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EFFECT OF MINIMUM QUANTITY LUBRICATION (MQL) ON CUTTING PERFORMANCE IN TURNING MEDIUM CARBON STEEL BY UNCOATED CARBIDE INSERT AT DIFFERENT SPEED-FEED COMBINATIONS

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Abstract:
Minimum quantity lubrication (MQL) refers to the use of cutting fluids of only a minute amount typically of a flow rate of 50 to 500 ml/hour which is about three to four orders of magnitude lower than the amount commonly used in flood cooling condition. The concept of minimum quantity lubrication (MQL) has been suggested since a decade ago as a means of addressing the issues of environmental intrusiveness and occupational hazards associated with the airborne cutting fluid particles on factory shop floors. This paper deals with experimental investigation on the role of MQL by cutting oil on chip thickness ratio, cutting temperature, cutting forces, tool wear and surface roughness in turning medium carbon steel at industrial speed-feed combinations by uncoated carbide insert. The encouraging results include significant reduction in tool wear rate, dimensional inaccuracy and surface roughness by MQL over dry machining mainly through reduction in the cutting zone temperature and favourable change in the chip-tool and work-tool interaction. The results reveals that the MQL system can enable significant improvement in productivity, product quality and overall machining economy even after covering the additional cost of designing and implementing MQL system..

Key Words: Minimum Quantity Lubrication, Cutting Performance, Turning, Carbide Insert

1. INTRODUCTION

The quality of machined components is evaluated in respect of how closely they adhere to set product finish, and reflective properties. Dimensional accuracy, tool wear and quality of surface finish are three factors that manufacturers must be able to control at the machining operations to ensure better performance and service life of engineering component. In the leading edge of manufacturing, manufacturers are facing the challenges of higher productivity, quality and overall economy in the field of manufacturing by machining. To meet the above challenges in a global environment, there is an increasing demand for high material removal rate (MRR) and also longer life and stability of the cutting tool But high production machining with high cutting speed, feed and depth of cut generates large amount of heat and temperature at the chip-tool interface which ultimately reduces dimensional accuracy, tool life and surface integrity from which decisions can be made, or patterns discerned, of the machined component. This temperature needs to be controlled at an optimum level to achieve better surface finish and overall machining economy.

The conventional types and methods of application of cutting fluid have been found to become less effective with the increase in cutting velocity and feed when the cutting fluid cannot properly enter into the chip-tool interface to cool and lubricate the interface due to bulk plastic contact of the chip with the tool rake surface. The more serious concern by the use of cutting fluid, particularly oil-based type is the pollution of the working environment, water pollution, soil contamination and possible damage of the machine tool slide ways by corrosion [1].

The modern industries are therefore looking for possible means of dry (near dry), clean, neat and pollution free machining and grinding. Minimum Quantity Lubrication (MQL) refers to the use of cutting fluids of only a minute amount-typically of a flow rate of 50-500 ml/hour-which is about three to four orders of magnitude lower than the amount commonly used in flood cooling, where for example, up to 10 liters of fluid can be dispensed per minute. The concept of minimum quantity lubrication (MQL), sometimes referred to as ‘near dry lubrication’ [2] or ‘micro lubrication’ [3]. In machining process, the tool removes material from the surface of a less resistant body, through relative movement and application of force. The material removed called chip slides on the face of tool submitting it to high normal and shear stresses and moreover to a high coefficient of friction during chip formation. Most of the mechanical energy used to form the chip becomes heat, which generates high temperatures in the cutting region. A major portion of the energy is consumed in the formation and removal of chips. The greater the energy consumption, the greater the temperature and the frictional force at the tool-chip interface and consequently the higher is the tool wear. For this reason, conventional coolant is often used on the cutting tool to prevent overheating. However, the main problem with conventional coolant is that it does not reach the real cutting area [4].

The extensive heat generated evaporates the coolant before it can reach the cutting area. Hence, heat generated during machining is not removed and is one of the main causes of the reduction in tool life [5].

