AN EXPERIMENTAL STUDY ON EFFECT OF MINIMUM QUANTITY FLUID ON TOOL WEAR ON MACHINING STEEL

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Abstract.

Today higher production rate is the basic principle in industry and there are serveral economic means of achieving this. High productivity in machining is mainly achieved when using high cutting speed and feed rates. However, elevated cutting temperatures generated at cutting zone in high cutting speed reduce tool life, causing dimensional changes to the work material and adversely affecting dimensional accuracy of machined component as well as affecting the strength, hardness and wear resistance of the cutting tool. Into his context cutting fluids, when properly chosen and applied, are used to minimise problems associated with the high temperature and high stresses at the cutting edge of the tool during machining because their lubrication, cooling, and chip flushing functions. Unfortunately, process-generated pollution in machining has been mainly coming from waste cutting fluids. Conventional cutting fluids also causes environmental and health problems. The current attention to the environmental impacts of machining processes by government regulations has been forcing manufacturers to reduce or eliminate the amount of wastes. A viable alternative to improving the characteristics of the tribological processes present at the tool-workpiece interface in order to improve the machinability of materials and at the same time eliminate environmental damages as well as minimizing some problems associated with the health and safety of operators is MQF application, which consists of applying a small amount of the highly efficient coolant/lubricant at a flow rate often below 100 ml/h compared to 120000-720000 ml/h generally employed in conventional coolant flow. This is why this technique is considered a “clean cutting process”. The concept of MQF sometimes is referred to as near dry lubrication or micro lubrication. This paper evaluates the performance of MQF technique (20 and 60 ml/h) compared to dry condition when turning of AISI 1047 steel grade with coated cemented carbides at various cutting speeds and feed rates. Tool wear rate, failure modes (SEM images of wear) and surface finish were recorded and used to assess the performance of MQF technique. Results show that the use of MQF technique promotes reduction in tool wear and improves surface finish of machined component.

Keywords*: MQF technique, Turning, AISI 1047 steel, Tool wear, Dry cutting, surface finish*

1. INTRODUCTION

Turning operation is probably the most common of all the machining processes and, then, more studies on friction conditions are expected to be carried out, mainly because of the complexity of conditions existing in cutting zone. Also this operation presents some problems during machining compared to milling operation such as the generation of continuous chip formed when cutting ductile metals and alloys that do not fracture on the shear plane (Trent and Wright, 2000; and Childs, 2006) such as aluminum, low alloys steels and copper. Continuous chips are undesirable because they usually wrap themselves around the workpiece or get tangled around the tool holder, thus adversely affecting the surface finish generated and/or causing tool damage. In some cases machining has to be interrupted in order to clear them away.

In a machining process, new surfaces are cleaved from the workpiece through the removal of material in the form of chips which demands a large consumption of energy. The mechanical energy necessary for the machining operation is transformed into heat. As a result high temperatures, pressures and severe thermal/frictional actions occur at the tool edge in the cutting zone. The greater the energy consumption, the more severe the thermal/frictional actions, consequently accelerating tool wear and making the metal cutting process more inefficient in terms of tool life, dimensional accuracy and material removal rate (Kovacevic et al, 1995). Therefore, the efficiency of the metal cutting process depends to a large extent on the effectiveness of the tribological condition provided for specific material-cutting tool interaction (Da Silva, 2006). Into this context an efficient cooling and lubrication functions of cutting fluid in cutting zone is required (Machado and Wallbank, 1997; Attanasio et al., 2006; Klocke and Eisenbläter, 1997; Sharma et al., 2009; Diniz and Micaroni, 2006; Dhar et al., 2007).

