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PERFORMANCE EVALUATION OF DIFFERENT TYPES OF CUTTING FLUID IN MQL MACHINING OF ALLOY STEEL BY COATED CARBIDE INSERT

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ABSTRACT

The research work studied some aspects of the turning process applied on alloy steel using coated carbide insert at different speed-feed combinations under minimum quantity lubrication (MQL) by different types of cutting fluids (water soluble cutting fluid, vegetable oil and VG68 cutting oil) as compared to completely dry cutting with respect to cutting temperature, chip thickness ratio, cutting forces, tool wear and surface roughness. In this study, the minimum quantity lubrication was provided with a spray of air and cutting fluids at a pressure 23 bars and coolant flow rate of 150 ml/hr. Compared to dry condition, MQL performed better mainly due to substantial reduction in cutting temperature that enabling favorable chip-tool interaction. This also facilitated the significant reduction in tool wear and surface roughness. The results indicated that the use of minimum quantity lubrication (MQL) by VG68 cutting oil reduced cutting temperature, cutting forces, delayed tool wear and lowered surface roughness significantly in compare to other environments.

Keywords: MQL, Cutting Fluids, Temperature, Force, Tool Wear And Roughness

1. INTRODUCTION

Machining is the process in which a tool removes material from the surface of a less resistant body, through relative movement and application of force. The material removed as chip, slides on the face of tool, called tool rake face, submitting it to high normal and shear stresses. Most of the mechanical energy used to form the chip becomes heat, which generates high temperatures in the cutting region. During machining at high cutting speed and feed, the heat generation [1] also raises the temperature of the cutting tool tips and the work surface near the cutting zone which results in high tool wear rate, reduced tool life. This may occur as these contact conditions become very severe and the tool wear is mainly caused by thermal softening, abrasion and a built-up edge (BUE) formation, which affects the quality of the generated surface and dimensional accuracy [2,3]. Machining under high cutting velocity and unfavorable process parameters require high specific energy. This machining results in very high cutting temperature and reduction of the dimensional accuracy and tool life by plastic deformation and rapid wears of the cutting points [4, 5]. During machining, in complete absence of coolant, chip transportation causes an increase of tool-chip and tool-workpiece friction, which results increased cutting force as well as abrasive wear and attrition. As a result the surface quality of the finished products deteriorates with the increase in cutting temperature due to built-up-edge formation, oxidation, rapid corrosion, induction of tensile residual stresses and surface. At elevated temperature the cutting tool if not enough hard may lose their form stability quickly or wear out rapidly resulting in increased cutting force, dimensional inaccuracy of the product and shorter tool life [6]. Some recent techniques have enabled partial control of the machining temperature by using heat resistant tools like coated carbides, CBN etc. The improvement in the coatings of carbide tools and in the chemical and mechanical properties of tool materials has caused the increase of tool working life in machining processes.

Due to the fact that the higher the tool temperature, the faster it wears. The use of cutting fluids in machining processes is the most common strategy, as its main goal, the reduction of the cutting zone temperature, either through lubrication reducing friction wear, or through cooling by conduction, or through a combination of these functions. The application of coolant during a machining operation is believed to reduce tool wear [7]. Cutting fluids also act as chip-breaker during machining and chip formation is also affected when coolant is applied during a machining operation. The chip curl changes with the temperature gradient along the thickness of the chip and affects the size of the crater wear and the strength of the tool cutting edge.

It has already been reported [8, 9] that the use of conventional cutting fluids (wet machining) does not serve the desired purpose in machining steels by carbides, rather reduce tool life and often may cause premature failure of the insert by brittle fracture. Cutting with the excess amount of cutting fluids is still very common in conventional machining to control high cutting temperature which adversely affects, directly and indirectly, chip formation, cutting forces, tool life and dimensional accuracy and surface integrity of the products. When inappropriately handled, cutting fluids may damage soil and water resources, causing serious loss to the environment. Therefore, the handling and disposal of cutting fluids must obey rigid rules of environmental protection. On the shop floor, the machine operators may be affected by the bad effects of cutting fluids, such as by skin and breathing problems. Eliminating use of cutting fluids can be a significant economic incentive.

