

MQL APPLICATIONS IN GRINDING OF 16MnCr5 STEEL: A COMPARISON WITH WET AND DRY GRINDING

N. R. Dhar¹, M. Hossain¹ and M. Kamruzzaman²

¹Department of Industrial & Production Engineering
Bangladesh University of Engineering & Technology (BUET), Dhaka, Bangladesh.

²Department of Mechanical Engineering
Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh.

ABSTRACT

Application of conventional cutting fluids often cannot control the high cutting temperature especially in high production machining and grinding. Besides, environmental pollution, inconvenience, health hazards and wastage of space and additional system requirement in the machine shops due to conventional application of cutting fluids essentially required for cooling and lubrication have been a great concern of the industries and the modern societies. One of the possible and potential techniques to overcome such problem is application of minimum quantity lubrication (MQL) especially where the cutting temperature is a major constraint in achieving high productivity and job quality. The present investigation is to evaluate the influence of MQL on chip formation mode, grinding zone temperature and surface roughness in grinding 16MnCr5 steel at different infeed rates. The results have been compared with dry grinding and oil as coolant. The experimental results indicate that such MQL enables reduction in the cutting zone temperature and surface roughness. It was also noted that the chip formation becomes more favorable with the use of MQL. Thus MQL, if properly employed, not only provides environment friendliness but can also improve the grindability characteristics.

Keywords: Wet grinding, MQL, Temperature, Chip and Surface roughness.

1. INTRODUCTION

Grinding process is characterized by high specific energy requirement and high grinding zone temperature, which shortens the tool life and deteriorates the job quality. Such high temperature is required to be controlled properly, otherwise it may lead to severe wheel loading, rapid wheel wear, poor surface integrity of the product and over an above development of tensile residual stresses surface and subsurface micro cracks which reduce the fatigue strength of the product in functioning. 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. Thus, grinding fluid is normally used during grinding to prevent burning of the cutting edge and to maintain high surface quality. Grinding fluid is normally used to cool the area near the grinding point, for lubrication and to remove chips. However, splattering of the mineral oil contained in oil-based grinding fluids and the smoke that is generated have negative effect on the operators in the immediate vicinity of the machines and on the environment in general [1,2]. Water-soluble coolants contain sulfur, phosphorous, chlorine and other extreme-pressure additives that are harmful to the throat and skin [3].

The machining costs (labour and overhead) in the US alone are estimated to be US\$300 billion/year [4]. The costs associated with the use of cutting fluids is estimated to be about 16% of the manufacturing costs [5] which is many more times than the labour 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 [6]. The use of cutting fluids also requires additional equipment for plant housekeeping. Furthermore, the permissible exposure level for metalworking fluid aerosol concentration is 5 mg/m³, as per the OSHA, U.S. [6], and is 0.5 mg/m³ according to the NIOSH, U.S. [7]. The oil mist level in U.S. automotive parts manufacturing facilities has been estimated to be generally on the order of 20-90 mg/m³ with the use of traditional flood cooling and lubrication [3]. This suggests an opportunity for improvement of several orders of magnitude.

The traditional methods that use coolants are now obviously becoming obsolete. Change is clearly taking place in the machine industry. Environmental laws are closing in on machining coolants. Many engineers are looking seriously at dry machining. Dry machining

means cutting without using any fluids in production. The use of dry cutting has been an eagerly awaited objective worldwide [6]. The minimized use of cutting fluids, where the usage of fluids is restricted to the least possible level, is a transitional form of both ordinary cutting and dry cutting. One of the possible and potential techniques to overcome such problem is application of minimum quantity lubrication (MQL) especially where the cutting temperature is a major constraint in achieving high productivity and job quality [8-10]. The purpose of this work is to study the effects of MQL on chip formation mode, grinding zone temperature and surface roughness in grinding 16MnCr5 steel at different infeed rates. In the study, the MQL is provided with a spray of soluble oil. During each test, grinding zone temperature and surface roughness are measured and compared with dry and wet grinding with soluble oil as coolant and also observed the chip formation mode.