Cutting fluids is supposed to play a significant role in improving lubrication as well as minimizing temperature at the tool-chip and tool-workpiece interfaces, consequently minimizing seizure during machining but it can only perform these functions at the point of chip formation if the coolant actually reaches the cutting zone Flood cooling of the cutting zone can effectively reduce the cutting temperature when machining at lower speed. Flood cooling is not effective in terms of lowering cutting temperature when machining exotic materials or machining at high speed. The coolant does not readily access the tool-workpiece and tool-chip interfaces that are under seizure condition as it vaporized by the high temperature generated close to the tool edge. During machining [6, 7], especially of very hard materials, much heat is generated by the friction of the cutter against the workpiece, which is one of the major causes of reduction in tool hardness and rapid tool wear. For this reason, conventional coolant is often used on the cutting tool, to prevent overheating. However, the main problem [4] with conventional coolant is that it does not reach the real cutting area. The extensive heat generated evaporates the coolant before it can reach the cutting area. The high cutting forces generated during machining will induce intensive pressure at the cutting edge between the tool tip and the workpiece. Conventional coolant might not be able to overcome this pressure and flow into the cutting zone to cool the cutting tool. Hence, heat generated during machining is not removed and is one of the main causes of the reduction in tool life. Proper selection and application of cutting fluid generally improves tool life. At low cutting speed almost four times longer tool life was obtained [8] by such cutting fluid. But surface finish did not improve significantly.

Machining leads to environmental pollution mainly because of use of cutting fluids [9, 10]. 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.

Skin exposure to cutting fluid can cause various skin diseases [11]. In general, skin contact with straight cutting oils cause folliculitis, oil acne, and keratoses while skin exposure to soluble, semi-synthetic and synthetic cutting fluid would result in irritant contact dermatitis and allergic contact dermatitis. Another source of exposure to cutting fluids is by inhalation of mists or aerosols. Airborne inhalation diseases have been occurring with cutting fluid aerosols exposed workers for many years. These diseases include lipid pneumonia, hypersensitivity pneumonitis, asthma, acute airways irritation, chronic bronchitis, and impaired lung function [11]. In response to these health effects through skin contact or inhalation, the National Institute for Occupational Safety and Health (NIOSH) has recommended that the permissible exposure level (PEL) is 0.5 mg/m3 as the metalworking fluid concentration on the shop floor [11, 12]. Bennett and Bennett [13] stated that during machining operations, workers could be exposed to cutting fluids by skin contact and inhalation

Enormous efforts to reduce the use of lubricant in metal cutting are being made from the viewpoint of cost, ecological and human health issues [1, 14-16]. Minimal quantity lubrication (MQL) can be considered as one of the solutions to reduce the amount of lubricant. Again 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 Minimum Quantity Lubricant (MQL) machining process as one of the viable alternative instead of using conventional cutting fluids. Machining under minimum quantity lubrication (MQL) condition is perceived to yield favorable machining performance over dry or flood cooling condition.

2. OBJECTIVE OF THE STUDY

The objective of the present work is to examine the effects of minimum quantity lubrication on the cutting performance of medium carbon steel at different cutting velocities and feeds in terms of main cutting force and feed force, average chip-tool interface temperature, tool wear and surface finish.

3. EXPERIMENTAL INVESTIGATIONS

The concept of minimum quantity lubrication (MQL) may be considered as a rigorous solution in achieving reduced tool wear and improved surface finish while maintaining cutting forces or power at reasonable levels, if the MQL system can be properly designed. MQL technique not only provides reduction in tool wear or increase in tool life and improvement in surface roughness but also reduces the consumption of cutting fluid. The machining tests have been carried out by straight turning of medium carbon steel on a lathe (7.5 kW) by a standard uncoated carbide insert with ISO designation-SNMG 120408 at different speed-feed combinations. MQL machining has been considered to be an effective semidry application because MQL offers positive part on environment friendliness as well as techno-economical benefit.

The conditions under which the machining tests have been carried out are briefly given in Table I. All these parameters have been selected as per tool manufacturer’s recommendation as well as industrial practices for machining medium carbon steel with uncoated carbide insert. Effectiveness of cooling and the related benefits entirely depends on how closely the MQL jet can reach the chip-tool and the work-tool interfaces where, apart from the primary shear zone, heat is generated. The tool geometry is reasonably expected to play significant role on such cooling effectiveness. Keeping this view tool configuration namely SNMG-120408 has been undertaken for this work. The insert was clamped in a PSBNR-2525 M12 type tool holder.

Table I: Experimental conditions.

Machine tool	:	Lathe Machine(China), 7.5 kW
Work materials	:	Medium Carbon Steel
Cutting tool	:	Uncoated Carbide, (p-30 grade), Sandvik
Geometry	:	-6°,-6°,6°,15°,75°,0.8 mm
Tool holder	:	PSBNR 2525 M12 (ISO specification), Widia
Cutting parameters		
Cutting velocity, V	:	68, 95, 133, 190 and 266 m/min
Feed rate, f	:	0.10, 0.12, 0.14, 0.18 and 0.20 mm/rev
Depth of cut, d	:	1.0 and 1.5 mm
MQL supply	:	Flow Rate 150 ml/hr, Air Pressure 23 bar, Oil Pressure 25 bar
Environment	:	MQL (VG-68 Cutting oil)

The photographic view of the experimental set-up is shown in Figure 1. A cylindrical bar of medium carbon steel of 173 mm diameter was selected for straight turning. During machining, the cutting insert was withdrawn at regular intervals and then VB, VM, VS were measured under metallurgical microscope (Carl Zesis, 351396, Germany) fitted with micrometer of least count 1μm. Surface roughness was measured respectively by a Talysurf (Surtronic 3+ Roughness checker, Taylor Hobson, UK) using a sampling length of 4.00 mm.