Enormous efforts to reduce or eliminate the use of lubricant in metal cutting are, therefore, being made from the viewpoint of cost, ecological and human health issues. According to Diniz et al. [10] machining processes with the minimum quantity lubrication (MQL) technique or without any cutting fluid (dry cutting) reduced the utilization of cooling lubricants, in order to improve environmental protection, safety of machining processes and to decrease time and costs related to the number of machining operations.

The concept of minimum quantity lubrication (MQL) presents as a possible solution for machining in achieving slow tool wear while maintaining cutting forces/power at reasonable levels, provided that the minimum quantity lubrication parameters can be strategically tuned. The conventional flood supply system demands more resources for operation, maintenance, and disposal, and results in higher environmental and health problems. MQL machining has many advantages in this regard [11, 12, and 13]. Minimal quantity lubrication (MQL) is a technique of supplying lubrication in machining to achieve both environmental and economical benefits. The present work experimentally investigates the role of minimum quantity lubrication (MQL) by different types of cutting fluids (water soluble cutting fluid, vegetable oil and VG68 cutting oil) on cutting temperature, chip thickness ratio, cutting forces, tool wear mechanism and surface finish in continuous turning 42CrMo4 steel using coated carbide insert (SNMM-TN 2000) at industrial speed-feed condition and compares the effectiveness of MQL with that of dry machining.

2. EXPERIMENTAL SETUP AND PROCEDURE

The experiment was carried out on lathe, which has a 7.5 kW spindle and maximum spindle speed of 1400 rpm. The work material was alloy steel (42CrMo4) having external diameter of 160 mm and length of 550 mm. The cutting tool used was coated carbide insert (Widia SNMM TN-2000). The tool holder provided negative 6° side and back rake angles and 6° side cutting-edge and end cutting-edge angles. The ranges of the cutting speed (V), feed (f) and depth of cut (d) were selected based on the tool manufacturer's recommendation and industrial practices. The experimental conditions are given in Table-1.

Table 1 Experimental conditions

Machine tool	: Lathe (China), 7.5 kW
Work material	: 42CrMo4 steel
Tool geometry	: -6°,-6°,6°,15°,75°,0.8 (mm)
Coating	: TiCN
Tool holder	: PSBNR 2525 M12 (WIDIA)
Process parameters	
Cutting speed, V	: 175, 247 and 352 m/min
Feed rate, f	: 0.10, 0.12 and 0.14 mm/rev
Depth of cut, d	: 1.00 mm
MQL supply	: Air pressure 23 bars, oil pressure 25 bars and flow rate 150 ml/hr
Environment	: • Dry • MQL with Soluble oil • MQL with Vegetable oil and • MQL with VG 68 Cutting oil

The experimental set-up shown in Fig.1, where a minimum quantity lubrication jet was injected through the tool rake face, consists of a compressor, MQL applicator, centre lathe machine, tool-wear thermocouple and hardened steel. In this study, the minimum quantity lubrication was provided with a spray of air and cutting fluids at a pressure 23 bars and coolant flow rate of 150 ml/hr.

Fig 1. Photographic view of the experimental set up

The average cutting temperature was measured by tool-work thermocouple technique with proper calibration [14].The thickness of the chips directly and indirectly indicates the nature of chip-tool interaction influenced by the machining environment. The chip samples were collected during short run and long run machining for the V-f combinations under dry and MQL conditions. The thickness of the chips was repeatedly measured by a slide caliper to determine the value of chip thickness ratio. The cutting insert was withdrawn at regular intervals to study the pattern and extent of wear on main and auxiliary flanks under both dry and MQL conditions. The average width of the principal flank wear, VB and auxiliary flank wear, VS were measured using metallurgical microscope (Carl Zesis, Germany) fitted with micrometer of 1μm resolution. No notch wear was observed during measuring under optical microscope. The surface roughness of the machined surface after each cut was measured by a Talysurf (Surtronic 3^+) using a sampling length of 0.8mm.

