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Requirement of Minium Quantity of Lubricant on Machining Performance: A Review

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Abstract: *This paper reviews the effect of minimum quantity lubricant (MQL) on machining performance. Minimum quantity of lubrication in machining is an established alternative to completely dry or flood lubricating system from the viewpoint of cost, ecology and human health issues. The effect of MQL, dry cutting and flooded coolant were reviewed with respect to cutting forces, surface roughness of the machined work piece and tool wear. Results from literatures indicated that the MQL leads to lower cutting forces, reduced surface roughness and tool wear. Therefore, it appears that MQL, if properly employed not only provides environment friendliness but also improve the machinability characteristics.*
Keywords: *minimum quantity lubricant, cutting forces, surface roughness, tool wear*

I. Introduction

In recent years, energy consumption, air pollution and industrial waste have been the focus of special attention on the part of public authorities. The environment has become one of the most important subjects within the context of modern life, for its degradation directly impacts humanity. Driven by pressure from environmental agencies, politicians have drawn up increasingly strict legislation aimed at protecting the environment and preserving natural energy resources. These combined factors have led the industrial sector, research centers and universities to seek alternative production processes, creating technologies that minimize or avoid the production of environmentally aggressive residues. In high speed machining, conventional cutting fluid application fails to penetrate into chip-tool interface and thus cannot remove heat effectively (Dhar et al., 2000). Addition of extreme pressure additives in the cutting fluids does not ensure penetration of coolant at the chip-tool interface to provide lubrication and cooling (Boothroyed and Cassin, 1965). However, high pressure jet of soluble oil, when applied at the chip-tool interface, could reduce cutting temperature and improve tool life to some extent (Kubala et al., 1989). Due to several negative effects, a lot has been done in recent past to minimize or even completely avoid the use of cutting fluids (Sokovic and Mijanovic, 2001). Dry machining is now of great interest and actually, they meet with success in the field of environmentally friendly manufacturing (Klocke and Eisenblatter, 1997, 1999). In reality, however, they are sometimes less effective when higher machining efficiency, better surface finish quality and severe cutting conditions are required. For these situations, semi-dry operations utilizing very small amount of cutting fluids are expected to become a powerful tool and, in fact, they already play a significant role in a number of practical applications (Sutherland, 2000; Suda et al. 2001; McCabe and Ostaraff, 2001).

Minimum quantity lubricant in machining is an alternative to completely dry or flood lubricating system, which has been considered as one of the solutions for reducing the amount of lubricant to address the environmental, economical and mechanical process performance concerns (Heinemann et al., 2006). MQL refers to the use of only a minute amount of cutting fluids typically at a flow rate of 50–500 ml/h. Many researchers have suggested the MQL technique in machining process (Rahman et al., 2001; Davim et al., 2006; Machado and Wallbank, 1997). Dhar et al. (2006) were used this technique in turning process and concluded that MQL has been shown to be better than flood cooling. Lugscheider et al., (1997) applied this technique in reaming process of grey cast iron and aluminium alloy with coated carbide tools. The significant reduction in tool wear and improvement in surface quality of the holes have been observed by using MQL when compared to dry cutting.

The drilling of aluminium-silicon alloys is one of those process where dry cutting impossible due to high ductility of the workpiece material (Braga er al., 1999). Without cooling and lubrication, the chip sticks to the tool and breaks it in a very short cutting time. Therefore, in this process a good alternative is the use of MQL technique (Rahman, 2004). Kelly and Cotterell (2002) were investigated the role of different coolant application methods in the drilling of a 30 mm aluminum alloy ACP 5080 plate with a brinell hardness of 85. Drilling was carried out on a Hurco BMC-20 three-axis computerized numerical control (CNC) machining centre using a 10 mm high speed steel twist drills. It was revealed that the MQL technique is preferable for higher cutting speeds and feed rates. This review reports on the effect of minimum quantity lubricant with respect on the tool wear, cutting forces and surface roughness produced during machining.

WORKING PRINCIPLE OF MQL SYSTEM

The MQL needs to be supplied at high pressure and impinged at high speed through the nozzle on the cutting zone. Considering the conditions required for the present research work and uninterrupted supply of MQL at a constant pressure of around 6 bar over a reasonably long cut, a MQL delivery system was designed, fabricated and used. The typical schematic view of the MQL set-up is shown in Figure 1 (Khan et al., 2009). In this system, a compressor was used to supply air at a high-pressure of 10 bar. This high- pressure air from the compressor entered into two chambers like fluid chamber and mixing chamber at two different but pre-selected pressures of 10 and 6 bar respectively. The fluid chamber was connected to the mixing chamber at the bottom by very small diameter flexible tube. This tube was passed through a roller-type flow controller to permit a little amount of fluid to flow under high pressure. The compressed air entering into the inlet port created pressure to cause the fluid to flow continuously to the mixing chamber through controller at a constant rate. The air and the vegetable oil were mixed in the mixing chamber so that the mixture of vegetable oil and air impinged at a high velocity through the nozzle on the chip–tool interface. During experimentation, the thin but high velocity stream of MQL was projected at the tip of the cutting tool along the auxiliary cutting edge making an angle 15° with it. Consequently, the coolant reached as close to the chip–tool and the work-tool interfaces as possible. The MQL jet was used mainly to target the rake and flank surface and to protect the auxiliary flank to enable better dimensional accuracy. The typical photographic view of the experimental set-up is shown in Figure 2.