Figure1: Photographic view of experimental set-up.

3.1 Chip thickness ratio

Chip thickness ratio, r_c (ratio of chip thickness before and after cut) is an important machinability index for identifying machining performance. For given tool geometry and cutting conditions, the value of r_c depends upon the nature of chip-tool interaction, chip contact length and chip form, all of which are expected to be influenced by MQL in addition to the levels of V and f. The variation in value of r_c with change in cutting velocity, V and feed rate, f and as well as machining environment evaluated for medium carbon steel for the depth of cuts of 1.0 and 1.5 mm have been plotted and shown in the Figure 2 and Figure 3 respectively.

3.2 Cutting temperature

Any machining process associated with high velocity and feed rate inherently generate large amount of heat as well as high cutting zone temperature. The magnitude of this cutting temperature increases, though in different degree, with the increase of cutting velocity, feed and depth of cut, as a result, high production machining is constrained by rise in temperature. The average chip-tool interface temperature was measured under both dry and

MQL condition by tool-work thermocouple techniques with proper calibration during turning of medium carbon steel at different cutting velocities and feeds in the present investigation. The evaluated role of MQL on average chip-tool interface temperature in turning medium carbon steel by uncoated carbide insert (SNMG-120408) at different V–f combinations for the depth of cuts of 1.0 and 1.5 mm under both dry and MQL condition have been shown in Figure 4 and Figure 5.

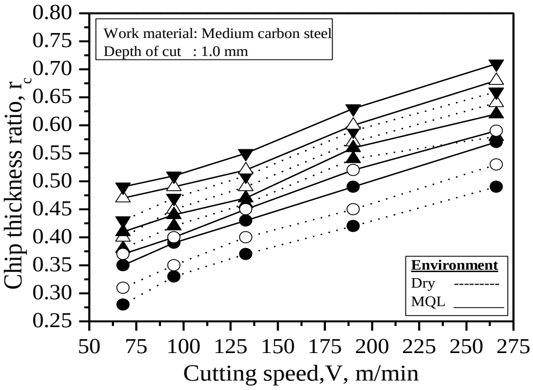
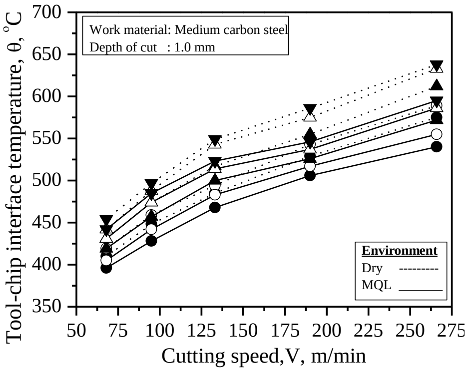


Figure 2: Variation in Chip thickness ratio (r_c) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.00 mm.

3.3 Cutting force

Cutting forces are generally resolved into components in mutual perpendicular directions for convenience of measurement, analysis, estimation of power consumption and for the design of machine-fixture-tool-work systems. In turning by single point tools like inserts, the single cutting force generated is resolved into three components namely; tangential force or main cutting force, F_c, axial force or feed force, F_f and transverse force, F_t. Each of those interrelated forces has got specific significance. In the present work, the magnitude of F_c and F_f have been monitored by dynamometer for all the combinations of cutting speeds, feeds, depth of cuts and environments undertaken. The effect of MQL on F_c and F_f that have been observed while turning medium carbon steel specimen by the uncoated carbide inserts SNMG-120408 under different V and f with depth of cuts of 1.0 and 1.5 mm have been graphically shown in Figure 6, Figure 7, Figure 8, and Figure 9.



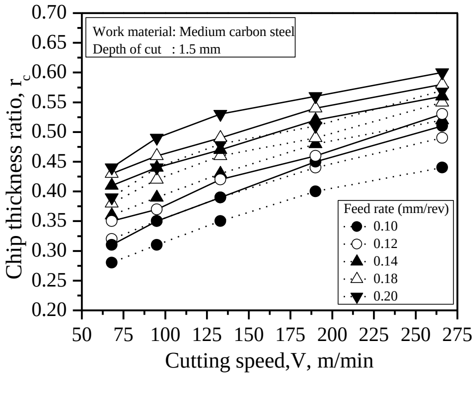


Figure 3: Variation in Chip thickness ratio (r_c) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.50 mm

Figure 4: Variation in temperature (θ) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.00 mm.

