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EFFECT OF HIGH-PRESSURE COOLANT JET ON GRINDING TEMPERATURE, CHIP AND SURFACE ROUGHNESS IN GRINDING AISI-1040 STEEL

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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. However, high-pressure coolant (HPC) jet effectively reduces cutting zone temperature entering into chip tool interface maintaining a good surface integrity. The present work investigates the role of high-pressure coolant jet on chip formation, grinding zone temperature and surface roughness in grinding AISI-1040 steel. The experimental results indicate significant reduction in cutting temperature on application of high-pressure coolant, which enables favorable chip formation and a better surface integrity for the finished work piece.

Keywords: pressure, coolant, hpc, grinding, temperature, chip, surface, roughness.

INTRODUCTION

Grinding is basically a mechanical process, characterized by high temperature, which is generally controlled by application of grinding fluid but 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 [**1**]. Though the application of grinding fluids brings down the temperature, but their film boiling temperature restricts their effectiveness [**2**]. The lubricating and the cooling properties of the grinding fluids directly influence the surface integrity of the work piece. However, the effectiveness of coolants are lost if the temperature exceeds the film boiling temperature of the fluids [**3**]. The grinding fluids should be used to lubricate and thus reduce the specific energy requirement, as the normal grinding fluids are ineffective in controlling the high temperature [**4**].

Nee [**5**] 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. The chips adhering to the wheel act as additional heat source, which may lead to overheating of the wheel and hence more wheel wear [**6**].

Early investigators [**7**] identified the mechanism of chip formation in grinding to be mainly shearing, like that in other conventional machining processes, by studying the shapes of the chips under optical microscope. Ramanath and Pai [**8**], opined 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. Marshall and Shaw [**9**] described burning as the appearance of the temper color on the ground surface due to high temperature. It is realized that the machining temperature has a critical influence on chip reduction coefficient, cutting forces, tool wear and tool life.

High pressure assisted cooling is one of the preferred technologies, currently, under exploitation especially in the aerospace and power plant industries for machining exotic materials [**10**]. The credibility of high pressure coolant assisted machining had been thoroughly investigated over the years. The system not only provides adequate cooling at the tool-workpiece interface but also provides an effective removal (flushing) of chips form the cutting area [**11**]. The coolant jet under such high pressure is a capable of creating a hydraulic wedge between the tool and workpiece, penetrating the interface deeply with a speed exceeding that necessary even for very high speed machining. This phenomenon also changes the chip flow condition [**12**]. The penetration of the high-energy jet at the grinding zone reduces the temperature gradient and minimises the seizure effect, offering an adequate lubrication at the wheel metal interface with a significant reduction in friction. Excellent chip breakability has been reported when machining difficult-to-cut materials with high-pressure coolant supply [**13**]. This is attributed to a coolant wedge, which forms between the chip and tool forcing the chip to bend upwards giving it a desirable up curl required for segmentation. Graham and Whitson [**14**] 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.

The objective of the present work was to experimentally investigate the influence of high-pressure coolant jet on chip formation mode, grinding zone temperature and surface roughness in grinding AISI-1040 steel at different infeed rates under different environments. During each test, grinding zone temperature and surface

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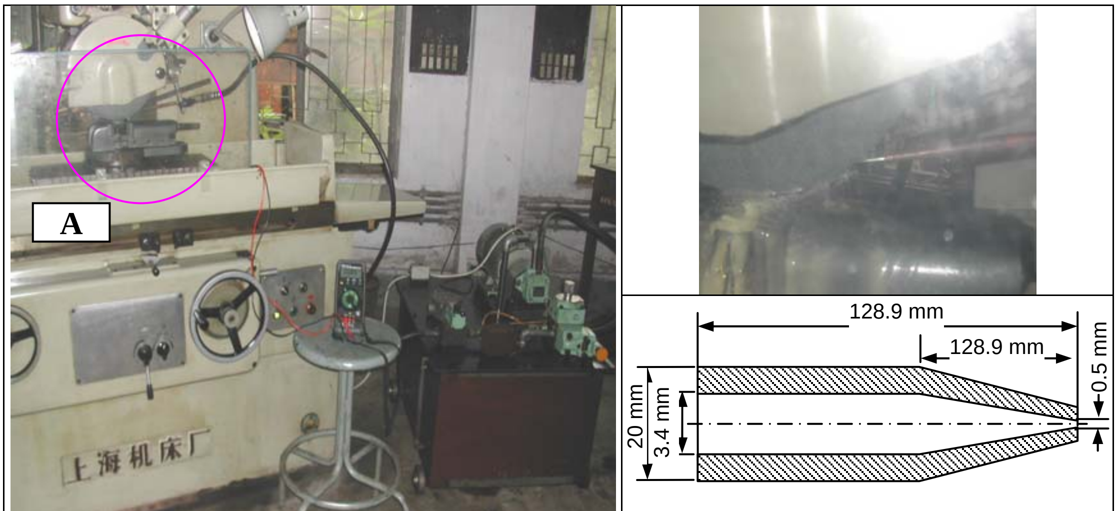
roughness are measured and compared with dry grinding and also observed the chip formation mode.