3. RESULT AND DISCISSION

Heat generation at the chip-tool interface is of prime concern in the machining process. The machining temperature at the cutting zone must be reduced to an optimum level. During machining, shearing of work material, friction between the flowing chips and rake face of the tool and friction of auxiliary flank with finished surface are the principal sources of heat generation. The magnitude of the cutting temperature increases with the increase of material removal rate i.e. with the increase of cutting velocity, feed and depth of cut, as a result, high production machining is constrained by the ascend in temperature. This problem increases further with the increase in strength and hardness of the work material.

The variation in average chip-tool interface temperature at different cutting speed, feed and environment combinations is shown in Fig.2. The cutting temperature generally increases with the increase in V, f and d though in different degree due to increased energy input. So, for high-speed machining it is very important to control the cutting temperature. It could be expected that MQL would be more effective at higher values of V, f and d.

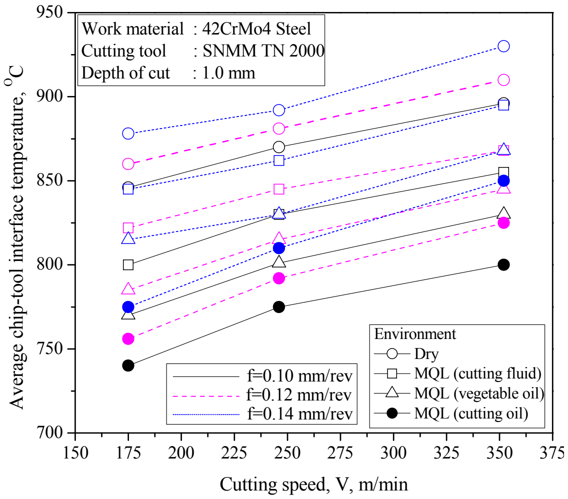

Fig 2. Variation of chip-tool interface temperature with V and f under different environments

Fig.2 shows that MQL is better than dry machining for all the V-f-d combinations but among three fluids used for MQL, cutting oil shows best results, secondly vegetable oil and than cutting fluid. The reduction in cutting temperature among all V-f combinations is more for the set V =175m/min and f = 0.10 mm/rev. In this V-f combination temperature reduction under MQL by cutting oil, vegetable oil and soluble oil varies from 8.60~12.53%, 6.67~8.98% and 3.36~5.44% respectively. It can be noticed that with the increase in speed and feed MQL becomes less effective. This may be due to the increase in chip load and increase in plastic contact length during cutting prevents the MQL to enter into the chip-tool interface. More over, it shows best reduction at higher cutting speed for lower feed rate. In all the tests through out the entire experiment, MQL with cutting oil (VG-68) shows the best performance due to its better cooling and lubrication irrespective of speed feed and depth of cut. The effects of different environments over dry condition on cutting temperature at different V-f combination have been evaluated by regression analysis using the limited experimental data. The result is shown in Fig.3.

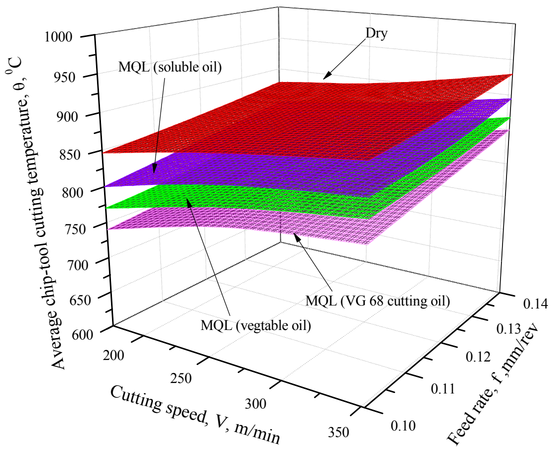

Fig 3. Effect of environment on chip-tool interface temperature evaluated by regression analysis of the experimental data