3.4 Tool wear

Productivity and economy of manufacturing by machining are significantly affected by life of the cutting tools. Cutting tools may fail by brittle fracture, plastic deformation or gradual wear. In conventional machining, particularly in continuous chip formation processes like turning, generally the cutting tools fail by gradual wear by abrasion, adhesion, diffusion, chemical erosion, galvanic action etc. depending upon the tool-work materials and machining condition. Tool wear initially starts with a relatively faster rate due to what is called break-in wear caused by attrition and micro-chipping at the sharp cutting edges. With the progress of machining the tools attain crater wear at the rake surface and flank wear at the clearance surfaces due to continuous interaction and rubbing with the chips and the work surfaces respectively. Systematic gradual wear is generally assessed by the average value of the principal flank wear (VB), which aggravates cutting forces and temperature and may induce vibration with progress of machining**.** The need for accurate assessment of tool wear has increased considerably in order to produce the required end products so that a new tool may be introduced at the instant at which the existing tool has worn out, thus preventing any hazards occurring to the machine or deterioration of the product surface finish. The importance of maximizing a tool's working time and doing the utmost to keep tools from breaking is directly related with cutting-process optimization. Tool life improvement is essential to reduce the cost of production as much as possible. The growth of principal flank wear, VB with progress of machining time recorded while turning the medium carbon steel by uncoated SNMG insert at lower speed and feed (V=66m/min, f=0.10 mm/rev) and higher speed and feed (V=258 m/min, f=0.20 mm/rev) with two depth of cut (d=1.0mm and 1.5 mm) under dry and MQL (cutting oil) conditions have been shown in Figure 10, Figure 11, Figure 12 and Figure 13.

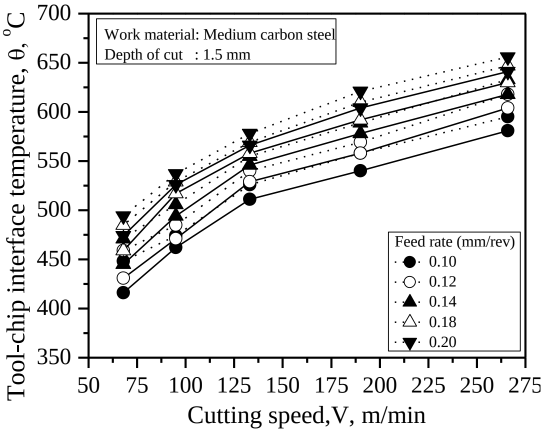


Figure 5: Variation in temperature (θ) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.50 mm.

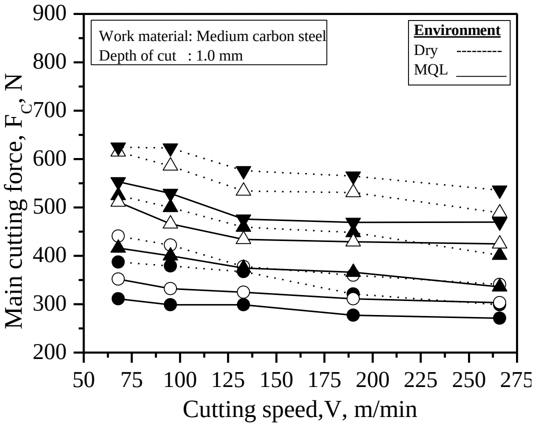


Figure 6: Variation in main cutting force (F_c) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.00 mm.

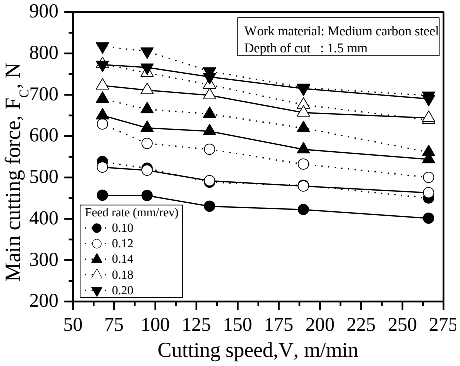


Figure 7: Variation in main cutting force (F_c) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.50 mm.

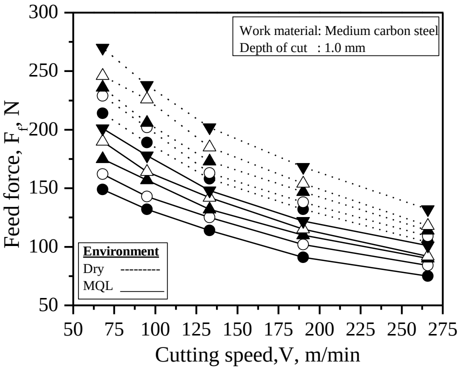


Figure 8: Variation in Feed force (F_f) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.0 mm.