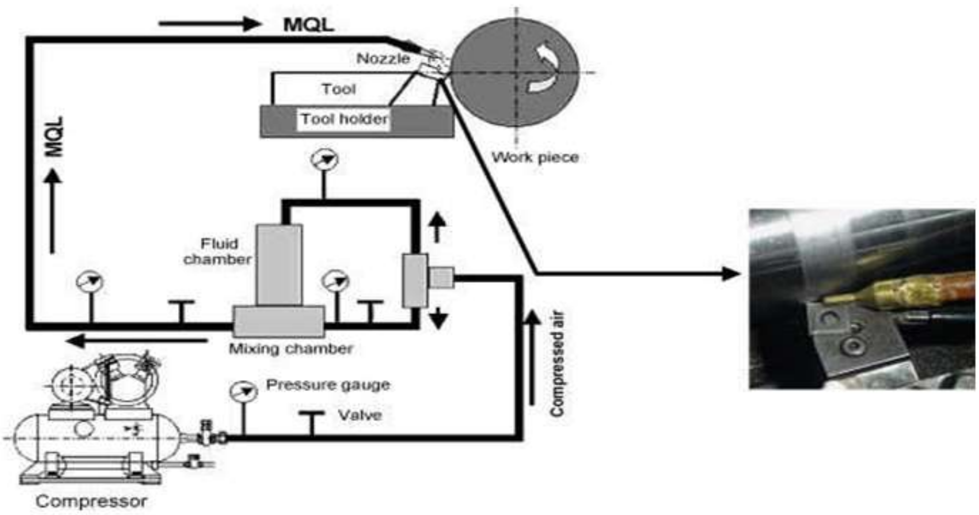


Figure 1: Typical schematic view of MQL unit (Khan et al. 2009).

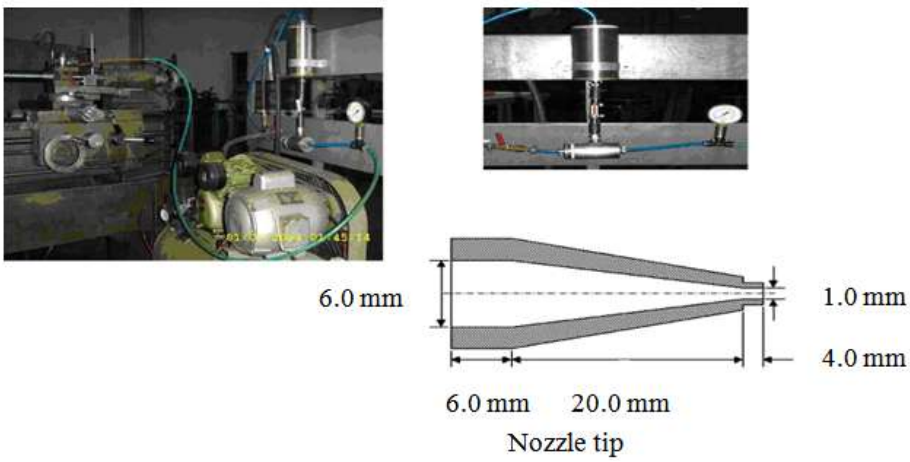


Figure 2: Photographic view of the experimental set-up (Khan et al. 2009).

Two different mixing methods can be used in application of MQL which are mixing inside nozzle and mixing outside nozzle. Using the mixing inside nozzle equipment, pressurized air and lubricant are mixed into the nozzle by a mixing device, as shown in Figure 3a. The lubrication is obtained by the lubricant supplied by the system, while a minimal cooling action is achieved by the pressurized air that reaches the cutting surface. Several advantages derive applying this method. Mist and dangerous vapours are reduced and the mixture setting is very easy to control. In the mixing outside nozzle method as shown in Figure 3b, the mixture is obtained in a mixing device positioned in a specific tank. Also, in this case lubrication between workpiece and tools can be achieved. As already seen, MQL provides a cooling action that often is negligible. But is it necessary to cool workpieces and tools. Nowadays there are several cutting operations where cooling is undesirable, because the induced thermal shock could cause tool failure. An example is the finish machining of hardened steel using cubic bore nitride (CBN) or polycrystalline diamond (PCD) tools, where dry cutting is mainly performed. In these cases, MQL is said to provide several advantages in terms of tool wear reduction. Other MQL advantages (depending on the low lubricant quantity) are chip, workpiece and tool holder have a low residue of lubricant and their cleaning is easier. During machining the working area is not flooded so, if necessary, the cutting operation can be readily observed. On the other hand, the main limit of the MQL method is its inability to cool the cutting surface. This means that MQL is not able to furnish advantages, if it is applied in a cutting operation where cooling action is strongly required, like in grinding .In these cases it is very important correctly to define the conditions that allow the MQL technique to be applied with real benefits.

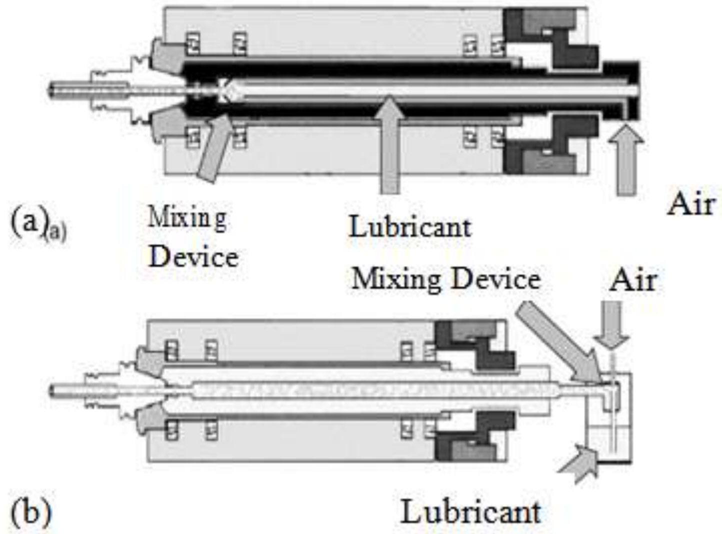


Figure 3: Mixing methods: (a) inside and (b) outside nozzles.