2. EXPERIMENTAL CONDITIONS AND PROCEDURE

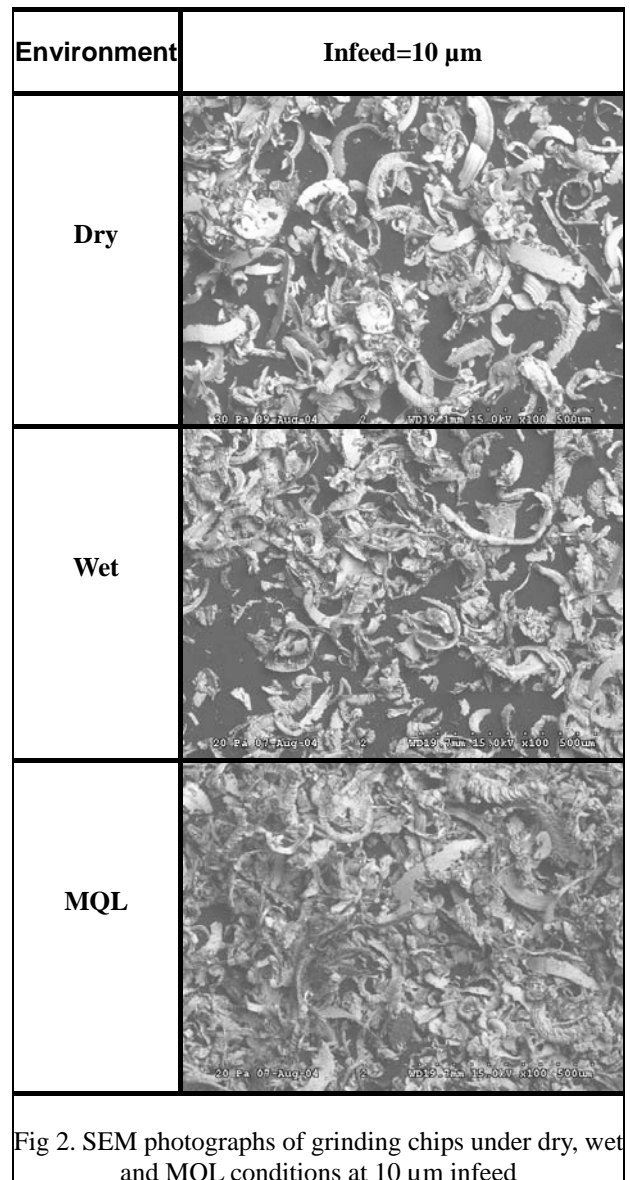
The present experiments were conducted in a surface grinder in plunge surface grinding mode. The grinding experiments have been carried out under dry, wet (soluble oil) and MQL conditions. The conventional cooling system provided in the machine has been used for wet grinding tests. In the MQL grinding, MQL jet is made to impinge the grinding zone from suitable distance and angle as shown in Fig.1. The present experimental conditions are given in Table-1.