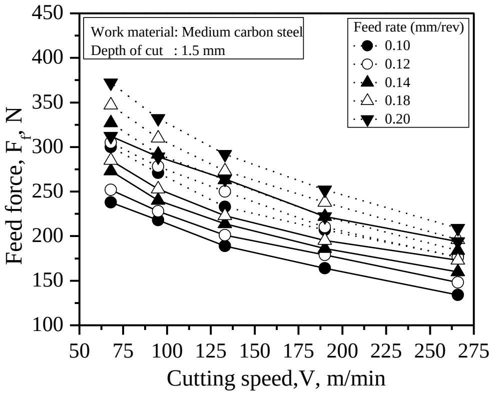


Figure 9: Variation in Feed force (F_f) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.50 mm.

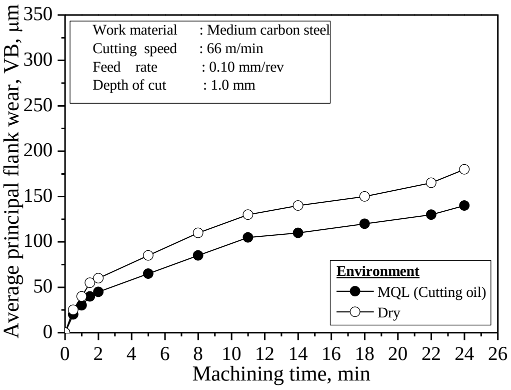


Figure 10: Growth of average principal flank wear (VB) with machining time turning medium carbon steel by SNMG insert under dry and MQL environments at depth of cut 1.00 mm.

The principal flank wear is the most important because it raises the cutting forces and related problems. Again the life of the tools, which ultimately fail by the

3.5 Surface roughness

Surface roughness is a widely used index of product quality and in most cases a technical requirement for mechanical products. The performance and surface life of any machined component is influenced by surface integrity of that component. Achieving the desired surface quality is of great importance for the functional behavior of a part. Therefore, the estimation of the magnitude of surface roughness under given cutting conditions resulting from metal removal operations is one of the major roles in this area. The surface roughness of machined parts is a significant design specification that is known to have considerable influence on properties such as wear resistance, clean ability, assembly tolerances, coefficient of friction, wear rate, corrosion resistance, fatigue strength and aesthetic appearance. The quality of surface finish is a factor of importance in the evaluation of machine tool productivity. As roughness of the machined surface is an important quality measure in metal cutting, it is important to monitor and control surface roughness over time during the machining operation.

Surface roughness has been measured at two stages; one, after a few seconds of machining with the sharp tool while recording the cutting temperature and forces and second, with the progress of machining while monitoring growth of tool wear with machining time. Here the surface finish has been measured by a Talysurf (Surtronic 3+, Rank Taylor Hobson Limited) by the machining of the steel bar by the uncoated carbide insert at different V-f combination for the depth of cuts of 1.0 and 1.5 mm under dry and MQL using a sampling length of 4.00 mm. The arithmetic average value is measured several times and it is then averaged to obtain the surface roughness value for the combinations of cutting speed, feed and depth of cut.

Variation of surface roughness with increase of cutting speed for different feed rates with depth of cut of 1.00 mm and 1.50 mm are shown in Figure 14 and variation of surface roughness with progress of machining time at lower speed and feed (V=66m/min, f=0.10 mm/rev) and higher speed and feed (V=258 m/min, f=0.20 mm/rev) with two depth of cut (d=1.0mm and 1.5 mm) under dry and MQL (cutting oil) conditions have been shown in Figure 15.

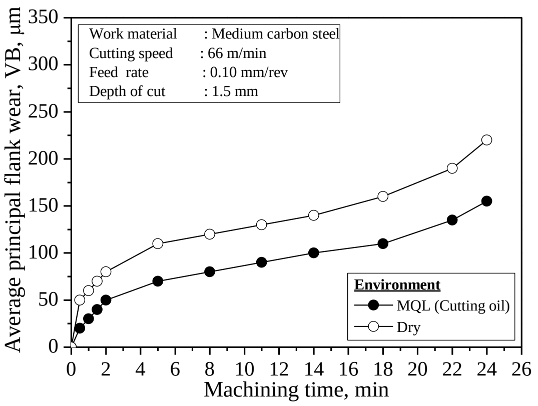


Figure 11: Growth of average principal flank wear (VB) with machining time turning medium carbon steel by SNMG insert under dry and MQL environments at depth of cut 1.50 mm.