EFFECT MQL ON TOOL WEAR

Tool wear, which results in tool substitution, is one of the most important economical penalties to take into account during cutting. Thus it is very important to improve tool life, minimizing the wear and optimizing all the cutting parameters and factors: depth of cut, cutting velocity, feed rate, cutting fluids and cutting fluids application. In cutting operations fluids play an important role. They must mainly guarantee lubrication and cooling, secondly protect workpiece and tool from corrosion and promote the chip evacuation. During machining, at all cutting environments, work material adhered to the edges of the tool, but the quantity adhered material varied with the type of coolant environment. Lugscheider et al. (1997) applied this technique in reaming process of grey cast iron and aluminium alloy with coated carbide tools. The significant reduction in tool wear and improvement in surface quality of the holes have been observed using MQL technique when compared to dry cutting. Wakabayashi et al. (1998) in their turning process investigations were found that the flank wear rate with MQL application of a mineral oil-based agent at 2 ml/h (two nozzles: one directed at the rake-face, and the other at the flank) was comparable to that with conventional flooding, and superior to that with dry cutting, during turning of AISI 4340 steel with coated carbide tools at high cutting speeds (400 m/min). The lubricating action of the oil was credited with achieving this improvement over dry cutting, and the use of MQL agents with moderately reactive EP constituents was recommended. Another important tool wear criteria is average auxiliary flank wear, V_S, which governs the surface finish on the job as well as dimensional accuracy. Irregular and higher auxiliary flank wear leads to poor surface finish and dimensional inaccuracy (Klocke and Eisenblatter, 1999). The growths of average auxiliary flank wear, V_S with time of machining of the steel under dry, wet and MQL conditions have been shown in Figure 4. The nature of growth of V_S matches with that of V_B expectedly. The application of MQL has reduced V_S, which is expected to provide better surface finish.

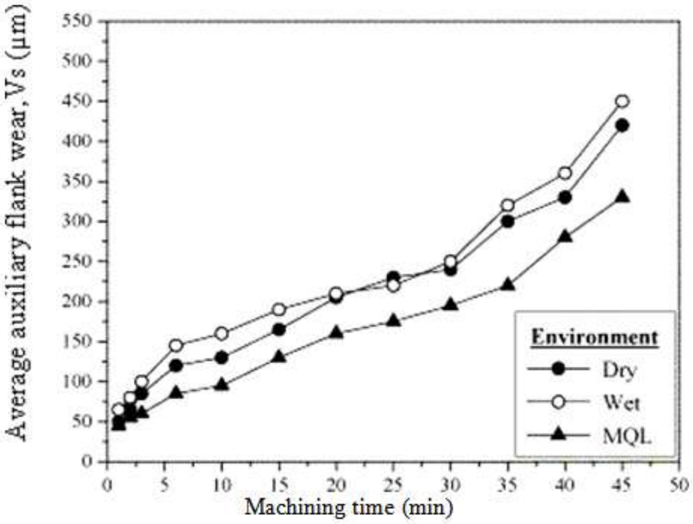


Figure 4: Growth of average auxiliary flank wear, V_S with time under dry, wet and MQL conditions.

In addition of that, Diniz et al. (2003) were found that during turning of hardened 52100 steel with cubic boron nitride tools at moderate cutting speeds (110 m/min), dry cutting yielded the lowest flank wear, while directing a compressed air jet at the cutting zone caused the highest flank wear. The proposed explanation for this observation was that lack of any cooling action under dry condition enhances thermal softening of workpiece material, thus making cutting easier, whereas the cooling action of an air jet causes the reverse effect by promoting strain hardening in the work material. MQL was found to perform slightly better than plain compressed air, and this was explained to be occurring because the lubricating effect of the oil partly mitigated the increased forces (arising from lack of thermal softening) due to the compressed air jet of the MQL supply. A similar hypothesis was suggested for the case of conventional flooding, which ranked intermediate to MQL and dry in terms of flank wear. Dhar et al. (2006) were reported that the growth in average flank wear, V_B, on the main cutting edge under dry, wet (conventional cooling with 1:20 soluble oil) and MQL conditions (Figure 5). The gradual growth of $V_{B,}$ the predominant parameter to ascertain expiry of tool life, observed under all the environments indicates steady machining without any premature tool failure by chipping, fracturing, etc. establishing proper choice of domain of process parameters. Figure 5 also clearly shows that flank wear, V_B particularly its rate of growth decreased by MQL. The cause behind reduction in V_B observed may reasonably be attributed to reduction in the flank temperature by MQL, which helped in reducing abrasion wear by retaining tool hardness and also adhesion and diffusion types of wear which are highly sensitive to temperature. Because of such reduction in rate of growth of flank wear the tool life would be much higher if MQL is properly applied.