EXPERIMENTAL CONDITIONS AND PROCEDURE

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 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 Figure-1. The cutting fluid needs to be drawn at high pressure from the coolant tank and impinged at high speed through the nozzle. Considering the conditions required for the present research work and uninterrupted supply of coolant at pressure around 50 bar over a reasonably long cut, a coolant tank has been designed, fabricated and used. The photographic view of the experimental setup along with high pressure coolant system which contain motor-pump assemble, flow control valve, relief valve and directional control valve is shown in Figure-1. The present experimental conditions are given in Table-1. 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 Figure-2. The high-pressure coolant jet is directed in such a way that it reaches at the grinding wheel and work piece interface.



Nozzle tip (close-up view of point A)

Figure-1. Photographic view of HPC jet delivery nozzle injecting cutting oil during grinding

Table-1. Experimental conditions.

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

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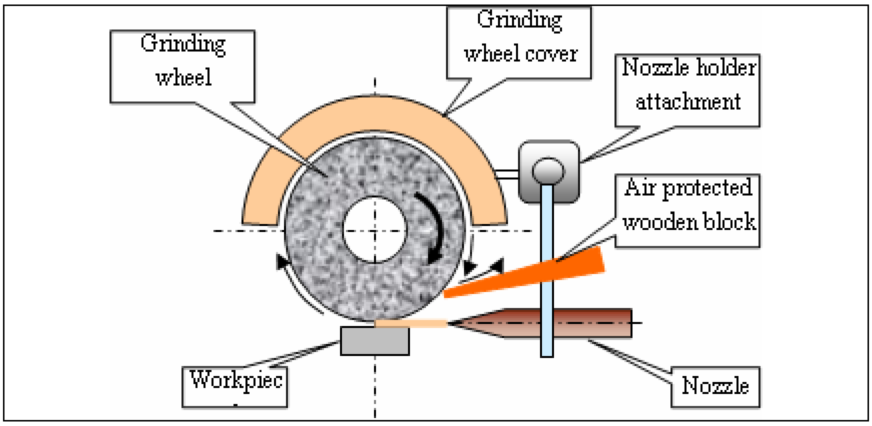
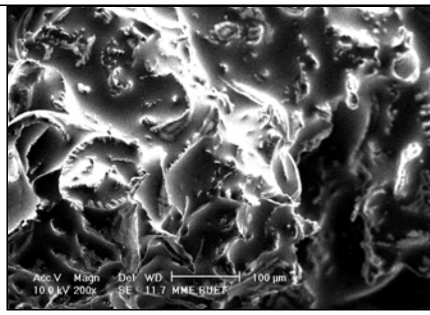
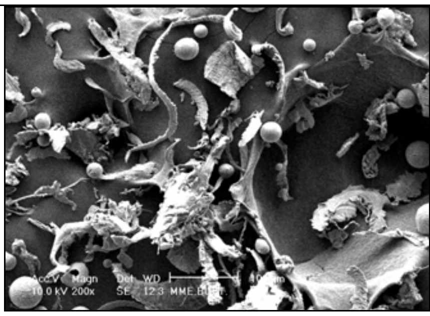
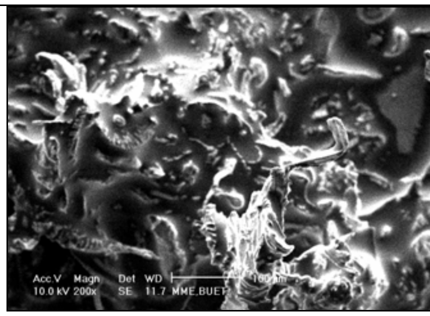


Figure-2. Schematic view of the nozzle positioning of the grinding wheel.

The chips were collected for all the treatments by placing a glass slide coated with petroleum jelly on the spark stream during grinding. 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 chips were thoroughly washed with acetone, dried and magnetically separated from the grinding wheel debries. Then the cleaned chips were mounted on small brass disk and observed under scanning electron microscope (HITACHI, S-2600N Scanning Electron Microscope, Japan) to study the morphological characteristics of the chips. The photographs of the chips obtained under the different environments and infeeds have been shown in Figure-3.