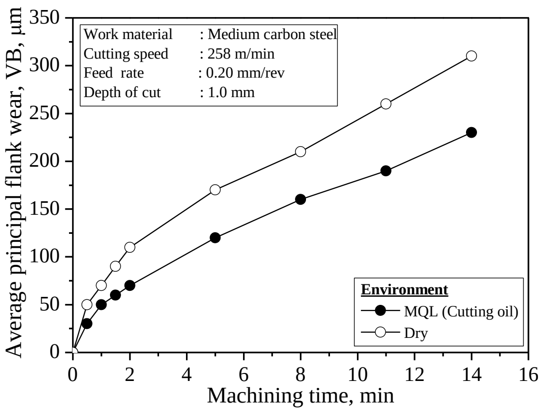


Figure 12: Growth of average principal flank wear (VB) with machining time turning medium carbon steel by SNMG insert under dry and MQL environments at depth of cut 1.00 mm.

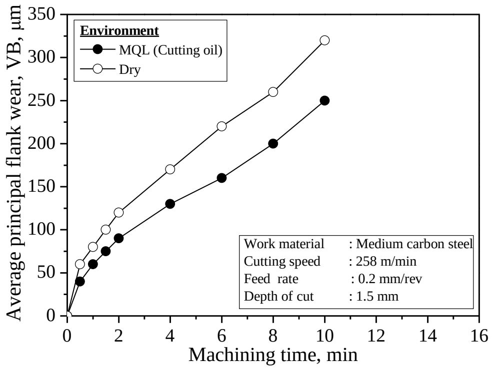
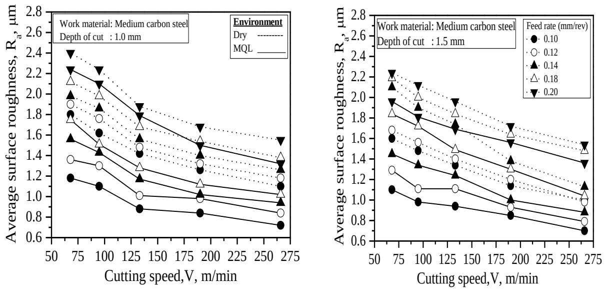
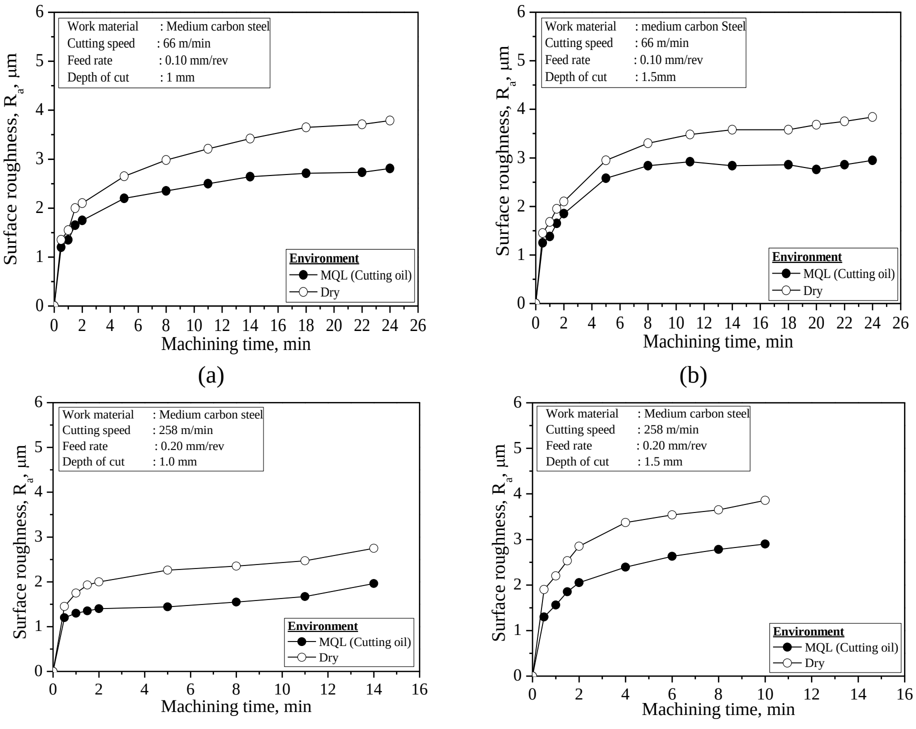


Figure 13: Growth of average principal flank wear (VB) with machining time turning medium carbon steel by SNMG insert under dry and MQL environments at depth of cut 1.50 mm.