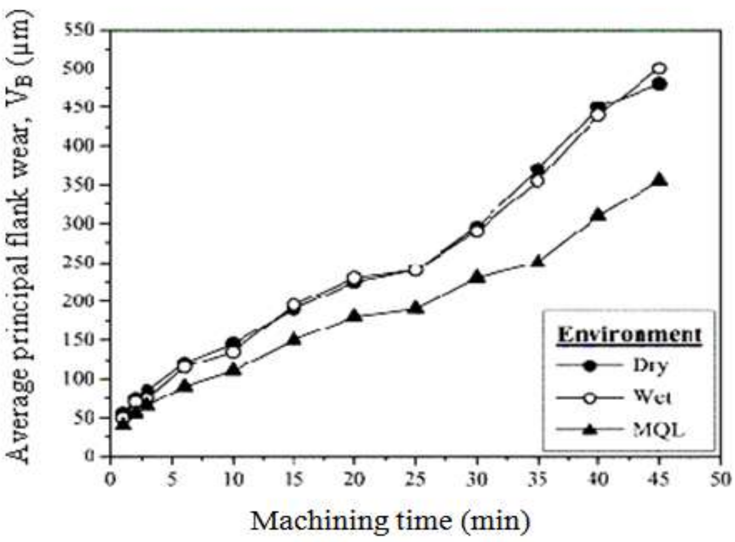
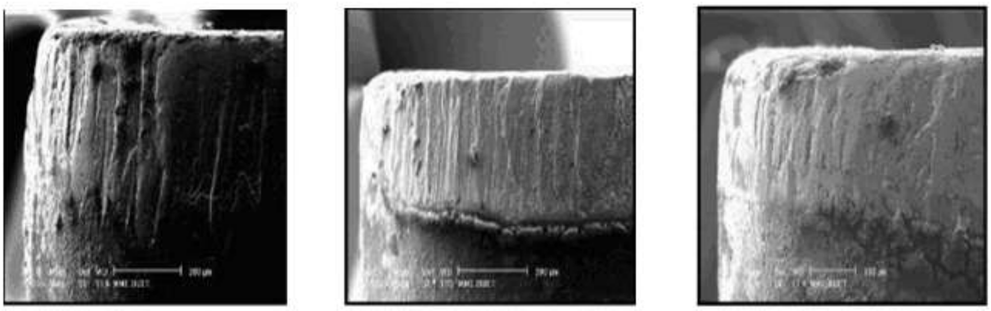


Figure 5: Growth of average principal flank wear, V_B with machining time under dry, wet and MQL conditions.

Besides that, Srejith (2008) was conducted investigations in turning process of aluminium alloys stated that the speed of machining increased from 50 to 400 m/min, the adhesion between the tool and the chip also increased correspondingly. This could be due to the increase in thermal softening of the chip as the temperature increased with the increase in cutting speed. The adhesion of the work material to the tool was observed to be having the highest rate during dry cutting. The material adhesion was seen all over the tool surfaces like flank, rake and clearance surfaces especially when the speed of machining was increased from 250 to 400 m/min. The quantity of the adhered material reduced considerably with flooded coolant compared to the dry cutting operation. During MQL machining, the amount of material adhered was seen to be more compared with flooded coolant and less compared to dry machining. As the quantity of the lubricant was increased from 50 ml/h to 100 ml/h during MQL, there was not any considerable reduction in the adhered material. The larger amount of adhered material during MQL conditions may be due to the tool geometry.

Khan et al. (2009) were carried out experiments by plain turning alloy steel using lathe machine stated under all the environments, abrasive scratch marks appeared in the flanks. There were some indications of adhesive wear in the insert. Severe groove wear at the flank surfaces were found in insert under dry and wet conditions. Some plastic deformation and micro chipping were found to occur under dry machining. Effective temperature control with MQL by vegetable oil almost reduced the growth of groove wear on the main cutting edge as well as auxiliary cutting edges. Further, Figure 6 clearly shows reduced average principal flank wear the predominant parameter to ascertain expiry of tool life, observed under all the environments indicates steady machining without any premature tool failure by chipping, fracturing etc. establishing proper choice of domain of process parameters, and average auxiliary flank wear under MQL by vegetable oil condition.



a) Dry machining
b) Wet machining
c) MQL machining

Figure 6: SEM views of principal flank wear of the worn out insert after machining 43 min under dry, wet and MQL conditions.

Khan et al. (2009) were extended discussion stated the significant contribution of MQL jet in machining the low alloy steel by the carbide insert undertaken has been the reduction in flank wear, which would enable either remarkable improvement in tool life or enhancement of productivity (MRR) allowing higher cutting velocity and feed. Such reduction in tool wear might have been possible for retardation of abrasion, decrease or prevention of adhesion and diffusion type thermal sensitivity wear at the flanks and reduction of built-up edge formation that accelerates wear at the cutting edges by chipping and flaking. Minimum quantity lubrication reduces deep grooving, which is very detrimental and may cause premature and catastrophic failure of the cutting tools.

EFFECT MQL ON SURFACE ROUGHNESS

Surface finish is an another important index of machinability as the performance and service life of the machined component are often affected by its surface finish, nature and extent of residual stresses and presence of surface or subsurface micro-cracks, particularly when that component is to be used under dynamic loading or in conjugation with some other mating part(s). Generally, good surface finish is achieved by finishing processes like grinding but sometimes it is left to machining. Even if it is to be finally finished by grinding, machining prior to that needs to be done with surface roughness as low as possible to facilitate and economize the grinding operation and reduce initial surface defects as far as possible. The major causes behind development of surface roughness in continuous machining processes like turning ductile metals in particular are regarding to regular feed marks left by the tool-tip on the finished surface, irregular deformation of the auxiliary cutting edge at the tool-tip due to chipping, fracturing and wear, vibration in the machining system, and built-up edge formation, if any.