Fig 1. Photographic view of the experimental set-up

Table 1: Experimental conditions

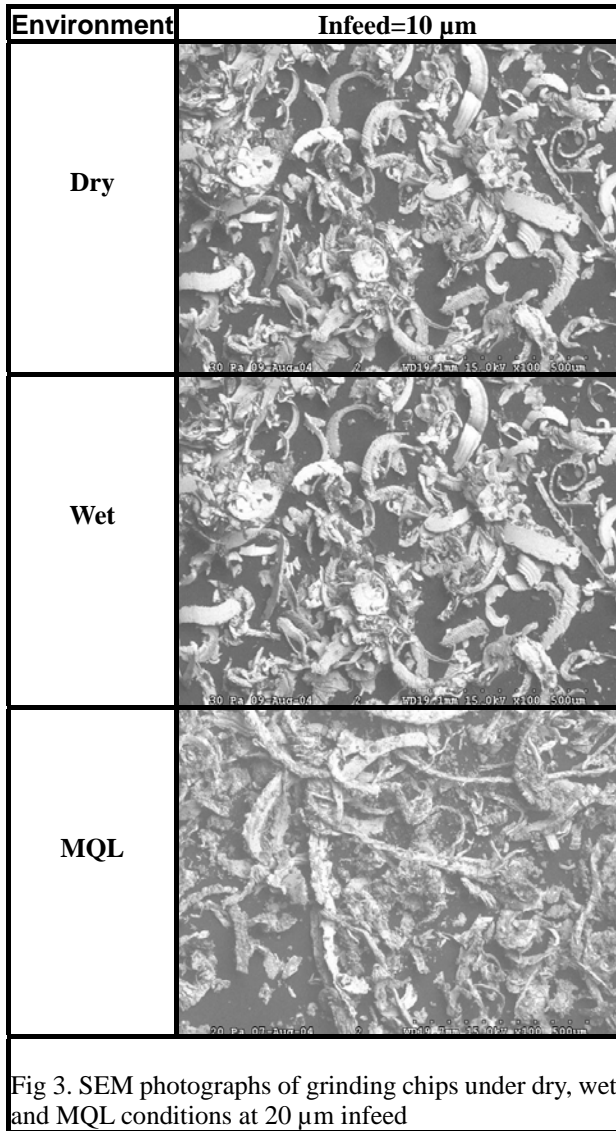
Machine	Horizontal Spindle Surface Grinding Machine with Rectangular Table (model: M7120A), 2.8 kW
Workpiece	16MnCr5 Steel
Workpiece Size	100mm X 68mm X 16mm
Wheel	D126R100 B60-3 mm
Spindle speed	3000 rpm
Wheel speed	39.89 m/sec
Table speed	6 m/min
Infeed	10 μ m, 20 μ m, 30 μ m and 40 μ m
MQL supply	Air: 3.5 bar, lubricant: 200ml/h through external nozzle
Environment	Dry, Wet with soluble oil and MQL



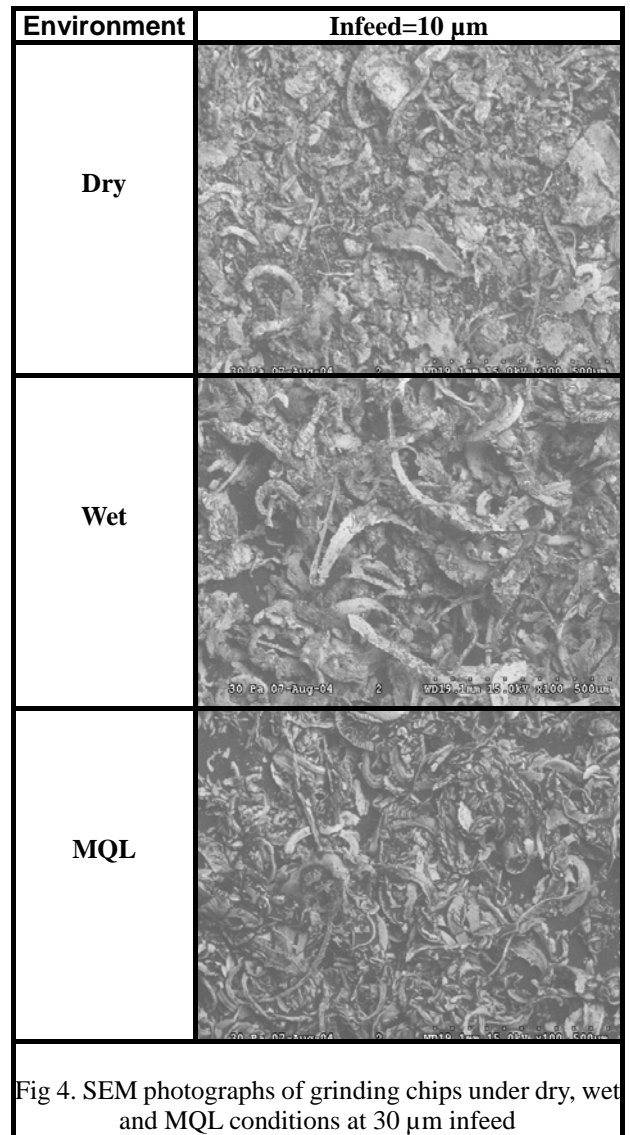
The chips were collected for all the treatments by placing a glass slide coated with petroleum jelly on the spark stream during grinding. The collection of the chips were carried out only after the grinding has reached the steady state indicated by almost no vibration in the magnitude of the grinding forces with the number of passes. Those chips were thoroughly washed with acetone, dried and magnetically separated from the grinding wheel debris. 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 at different infeeds have been shown in Fig 2, Fig 3, Fig 4 and Fig 5 respectively.