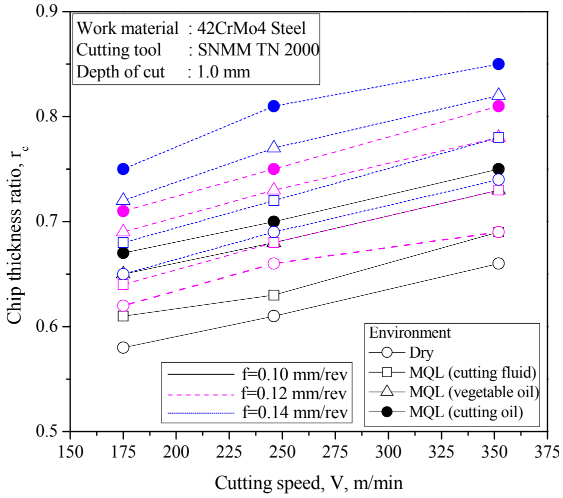

Fig 4. Variation of chip-thickness ratio with V and f under different environments

Chip thickness depends on almost all the parameters involved in machining. The degree of chip thickness which is measured by chip thickness ratio, plays an important role on cutting forces and hence on cutting energy requirements and cutting temperature. Fig.4

shows the effect of increase in V and f and the change in environment on the value of chip-thickness ratio (r_c) obtained during turning 42CrMo4 steel. MQL has increased the value of chip thickness ratio for all V-f-d combinations due to reduction in friction at the chip-tool interface, reduction in built-up-edge formation and wear at the cutting edges. The percentage increment of chip thickness ratio for the above mentioned V-f combinations for MQL by cutting oil, vegetable oil and soluble oil over dry condition are 14~17%, 10~13% and 3~6% respectively.

The magnitude of the cutting force is a major index of machinability which governs productivity, product quality and overall economy in machining. The cutting forces increase almost proportionally with the increase in chip load and shear strength of work material. The magnitude of main cutting force, F_C and feed force, F_f have been monitored by dynamometer for all the speed-feed combinations under dry, MQL (soluble oil), MQL (vegetable oil) and MQL (VG 68 cutting oil) machining by coated carbide insert (SNMM-TN2000) which have been shown graphically in Fig.5 and Fig.6 respectively. The figures clearly indicate the influence of feed and cutting speed on main cutting force (F_C) and feed force (F_f). The main cutting force and feed force are increased though in different degree by increasing feed due to increased energy input and chip load and decreased by increasing cutting speed due to much softening of the work material ahead of the advancing tool.

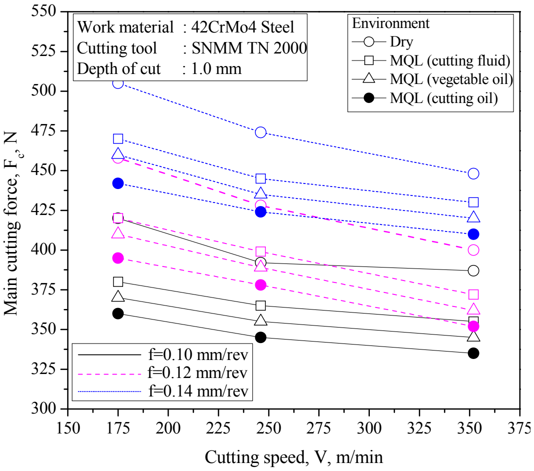

Fig 5. Variation of main cutting force with cutting speeds and feed rates under different environments

The percentage of reduction in main cutting force for the stated V-f combinations under MQL using cutting oil, vegetable oil and soluble oil over dry condition are 8~14%, 6~11% and 4~9% respectively with an average of 12%, 9% and 7% respectively. Percentage of reduction in feed force for the stated V-f combinations for MQL using cutting oil, vegetable oil and soluble oil over dry condition are 6~12%, 4~10% and 2~7% respectively with an average of 9%, 7% and 5% respectively. Among the environments MQL cutting oil (VG 68) gives the best performance.