(a) (b)

Figure 14: Variation in surface roughness (Ra) with that of V and f in turning medium carbon steel by SNMG insert under Dry and MQL conditions at depth of cut of 1.00 mm (a) and 1.50 mm (b).



(a) (b)

(c) (d)

Figure 15: Variation in average surface roughness (R_a) with time during turning medium carbon steel by SNMG insert under dry and MQL environments for v=66 m/min at depth of cut of 1.00 mm (a) and 1.50 mm (b); for v=258 m/min at depth of cut of 1.00 mm (c) and 1.50 mm (d).

4. DISCUSSION ON EXPERIMENTAL RESULTS

4.1 Chip thickness ratio

All parameters in machining are directly or indirectly linked with the chip thickness ratio. If there is excessive heat generated at the cutting zone, there will be high friction between the tool and the work material. This frictional force will cause high energy consumption hence higher cutting force. These will lead to a low chip thickness ratio which is not desirable. The variation in value of r_c with change in cutting velocity, V and feed rate, f and as well as machining environment evaluated for medium carbon steel for the depth of cuts of 1.0 and 1.5 mm have been plotted and shown in the Figure 2 and Figure 3 respectively. From Figure 2 and Figure 3 it has been shown that application of MQL jet has improved the value of chip thickness ratio for all V-f combinations due to reduction in friction at the chip-tool interface, reduction in built-up-edge formation and wear at the cutting edges. In all V-f combinations MQL by cutting oil shows more effectiveness than machining in a dry environment. The MQL jet, with both its lubricating and cooling effect, minimized the shrinkage of shear zone and plasticization and reduced the formation of built-up-edge. The figures 2 and 3 clearly represent that throughout the present experimental domain the value of r_c gradually increased with the increase in V and f in different degree under both dry and MQL conditions. . This is due to the higher energy utilization associated with higher material removal rate.

4.2 Cutting temperature

Generation of heat at the cutting zone is of prime concern in any machining process and this heat needs to be controlled to an optimum level in order to achieve better machining performance. Cutting temperature increases with the increase in specific energy consumption and 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. The high temperature generated adversely affects, directly or indirectly, chip formation, cutting forces, tool life, dimensional accuracy and surface integrity of the machined components. Therefore, application of MQL at chip-tool interface is expected to improve upon the aforesaid machinability characteristics that play vital role on productivity, product quality and overall economy in addition to environment-friendliness in machining particularly when chip-tool or work-tool interface temperature is high. In this research work, a tool-work thermocouple with proper calibration [17] was used to determine the average chip-tool interface temperature during turning of medium carbon steel at different cutting velocities and feeds and the values were plotted against different cutting speed under both dry and minimum quantity lubrication (MQL) condition. The evaluated role of MQL on average chip-tool interface temperature in turning medium carbon steel by uncoated carbide insert (SNMG-120408) at different V–f combinations for the depth of cuts of 1.0 and 1.5 mm under both dry and MQL condition have been shown in Figure 4 and Figure 5. The figure 4 and 5 clearly depicts in what extent tool-chip interface temperature has been decreased due to minimum quantity lubrication (MQL) under different experimental conditions. With the increase in cutting speed and feed rate , tool-chip interface temperature has been increased as usual, even under MQL due to increase in energy input.

4.3 Cutting force

The cutting forces generated during the machining process bears a significant effect on the quality of any machined component. High cutting forces may result in premature tool failure, tool vibration, high temperature generation, large tool deflections and significant mechanical loads on the workpiece surface. Large tool deflections can lead to form errors because the tool tip position deviates from the expected position. Large mechanical loads on the workpiece surface can affect the topography and integrity of a machined surface. For these reasons, it is obviously important to understand how changing process conditions affect cutting forces. In these investigations, two components of cutting force (main cutting force, F_c and feed force, F_f) were recorded during machining under dry and minimum quantity lubrication (MQL) conditions while turning medium carbon steel by uncoated SNMG insert at regular intervals. The force components were measured with a strain-gauge type force dynamometer and recorded with a PC-based data acquisition system for the combination of cutting velocities, feeds, depth of cuts and environments undertaken. Figure 6 to Figure 9 clearly show that the MQL jet has been quite successful in reducing the main cutting force and feed force. This is attributed to mainly the reduction of friction accomplished by the lubricating effect of the MQL jet. The MQL jet, with its and velocity, was able to reach the tool tip where it performed its lubricating and cooling effects and minimized friction to a remarkable amount. Reason acting behind reduction of cutting forces may be the reduction in chip load. The high velocity MQL jet impinged on the rake face uplifted the chip and reduced chip load which eventually helped to reduce the cutting forces significantly. From the figures, it has also been seen that main cutting forces and feed forces decreases with the increase of cutting speed and the force component increases with the increase of feed rate.

