed though. The mechanism of chip formation is shifted from shearing to fracturing with increase in hardness of metal. The sizes of the long lamellar chips observed to be larger than under dry grinding.

- Lower surface roughness is observed under HPC grinding in comparison with dry. The aspect of HPC grinding has expectedly always been free from surface burning. This can obviously be attributed to lower temperature, retained grit sharpness and less rubbing and ploughing.

Chapter-6

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