The temperature of the grinding surface has been measured by simple technique by using a constantan wire fitted into a thin slit provided by wire cutting at the middle portion of the work specimens as indicated in Fig 6 [11, 12]. 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 [12]. The voltage signals from the thermocouple were monitored using a suitable digital millivoltmeter (RISH Multi 15S, India). Fig 7 shows the variation of the grinding zone temperature observed in different environments at various infeeds.

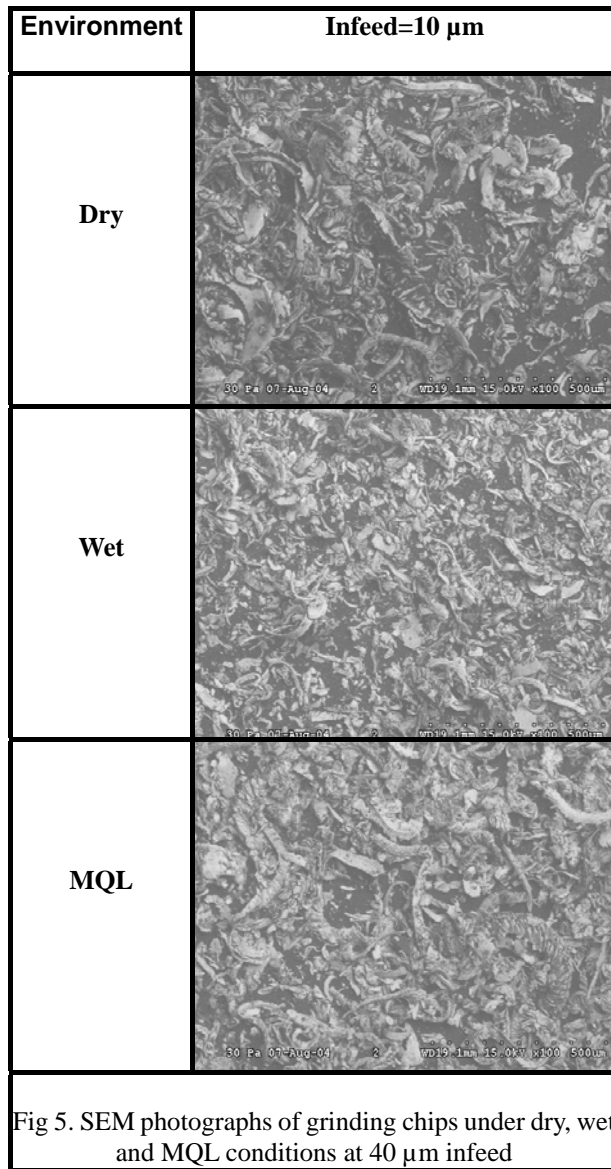


The grinding characteristics of any material for any given conditions of the wheel and the grinding process are judged also by the topography of the ground surface. The surface features include general textures, plastic deformation of the asperities, oxidations, and cracks etc. all of which are more or less governed by the high grinding temperature. The surface roughness of the ground specimens has been measured in transverse directions by a Talysurf (Rank Taylor Hobson, UK). Fig.8 shows the variation in surface roughness observed in different environments at various infeeds.