Infeed (μm)	Environment	
	Dry	HPC
10		
20		

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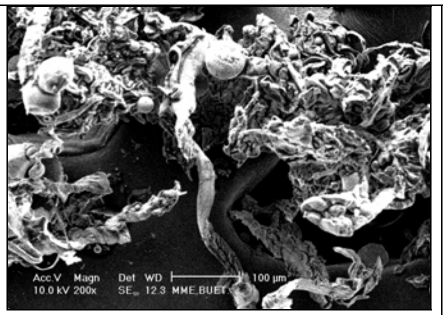
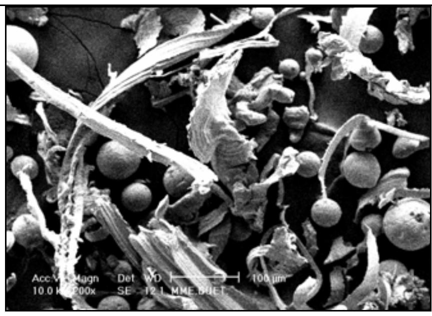
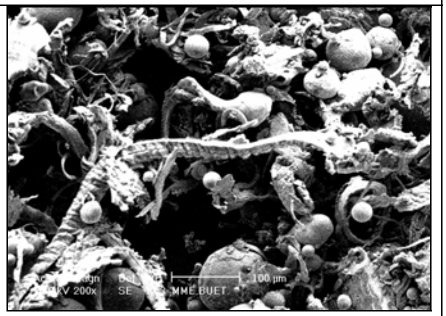
30		
40		

Figure-3. SEM photographs of grinding chips at different infeeds under (a) **dry** and (b) **HPC** conditions.

In the present work, the average cutting temperature has been measured by standard tool-work thermocouple technique. The calibration of the work-tool thermocouple has been carried out by external flame heating. The embedded thermocouple junction was constructed using a strip of the concerned work-material and a constantan wire. A standard chromel-alumel thermocouple is mounted at the site of work-constantan junction. The oxy-acetylene torch simulated the heat generation phenomena in machining and raised the temperature at the chip-tool interface. Standard thermocouple directly monitored the junction temperature when the emf generated by the hot junction of the tool-constantan was monitored by a digital multimeter (RISH Multi 15S, India). Figure-4 shows the calibration curve obtained for the work. In the present case, almost linear relationships between the temperature and emf have been obtained with multiple correlation coefficients around 0.994.

The temperature of the grinding surface has been measured by a simple technique using a constantan wire fitted into a thin slit provided by wire cutting at the middle portion of the work specimens [15]. The constantan wire has been properly secured and insulated in the slit. During grinding operation the wire tip contacted the work surface and formed the hot junction of the constantan-steel thermocouple pair. The voltage signals from the thermocouple were monitored using a suitable digital millivoltmeter. Figure-5 shows the variation in the average value of the grinding zone temperature observed in different environments at various infeeds.

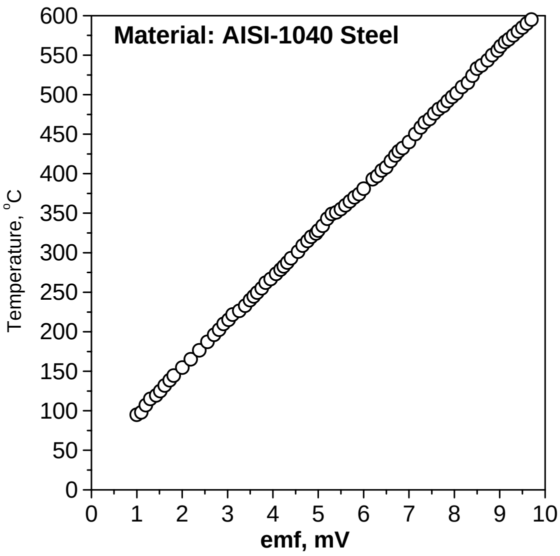


Figure-4. Tool-work thermocouple calibration curves.