Braga et al. (2002) were presented a paper to compare the performance of the uncoated and diamond coated carbide drills, using MQL (10 ml/h of oil in a flow of compressed air) and abundant soluble oil as a refrigerant/lubricant in the drilling of aluminum–silicon alloys (A356). They found that the holes obtained with the MQL system presented either similar or better quality than those obtained with flood of abundant soluble oil. Moreover, the values of flank wear were similar for the two cooling/lubrication systems used, which proves the feasibility of using the MQL technique. The mean values of the hole surface roughness were much better for the MQL condition than for the flood with soluble oil. Kelly and Cotterell (2002) also stated the R_a values obtained in the experiment with MQL and uncoated K10 tool were impressive (around 0.5 mm with very small dispersion). These values are not easily obtained with the drilling process, even when low feed is used as in the case of this experiment. The reasons of this occurrence are the high rigidity of the carbide tool and the effectiveness of the lubrication generated by the MQL system, which made a smooth chip formation possible.

Besides that, Islam et al. (2006) were carried out an experiment by turning 125 mm diameter and 760 mm long rod of AISI-1040 steel of common use in a powerful and rigid lathe (USA, 15hp) at different cutting velocities (V_c) and feeds (S_o) under both dry and MQL conditions to study the role of MQL on the machinability characteristics of that work material mainly in respect of cutting temperature, chip formation, cutting forces, tool wears, surface finish, and dimensional deviation. Result obtained shows the variation in surface roughness with machining time under both dry, wet and MQL environments. As MQL reduced average auxiliary flank wear and notch wear on auxiliary cutting edge, surface roughness also grew very slowly under MQL conditions. It appear 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 evident 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.

Moreover, Silva et al. (2007) used tempered and annealed steel with aluminium oxide grinding wheel to explore and discusses the concept of the MQL in the grinding process. They obtained with the conventional cutting fluid application system and with the MQL technique indicates that the application of cutting fluid by MQL technique led to a result superior to that of the conventional system due to the more efficient penetration of the fluid into the cutting region. The MQL technique led to lower roughness values, probably because of the more effective lubrication and cooling of the abrasive grains at the work–tool interface. Gaitonde et al. (2008) were conducted a research in turning brass process with taguchi method. They obtained from the analysis of means (ANOM) and analysis of variance (ANOVA) on multi-response signal-to- noise (S/N) ratio were employed for determining the optimal parameter levels and identifying the level of importance of the process parameters. The optimization results indicated that MQL of 200 ml/h, cutting speed of 200 m/min and a feed rate of 0.05 mm/rev is essential to simultaneously minimize surface roughness and specific cutting force. Meanwhile from the Taguchi optimization results, Sreejith (2008) found that high MQL is required for minimizing both surface roughness and specific cutting force. This can be explained by the fact that the surface roughness increases under minimum MQL due to more intensive temperature and stresses at tool chips. The high MQL improves surface finish depending upon work-tool material through controlling the deterioration of auxiliary cutting edge of abrasion, chipping and built-up edge formation. Further under high MQL, specific cutting force decreases due to reduction in cutting temperature especially at main cutting edge where built-up edge formation is more predominant. MQL with low to medium cutting speed is necessary to minimize both surface roughness and specific cutting force. This is due to the fact that thinner chips produced at lower cutting speed are pushed by high MQL due to capillary effect and enables it come closer to hot tool-chip zone to remove heat more effectively and hence surface roughness decreases.

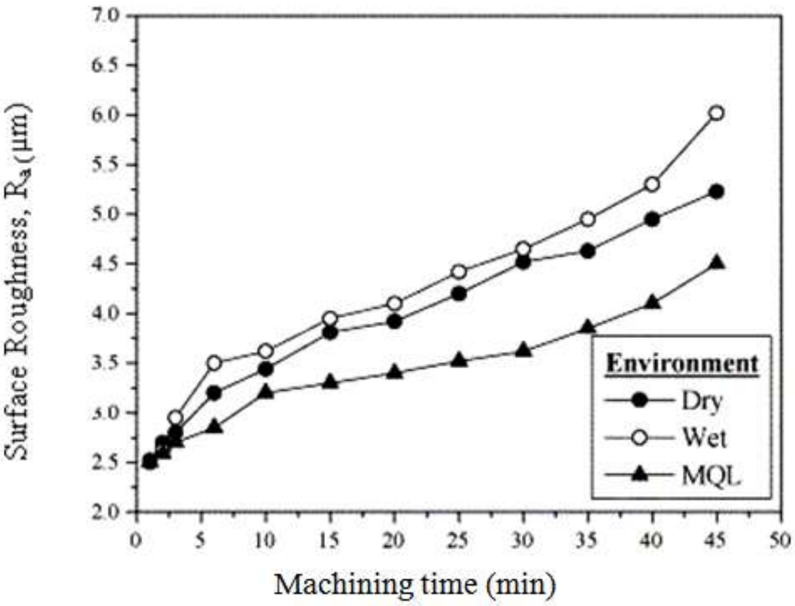


Figure 7: Surface roughness with progress of machining under dry, wet, and MQL conditions.