3. EXPERIMENTAL 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 16MnCr5 steel at different infeeds have been shown in Fig.2, Fig.3, Fig.4 and Fig.5 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 specimens are expected to yield larger number of spherical chips. Wet grinding at both 10 μm and 20 μm infeeds also provided almost all types of chips indicating the mechanism of chip formation to be primarily by shearing, ploughing and rubbing. Chips produced under MQL 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 almost similar types of chips suggesting similar mechanism of chip formation. Under wet grinding at higher infeeds of 30 μm and 40 μm , the chips attained at their backsides smooth appearance with central ridges produced by the tip of the grits and lamellar top surfaces. The increased width of the chip depicts distinct ploughing. MQL grinding on the other hand, 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 MQL condition. By studying the chip characteristics, it is evident that in dry and wet grinding the mechanism of chip formation is primarily shearing, ploughing and rubbing. And MQL substantially changed the mechanism of material removal to predominantly shearing and fracturing. However, no indication was obtained regarding the change in chip formation mechanism with the increase in infeed.

The experimental results shown in the Fig.7 clearly indicate that the grinding zone temperature decreases due to MQL. It is also noted that the cooling efficiency of the

MQL becomes higher at larger infeeds. Whereas, the ability of cooling by the soluble oil has been quite poor and decreased further with the increase in infeed possibly due to its inability to reach the grinding zone and film boiling at elevated temperature.



Fig 6. Methods of measuring the grinding temperature

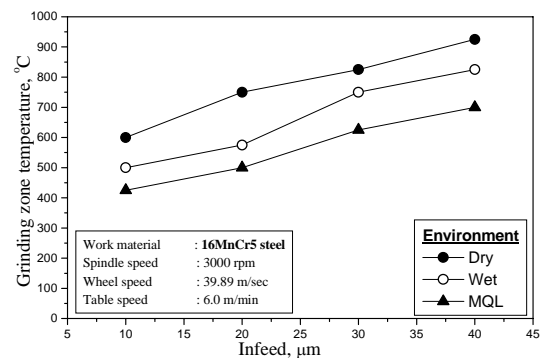


Fig 7. Variation in the grinding zone temperature with infeed under dry, wet and MQL conditions.

In respect of surface finish, Fig.8 shows that MQL grinding has all along provided relatively higher surface roughness in compare to dry grinding but lower surface roughness in compare to wet grinding. It has already been stated that in MQL grinding, efficient cooling and hence retained grit sharpness enable metal removal mainly by shearing, and partly by ploughing and fracturing, producing higher surface roughness in compare to dry grinding. Plastic deformation and oxidation occurring in dry grinding smoothens the surface irregularities. Hence, MQL grinding provided apparently higher surface roughness. The aspect of surface burning observed, which indicates that unlike dry and wet grinding, MQL 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 MQL grinding.

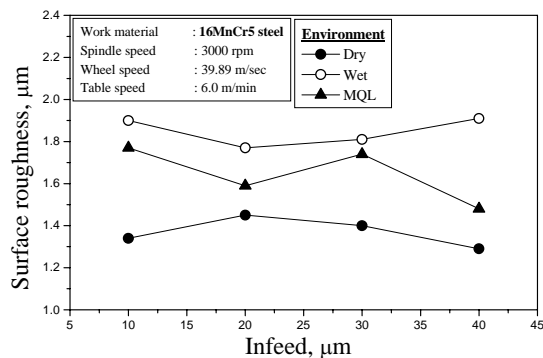


Fig 8. Variation in the surface roughness with infeed under dry, wet and MQL conditions.