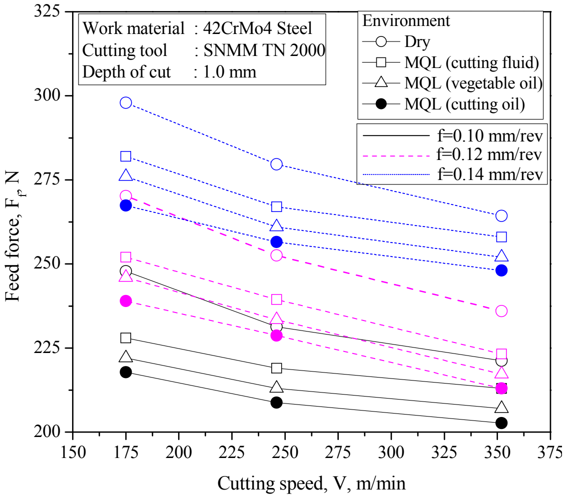

Fig 6. Variation of feed force with cutting speeds and feed rates under different environments

The life of carbide tools, which mostly fail by wearing, is assessed by the actual machining time after which the average value (VB) of its principal flank wear reaches a limiting value, like 0.3 mm. therefore, attempts should be made to reduced the rate of growth of flank wear (VB) in all possible ways without much sacrifice in MMR. The growth of average principal flank wear (VB) and auxiliary flank wear (VS) with progress of machining by SNMM insert under dry and MQL conditions have been shown in Fig.7 and Fig.8 respectively. From the previous discussion it is obtained that MQL by cutting fluid in feed 0.12 mm/rev is more effective, so the wear parameters are selected considering these fact.

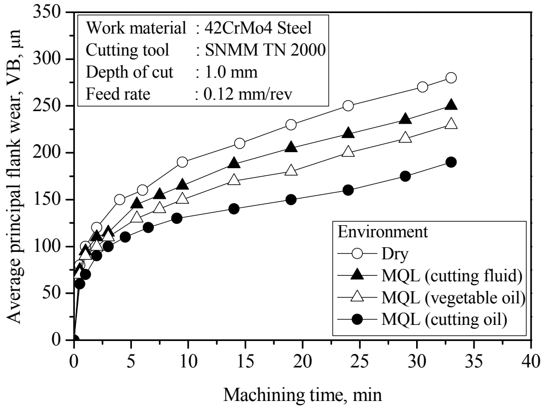

Fig 7. Growth of average principal flank wear (VB) with machining time under different environments

It is clearly appeared from Fig.6 and Fig.7 that flank wears, VB and VS particularly its rate of growth decreased substantially by MQL when turning 42CrMo4 steel by coated carbide SNMM inserts. Pressurized jet of MQL easily dragged into the plastic contact by its high energy jet, cools the interface and lubricate properly. It not only cools the interface but also reduces frictional heat generation by lubricating the friction zones.

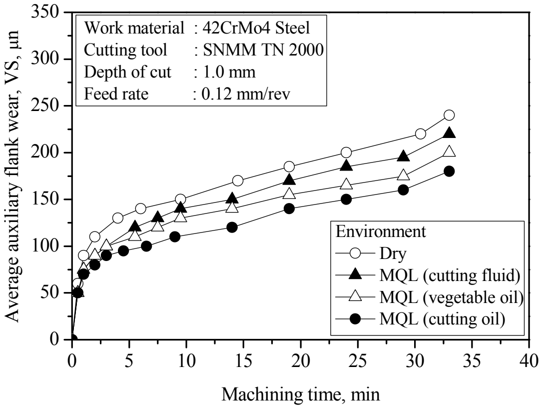

Fig 8. Growth of average auxiliary flank wear (VS) with machining time under different environments

Surface finish is also an important index of machinability. Feed force as well as chip thickness ratio is responsible for surface roughness along the longitudinal direction of the turned job. Usually surface roughness decreases with the increase in cutting velocity as cutting force decreases and chip thickness ratio increases with the increase in cutting speed. It is clear from Fig. 8 that surface roughness is reduced under MQL condition than dry through out the V-f-d combinations but MQL by cutting oil and vegetable oil show better results. In respect of surface roughness MQL is better for f=0.12 mm/rev and V=352 m/min. The value of percentage reduction for cutting oil and vegetable oil are 17~25% and 12~21% respectively.