Khan et al. (2009) were carried out experiments by plain turning alloy steel using lathe machine stated the variation in surface roughness observed during turning AISI 9310 low alloy steel by SNMG insert at a particular set of cutting velocity, feed rate and depth of cut under dry, wet and MQL conditions. Figure 7 shown, as MQL reduced average auxiliary flank wear and produced no notch wear on auxiliary cutting edge, surface roughness grew very slowly under MQL conditions. Conventionally applied cutting fluid did not reduce tool wear compared to dry machining. However, the surface roughness deteriorated drastically under wet machining compared to dry, which might possible be attributed to electrochemical interaction between insert and work piece. It is observed that surface roughness grows quite fast under dry machining due to temperature, which is more intensive and stresses at the tool-tips. MQL appeared to be effective in reducing surface roughness. Nevertheless, it is evident that MQL improves surface finish depending on the work-tool materials and mainly through controlling the deterioration of the auxiliary cutting edge by abrasion, chipping and built-up edge formation. Moreover, Tawakoli et al. (2009) were conducted an experimental investigation of the effect of the workpiece and grinding parameters on MQL in grinding process stated the good surface obtained by using MQL technique is probably because of the more effective lubrication and cooling of the abrasive grains at the workpiece tool interface. Efficient lubrication allows the chips to slide more easily over the tool surface and results in a better surface finish. Furthermore, there are lower tangential forces in grinding of both hardened and soft steel materials in high removal rates. The tangential forces of MQL grinding are lower than those in fluid cooling in higher wheel speeds. Under these circumstances, the surface roughness obtained from MQL grinding is better than fluid and dry conditions.

EFFECT OF MQL ON CUTTING FORCES

The magnitude of the cutting forces is one of the most important machinability indices because that plays vital roles on power and specific energy consumption, product quality and life of the salient numbers of the machine–fixture–tool systems. Varadarajan et al. (2002) were conducted investigations on hard turning by using hardned steel stated that the variation of cutting force with feed and cutting velocity respectively under specified conditions. It is observed that cutting force is lower during minimal application when compared to dry turning and conventional wet turning. Presumably minute capillaries exist at the tool–chip interface especially if the seizure and sublayer plastic flow at the tool–chip contact zone are not total, as was found in this case by an examination of the chip underside. So capillaries can also exist in the body of the chip as extensions of outer surface serrations. Penetration of the cutting fluid with EP additives in to the interface can reduce the frictional contribution to cutting force. So also penetration of the fluid through the mass of the chip can influence chip curl and the primary deformation process. Through high-pressure injection the fluid is fragmented into tiny droplets the size of which is inversely proportional to the pressure of injection (Seah, 1995). The velocity varies as a function of the square root of the injection pressure (Tönshoff, 1995). This high velocity (of the order of 100 m/s for a pressure of 20 MPa) facilitates better penetration of the cutting fluid on impact to the root as well as the underside of the chip facilitating its passage to the tool–chip interface resulting in the reduction of friction. Such a condition is not possible in conventional wet turning where no such fragmentation is taking place and the kinetic energy of the fluid jet is in no way comparable to that during fluid injection. In the same years, Varadarajan et al., (2002) developed alternative test equipment for injecting the fluid and used it with success in hard turning for which a large supply of cutting fluid is the normal practice. The test equipment consisted of a fuel pump generally used for diesel fuel injection in truck engines coupled to a variable electric drive. A high-speed electrical mixing chamber facilitated thorough emulsification. The test equipment permitted the independent variation of the injection pressure, the frequency of injection and the rate of injection. The investigations performed by the authors revealed that a coolant-rich (60%) lubricant fluid with minimal additives was the ideal formulation. During hard turning of an AISI 4340 hardened steel of 46HRC (460 HV), the optimum levels for the fluid delivery parameters were a flow rate of 2 ml/min, a pressure of 20 MPa and a high pulsing rate of 600 pulses/min. In comparison, for the same cutting conditions, with dry cutting and wet cutting, the minimum quantity of cutting fluid method led to lower cutting forces, temperatures, better surface finish, and longer tool life.

Furthermore, Kishawy et al. (2005) were performed high-speed face milling tests on A356 aluminum alloy reported that the lowest resultant cutting force value, recorded for flood coolant application method, are justified by the ability of the coolant to reduce material adhesion and consequently friction forces. The MQL application exhibits the same mechanism of reducing the friction forces, but the coolant composition (additives) will have to be customized for the A356 alloy in order to obtain an even more significant force reduction. Data extrapolated from experimental results, average resultant cutting forces and flank wear progress indicates that the optimal performance of the uncoated carbide inserts was obtained when using MQL. Furthermore, Dhar et al. (2007) investigated the effect MQL by turning AISI 1040 and stated that the cutting performance of MQL machining is better than that of dry machining because MQL provides the benefits mainly by reducing the cutting temperature, which improves the chip–tool interaction. MQL reduced the cutting forces by about 5–15%. P_x (axial component) decreased more predominantly than P_z (tangential component). Favorable change in the chip–tool interaction and retention of cutting edge sharpness due to reduction of cutting temperature seemed to be the main reason behind reduction of cutting forces by MQL. Based on above studied, the shear strength of the ductile type work material at the cutting zone in one hand, increases due to compression and straining and on the other hand decreases due to softening by the cutting temperature if it is sufficiently high. But again along with softening, the chip material becomes sticky for which the friction force and hence the cutting force may tend to increase. The overall effect of all such factors on the magnitude of the cutting forces will depend on the nature of the work material and the level of the cutting temperature. Therefore, it seems that MQL had ultimately favorable effect on the behavior of the present steel in respect of cutting forces for which MQL enabled reduction in the cutting forces to some extent even when built-up edge was not visible.