4.4 Tool wear

The cutting tools in conventional machining, particularly in continuous chip formation process like turning, generally subjected to gradual wear by abrasion, adhesion, and diffusion depending upon the tool-work materials and machining conditions. The growth of principal flank wear, VB with progress of machining time recorded while turning the medium carbon steel by uncoated SNMG insert at lower speed and feed (V=66m/min, f=0.10 mm/rev) and higher speed and feed (V=258 m/min, f=0.20 mm/rev) with two depth of cut (d=1.0mm and 1.5 mm) under dry and MQL (cutting oil) conditions have been shown in Figure 10, Figure 11, Figure 12 and Figure 13. The gradual growth of VB, the predominant parameter to ascertain expiry of tool life, observed under dry and MQL environments indicates steady machining without any premature tool failure by chipping, fracturing etc. establishing proper choice of domain of process parameters. The application of MQL jet along the auxiliary cutting edge substantially changes chip formation and controls the cutting temperature. These enabled reduced rate of tool wear to a great extent and hence improved tool life as revealed in those graphs. Such improvements by MQL jets can be attributed mainly to retention of hardness and sharpness of the cutting edge for their steady and intensive cooling, protection from oxidation and corrosion and absence of built-up edge formation, which accelerates both crater and flank wear by flaking and chipping.

4.5 Surface roughness

The quality of any machined product of given material is generally assessed by dimensional accuracy and surface integrity, which govern the performance and service life of that product. For the present study, only surface roughness has been considered for assessment of quality of product machined in dry and minimum quantity lubrication environment. . It is apparent from the figures that surface roughness increases with the increase of feed rate and decreases with the increase of cutting speed. Reduction in roughness with the increase in cutting speed may be attributed to smoother chip-tool interface with lesser chance of built up edge formation in addition to possible truncation of the feed marks and slight flattening of the tool-tip. Increase in cutting speed may also cause slight smoothing of the abraded auxiliary cutting edge by adhesion and diffusion type wear and thus reduced surface roughness. It is clear from the Figure 14 that MQL could provide improvement in surface finish to some extent. This improvement might be due to reduction in wear and also to the fact of prevention of built-up-edge formation. It is also seen that increase in depth of cut might result in improvement of surface finish to a slight amount sometimes but that is insignificant. Variation of surface roughness with progress of machining time at lower speed and feed (V=66m/min, f=0.10 mm/rev) and higher speed and feed (V=258 m/min, f=0.20 mm/rev) with two depth of cut (d=1.0mm and 1.5 mm) under dry and MQL (cutting oil) conditions have been shown in Figure 15. In the graphs it is seen that surface roughness is increasing with machining time both for dry and MQL environment. It appears from those figures that surface roughness grows quite fast under dry machining due to more intensive temperature and stresses at the tool-tips, MQL appeared to be effective in reducing surface roughness. However it is crystal clear that MQL improves surface finish depending upon the work-tool materials and mainly through controlling the deterioration of the auxiliary cutting edge by abrasion, chipping and built-up-edge formation.

5. CONCLUSION

In this paper, the effect of minimum quantity lubrication on machining performance in turning medium carbon steel in terms of chip-tool interface temperature, cutting force, tool wear and surface finish has been examined. The present MQL system has been proved to be successful in reduction of average chip tool interface temperature depending upon the work materials, tool geometry and cutting conditions. It is true that this small reduction has enabled significant improvement in machinability indices. MQL has reduced the cutting force. MQL provided effective cooling at the shear zone which reduced the chip-tool interface temperature. It also provided proper lubrication that minimizes the friction resulting in retention of tool sharpness for a longer period. Favorable change in the chip tool interaction and retention of cutting edge sharpness due to reduction of cutting zone temperature seemed to be the main reason behind reduction of cutting forces by the MQL application of

MQL jet in machining medium carbon steel by the uncoated insert SNMG-120408 has enabled reduction in flank wear which could contribute in the improvement of tool life or enhancement of productivity at higher cutting velocity and feed rate. Such reduction in tool wear might have been possible for retardation of abrasion and notching, decrease or prevention of adhesion and diffusion type thermal sensitivity wear at the flanks and reduction of built up edge formation which accelerates wear at the cutting edges by chipping and flaking. Minimum quantity lubrication reduces deep notching and grooving, which are very detrimental and may cause premature and catastrophic failure of the cutting tools. Dimensional accuracy and surface finish has been substantially improved mainly due to reduction of wear and damage at the tool tip and also due to reduction in the average chip tool interface temperature by the application of MQL.

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