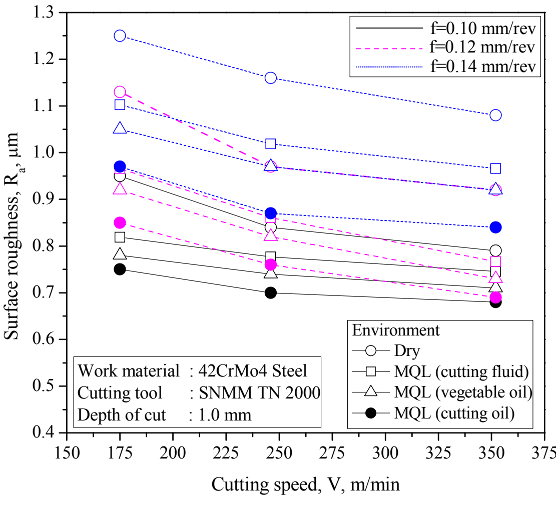

Fig 9. Variation of surface roughness with cutting speeds and feed rates under different environments

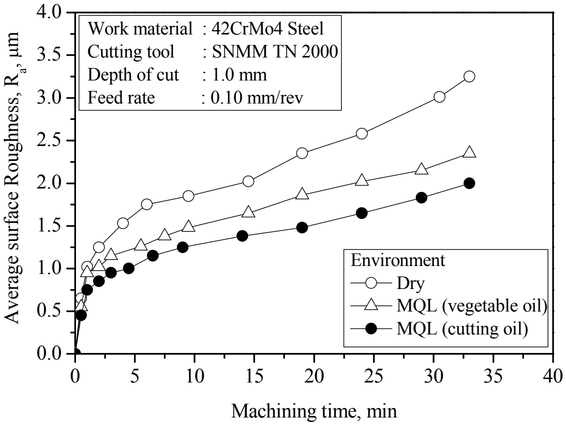

Fig 10. Variation of surface roughness with machining time

The variation in surface roughness observed with progress of machining 42CrMo4 steel at a particular set of cutting speed V, feed rate f and depth of cut d, by the coated carbide SNMM insert under dry and different MQL conditions has been shown in Fig.10. It is clear that surface roughness gradually increases with the machining time due to gradual increases in auxiliary flank wear VS. MQL has appeared to be more effective in reducing surface roughness as it did for auxiliary flank wear. The rate of increase in surface roughness decreases to significant extent when machining has been done under minimum quantity lubrication. MQL jet not only reduce the VS but also possibly of built-up edge formation due to reduction in temperature.

4. CONCLUSION

Based on the results of the present experimental investigation the following conclusions can be drawn:

i. MQL assisted jet enabled reduction in average chip-tool interface temperature from 3 to 12.5% depending upon the types of cutting fluids. Even such apparently small reduction, enabled significant improvement in the major machinability indices. MQL by VG 68 cutting oil reduced cutting temperature by about 8.6%-12.5% that indicates the effectiveness of cutting oil over other two MQL coolants.
ii. Among the three MQL coolants VG 68 cutting oil exhibits the best results in respect of chip thickness ratio when 42CrMo4 steel is machined using coated SNMM carbide insert. MQL by VG 68 cutting oil has increased the chip thickness ration (r_c) by 14% - 17%.
iii. MQL jet provided reduced tool wear, improved tool life and better surface finish as compared to dry and wet machining of steel. Surface finish improved mainly due to reduction of wear and damage at the tool tip by the application of MQL.

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