Moreover, Gaitonde et al. (2008) found at high MQL with low to medium cutting speed is necessary to minimize both surface roughness and specific cutting force. This is due to the fact that thinner chips produced at lower cutting speed are pushed by high MQL due to capillary effect and enables it come closer to hot tool-chip zone to remove heat more effectively and hence surface roughness decreases. On the other hand, at high cutting speed, coolant may not have enough time to remove heat accumulated at cutting zone resulting in less reduction of temperature under high MQL at high cutting speed and hence results in poor surface finish. Further, at low cutting speed, heat generated is successfully disposed to higher MQL as compared to lower MQL, thus decreasing the specific cutting force and hence better machining takes place without ploughing on work material. At low MQL with high feed rate, surface roughness increases mainly because of more friction at chip-tool interface and jamming of chips around the tool. On the other hand, under high MQL with low feed rate there is a reduction in adhesion of work material and consequently friction forces, which in turn reduces the specific cutting force.

Sreejith (2008) was studied the effect of the dry machining, minimum quantity lubricant (MQL),and flooded coolant conditions on tool wear, cutting forces and surface quality of the work-piece during turning operation of 6061 aluminum alloys. Figure 8 shows the resultant cutting forces was lower for MQL compare to dry machining and flooded coolant. The resultant cutting force was the highest under dry cutting conditions due to the effect of adhesion of the work material on the tool. MQL has the lowest value compare to the others because the adhesion on the tool is lowest and this lower adhesion produces lower frictional force and therefore the cutting forces getting lowest. This lower adhesion produces lower frictional force.

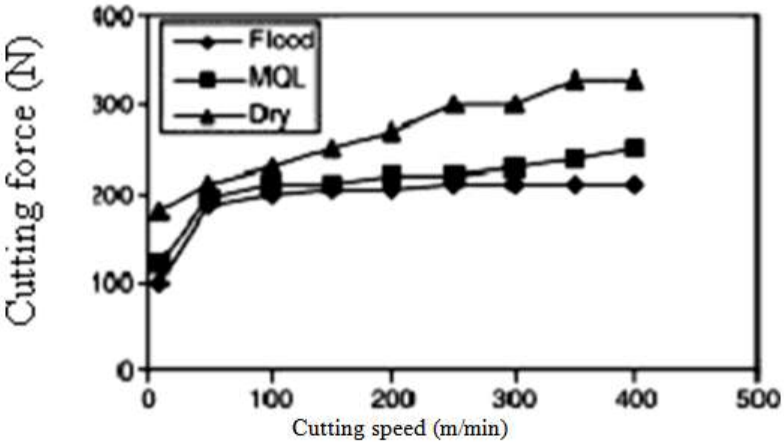


Figure 8: Variation cutting force with cutting speed.

II. Conclusion

Results from the previous research indicated that the use of minimum quantity lubricant (MQL) leads to lower cutting forces, reduce tool wear and decrease in surface roughness and since MQL conditions can be applied to the machining, it seems that this process has got economic advantage. Surface finish in MQL improves mainly due to reduction of wear and damage at the tool tip by the application of MQL. MQL also reduce the cutting forces by favorable change in the chip-tool interaction and retention of cutting edge sharpness due to reduction of cutting temperature seemed to be the main reason behind reduction of cutting forces by MQL. Besides that MQL jet provided reduced tool wear, improved tool life and better surface finish as compared to dry and wet machining and finally became powerful condition in order to enhance the machining performance.