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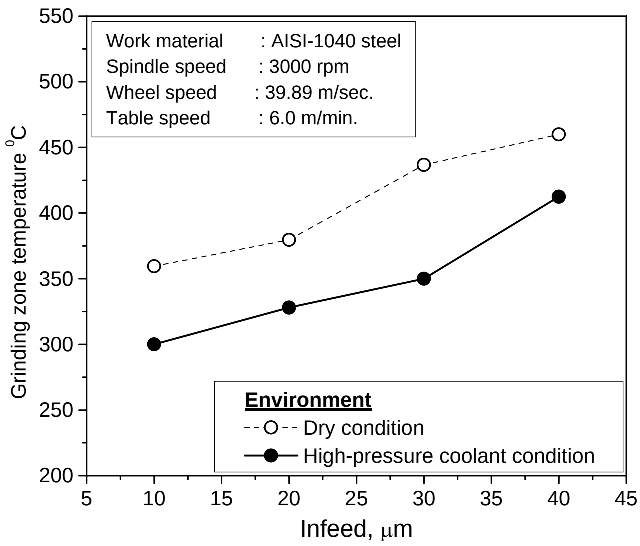

Figure-5. Variation in the grinding zone temperature with infeed under dry and high pressure coolant conditions.

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, and cracks 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 direction by surface roughness measuring equipment (Talysurf Surtronic 3+ roughness checker, Rank Taylor Hobson, UK). Figure-6 shows the variation in surface roughness observed in different environments at various infeeds.

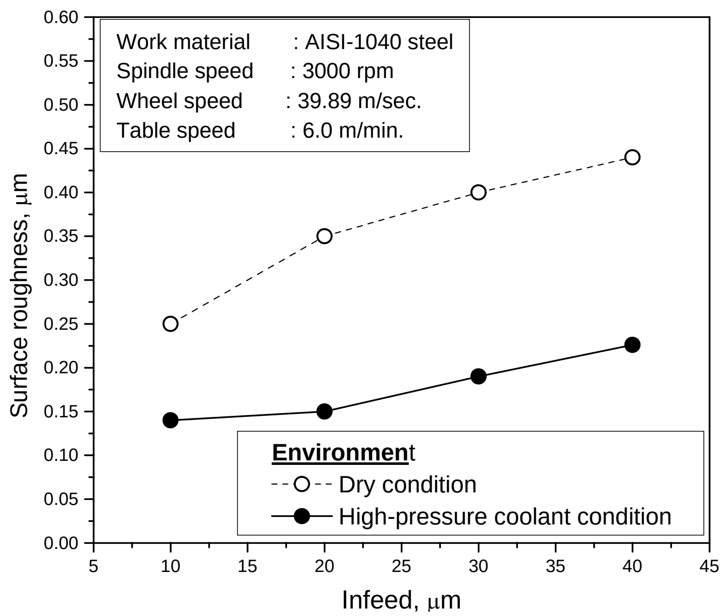

Figure-6. Variation in the surface roughness with infeed under dry and high pressure coolant conditions.

RESULTS AND DISCUSSION

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 Figure-3 under different environments. Dry grinding at both 10 µm and 20 µm infeeds provided different types of chips such as lamellar, spherical, leafy chips, irregular shaped chips 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 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 lamellar and leafy lamellar 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 coolant 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 and rubbing. Substantially, the mechanism of material removal is changed to predominantly shearing and fracturing under HPC jet condition.

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 cooling over dry conditions are also based mainly on the reduction in the grinding zone temperature. Therefore, to evaluate the major effects of high-pressure coolant in grinding steel and to explore the main causes of such effects it is essential to determine the grinding temperature under various conditions. The experimental results shown in the Figure-5 clearly indicate that the grinding zone temperature decreases due to high-pressure coolant condition. It is also noted that the cooling efficiency of the high-pressure coolant becomes constant through out infeeds.

In respect of surface finish, Figure-6 shows that high-pressure coolant 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 fracturing, producing sufficiently less surface roughness in compare to dry grinding. Plastic deformation and oxidation occurred in dry grinding smoothens the surface irregularities. Hence, high-pressure coolant grinding provided apparently considerably less surface roughness. The aspect of surface burning observed, which indicates that unlike dry grinding, high-pressure coolant grinding has expectedly always been free from burning. This can obviously be attributed to lower temperature, retained grit sharpness and less rubbing in high-pressure coolant grinding.

CONCLUSION

The following conclusion can be drawn about the performance of high-pressure coolant jet on grindability of steel based on the experimental results:

- High-pressure coolant jet reduces grinding zone temperature significantly due to effective cooling and lubrication at the grinding zone 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 sizes of the long lamellar chips observed to be larger than under dry grinding.
- High-pressure coolant grinding provides considerably less surface roughness in comparison with dry grinding. The aspect of high-pressure coolant grinding has expectedly always been free from surface burning. This can obviously be attributed due to lower temperature, retained grit sharpness and less rubbing.

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