4. CONCLUSIONS

Based on the experimental results the following conclusions can be drawn:

- MQL provided significant improvements expectedly, though in varying degree, in respect of chip formation modes, surface characteristics throughout the infeed range undertaken mainly due to reduction in the grinding zone temperature. Flood cooling by soluble oil could not to control the grinding temperature appreciably and its effectiveness decreased further with the increase in infeed.
- MQL grinding shifted the chip formation modes from shearing, ploughing and severe rubbing resulting in long lamellar, leafy, spherical and irregular shaped chips observed in dry as well as wet grinding to the more favorable modes like sharp shearing and minute fracturing due to retention of the sharpness of the grits, absence of wheel loading and lesser ductility of the steels under lower temperature. Such relative benefit of MQL enhanced with the increase in infeed rate.
- MQL provided relatively more surface roughness in compare to dry grinding but lower in compare to wet grinding for less plastic deformation and rubbing, shearing and fracturing modes of chip formation and retention of the grit's sharpness.

5. ACKNOWLEDGEMENT

This work has been funded by Directorate of Advisory Extension and Research Services (DEARS), Committee for Advanced Studies & Research (CASR), BUET, Dhaka, Bangladesh, sanction DEARS/CASR/R-01/2004/D-944(30) dated 28/2/2004. The authors are also grateful to the Department of Industrial and Production Engineering, BUET and Bangladesh College of Leather Technology (BCLT), Dhaka, Bangladesh for providing the facilities to carryout the experiment.

6. REFERENCES

- 1 Seah, K. H. W., Li, X. and Lee, K. S., 1995, "The Effect of Applying Coolant on Tool Wear in Metal Machining", *Journal of Material Processing Technology*, Vol.48, pp.495-501.
- 2 Dhar, N. R. and Mohiuddin, G. M., 2000, "Cutting Fluids and Their Effects on an Environment and the Skin- A Review", *Journal of the Institution of Engineers, Bangladesh, Multidisciplinary*, Bangladesh, Vol.Mul-dis25, No.I, pp.68-75.
- 3 Bennett, E. O and Bennett, D. L., 1985, "Occupational Airway Diseases in the Metal-working Industry", *Tribology Int.*, Vol. 18(3), pp.169-176.
- 4 Komanduri, R., and Desai, J., 1983, *Tool Materials, Encyclopedia of Chemical Technology*, 3rd Edition, John Wiley & Sons, NY, 23, pp.273-309.
- 5 Byrne, G. and Scholta, E., 1993, "Environmentally Clean Machining Process-A Strategic Approach", *Annals of CIRP*, Vol.42/1, pp. 471-474.
- 6 Aronson, R. B., 1995, "Why Dry Machining", *Manufacturing Engineering*, Vol.114, pp.33-36.
- 7 US Department of Health and Human Services, Occupational Exposure to Metalworking Fluids, NIOSH Publication No. 98-102, January 1998.
- 8 Dhar, N. R., Islam, M. W., Islam, S. and Mithu, M. A. H., 2005, "The Influence of Minimum Quantity of Lubrication (MQL) on Cutting Temperature, Chip and Dimensional Accuracy in Turning AISI1040 Steel" *Journal of Material Processing Technology*. [in press]
- 9 Islam, M. W., 2004, "Experimental Study of Effect of Minimum Quantity Lubrication (MQL) in Turning AISI-1040 Steel", M. Eng. Dissertation, BUET, Dhaka, Bangladesh.
- 10 Dhar, N. R., Rahman, K. M., Islam, S. and Hossain, M., 2005, "Using a Minimum Quantity of Lubricant (MQL) and a Carbide Tool in the Drilling of AISI-1060 Steel", *Journal of Mechanical Engineers, The Institution of Engineers, Bangladesh*. [in press]
- 11 Zhou, Z. X. and Lutervelt, C. A. van, 1992, "The Real Contact length between Grinding Wheel and Workpiece-A New Concept and a New Measuring Method", *Ann CIRP*, 41(1), pp.387.
- 12 Hossain, M., 2004, "Minimum Quantity Lubrication (MQL) Applications in Grinding Commercially Used Steels: A Comparison of MQL Grinding with Wet and Dry Grinding", M. Eng. Dissertation, BUET, Dhaka, Bangladesh.