Acknowledgment

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References

[1]. Boothroyed, G. and Cassin, C. 1965. Lubrication action of cutting fluids. Journal of Mechanical Engineering Science, 7(1): 67-81.
[2]. Braga, D.U., Diniz, A.E., Miranda, G. and Coppini, N.L. 1999. Minimal lubrication in the drilling process of aluminum–silicon alloy-A356 (SAE 323). Proceedings of the Third International Machining and Grinding Conference, USA, pp. 683–697.
[3]. Braga, D.U., Diniz, A.E., Miranda, G. and Coppini, N.L. 2002. Using minimum quantity of lubricant (MQL) and a diamond coated tool in the drilling of aluminum-silicon alloys. Journal of Materials Processing Technology, 122 : 127-138.
[4]. Davim, J. P., Sreejith, P.S., Gomes, R. and Peixoto, C. 2006. Experimental studies on drilling of alumunium (AA0150) under dry, minimum quantity lubricant, and flooded-lubricated conditions. Proc. ImechE. Part B: Journal of Engineering and Manufacturing, 220: 1605-1611.
[5]. Dhar, N.R., Ahmed, M.T. and Islam, S. 2007. An experimental investigation on effect
[6]. of minimum quantity lubrication in machining AISI 1040 steel. International Journal of Machine Tools and Manufacture, 47(5): 748-753.
[7]. Dhar, N.R., Kamaruzzaman, M. and Ahmed, M. 2006b. Effect of minimum quantity lubrication (MQL) on tool wear and surface roughness in turning AISI-4340 steel. Journal of Materials Processing Technology, 172(2): 299-304.
[8]. Dhar, N.R., S., Paul. and Chattopadhway, A.B. 2000. Beneficial effects of cryogenic cooling over dry and wet machining on tool wear and surface finish in turning AISI 1060 steel. Proceedings of ICAMT-2000, Malaysia, pp. 209-214.
[9]. Diniz, A.E., Ferreira, J.R. and Filho, F.T. 2003. Influence of refrigeration/lubrication condition on SAE 52100 hardened steel turning at several cutting speeds. International Journal of Machine Tools and Manufacture, 43(3): 317–326.
[10]. Gaitonde, V.N., Karnik, S.R., and Davim, J.P. 2008. Selection of optimal MQL and cutting conditions for enhancing machinability in turning of brass. Journal of Materials Processing Technology, 204(1-3): 459-464.
[11]. Heinemann, R., Hinduja, S., Barrow, G. and Petuelli, G. 2006. Effect of MQL on the
[12]. tool life of small twist drills in deep-hole drilling. International Journal of Machine Tools and Manufacture, 4(1): 1-6.
[13]. Islam, M.W., Dhar, N.R., Islam, S. and Mithu, M.A.H. 2006. The influence of minimum quantity of lubrication (MQL) on cutting temperature, chip and dimensional accuracy in turning AISI-1040 steel. Journal of Materials Processing Technology, 171(1): 93-99.
[14]. Kelly, J.F.M. and Cotterell, G. 2002. Minimal lubrication machining of aluminium alloys. Journal of Materials Processing Technology, 120(1-3): 327-334.
[15]. Khan, M.M., A. Mithu, M.A.H. and Dhar, N.R. 2009. Effects of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil-based cutting fluid. Journal of Materials Processing Technology, 209(15-16): 5573-5583.
[16]. Kishawy, H.A., Dumitrescu, M., Ng, E.G. and Elbestawi, M.A. 2005. Effect of coolant strategy on tool performance, chip morphology and surface quality during high-speed machining of A356 aluminium alloy. International Journal of Machine Tools and Manufacture, 45(2): 219–227.
[17]. Klocke, F. and Eisenblatter, G. 1999. Coted tools for metal cutting-features and application, CIRP, 48(2): 515-525.
[18]. Klocke, F., and Eisenblatter, G. 1997. Proceedings of the opening session of the dry cutting. CIRP. Annals, 46(2): 519-526.

[19]. Kubala, Z., Mazurkiewicz, M. and Chow, J. 1989. Metal machining with high pressure water-jet cooling assistance-a new possibility. Journal of Engineering Industry, pp. 7-12.
[20]. Lugscheider, E., Knotek, O., Barimani, C., Leyendecker, T., Lemmer, O. and Wenke, R. 1997 . Investigations on hard coated reamers in different lubricant free cutting operations. Surf. Coat. Technol., 90: 172–177.
[21]. Machado, A. R. and Wallbank. 1997. The effect of extremely low lubricant volumes in machining. Wear, 210(1-2): 76-82.
[22]. McCabe, J. and Ostaraff, M.A. 2001. Performance experience with near-dry machining of aluminum. Tribology and Lubrication Engineering, pp. 22–27.
[23]. Rahman, K.M. 2004. Effect of minimum quantity lubrication (MQL) in drilling commercially used steels. M. Eng. Dissertation, BUET, Bangladesh.
[24]. Rahman, M., Kumar, A.S. and Ul-Salam, M. 2001. Evaluation of minimal quantities of lubricant in end milling. International Journal of Advanced Manufacturing Technology, 18(4): 235-241.
[25]. Seah, K.H.W., Li, X. and Lee, K.S. 1995. The effect of applying coolant on tool wear in metal machining. Journal of Materials Processing Technology, 48(1-4): 495-501.
[26]. Silva Da, L.R., Bianchi, E.C., Fusse, R.Y., Catai, R.E., França, T.V. and Aguiar, P.R. 2007. Analysis of surface integrity for minimum quantity lubricant-MQL in grinding. International Journal of Machine Tools and Manufacture, 47(2): 412-418.
[27]. Sokovic, M. and Mijanovic, K. 2001. Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting process. Journal of Materials Processing Technology, 109(1-2): 181-189.
[28]. Sreejith , P.S. 2008. Machining of 6061 aluminium alloy with MQL, dry and flooded lubricant conditions. Materials Letters, 62(2): 276-278.
[29]. Suda, S., Hideo, Y., Fujio, K., Ichiro, I. and Toshiaki, W. 2001. Evaluation of machinability with MQL system and effectiveness in production lines. Proceedings of the International Tribology Conference, Nagasaki, 2: 203–208.
[30]. Sutherland, J.W. 2000. An experimental investigation of air quality in wet and dry turning. Ann. CIRP, 49(1): 61–64.
[31]. Tawakoli, T., Hadad, M.J., Sadeghi, M.H., Daneshi, A., Stöckert, S. and Rasifard, A. 2009. An experimental investigation of the effects of workpiece and grinding parameters on minimum quantity lubrication—MQL grinding. International Journal of Machine Tools and Manufacture, 49(12-13): 924-932.
[32]. Tönshoff, H.K., Wobker, H.G. and Brandt, D. 1995. Tribological aspects of hardturning with ceramic tools. Lubrication Engineering, 51(2): 163–168.
[33]. Varadarajan, A.S., Philip, P.K. and Ramamoorthy, B. 2002. Investigations on hard turning with minimal cutting fluid application (HTMF) and its comparison with dry and wet turning. International Journal of Machine Tools and Manufacture, 42(2): 193–200.
[34]. Wakabayashi, T., Sato, H. and Inasaki, I. 1998. Turning using extremely small amounts of cutting fluids. JSME International Journal, Series C: Mechanical Systems, Machine Elements and Manufacturing, 41(1): 143–148.