In fact, lubricant can only be effective in the sliding zone because the cutting fluid whether in liquid or gaseous form, is unable to gain access to the seizure zone (Machado and Wallbank, 1994). As a coolant the cutting fluids reduces the temperature generated at the tool-workpiece and tool-chip interfaces both by its cooling action and by reducing the heat generated during machining (Machado, 1990; Sales et al, 2001). Effective application of cutting fluids can also prolong tool life, thereby reducing the number of tool changes, increase dimensional accuracy as well as improve surface of the machined components (Da Silva et al., 2001) and decrease the amount of power consumed. However, machining without cutting fluids have been in latest years a great topic of research to many researchers which expect to optimize the use of cutting fluids in machining processes. Ecological regulations and economical considerations have emphasised the need for more dry machining or environmentally clean metal cutting processes. Additionally, use of cutting fluids causes environmental and health problems.

At the same time, tool material properties have been improved and new tool materials have been developed in order to avoid or minimize the use of cutting fluids. Therefore, properties such as resistance to abrasion and diffusion, hot hardness and ductility have been greatly improved with the new tool materials. Tool coatings have provided high hardness, low friction coefficient and chemical and thermal stability to the tool. Tool geometries have been optimized to better break chips and also to produce lower surface roughness values in the workpiece. New concepts of machine tool design have allowed machining speeds to become faster, and increased rigidity enables more severe cutting operations to be used (Diniz and Oliveira, 2004; Derflinger et al., 1999).

Due to these technological advances, machining without cutting fluid can be possible, in some situations. However, it is important to eliminate cutting fluids from the process without affecting productivity, tool life and workpiece quality.

In dry machining, the friction and adhesion between chip and tool is higher then when machining in presence of fluids, which generates higher temperatures, higher wear rates and, consequently, shorter tool life. So far, completely dry cutting still is not suitable for many machining processes (Da Silva, 2006).

A viable alternative to dry cutting is MQF that generally improves the characteristics of the tribological processes present at the tool-workpiece interface, i.e., improves the machinability of materials and at the same time eliminate environmental damages as well as minimizing some problems associated with the health and safety of operators (Machado and Wallbank, 1997). MQF technique consists of the application (pulverization) of a very small volume of cutting oil (usually less than 500ml/h), in a flow of compressed air. This small amount of oil, most of the time is enough to substantially reduce friction to avoid the adhesion of the chip on the tool (Diniz et al., 2003).

The cutting temperature observed when using MQF technique is comparatively less than that in dry and wet turning because cooling occurs by convective as well as evaporative heat transfer. In this condition, fluid droplet with their high velocity can puncture the blanket of vapors formed and reach the tool interfaces that are under high temperatures, facilitating evaporative heat transfer, which is more effective than the convective heat transfer. Cutting fluid injection thus provides better lubrication and effective heat transfer, hence generating lower cutting temperature than that observed under conventional wet turning.

Regard MQF technique parameters, Sharma et al. (2009) and Vikram et al. (2007) observed in their experiments that cutting performance mainly depends on fluid application parameters such as nozzle pressure, number of pulses and amount of cutting fluid delivered in each pulse. They concluded that by carefully choosing these parameters it is possible to produce high quality of machined components with MQF technique.

The minimization of cutting fluid also leads to economical benefits by way of saving lubricants costs workpiece/tool/machine cleaning cycle time. From viewpoints of performance, cost, health, safety and environment, vegetable oils are, therefore, considered as viable alternative to petroleum-based metalworking cutting fluids (Khan and Dhar, 2006) because:

(1) Molecules, being long, heavy, and dipolar in nature, create a dense homogeneous and strong lubricant film that gives the vegetable oil a greater capacity to absorb pressure;
(2) The lubricating film layer provided by vegetable oils, being intrinsically strong and lubricious, improves workpiece quality and overall process productivity reducing friction and heat generation;
(3) The higher boiling point and greater molecular weight of vegetable oil result in considerably less loss from vaporization and misting;
(4) Vegetable oils are nontoxic to the environment and biologically inert and do not produce significant organic disease and toxic effect;
(5) No signal and symptom of acute and chronic exposure to vegetable oil mist have been reported in human.

This paper evaluates the performance of MQF technique with two different flow rates (20 and 60 ml/h) when turning of AISI 1047 steel grade with coated cemented carbides at various cutting speeds and feed rates. Comparative trials were carried out under dry condition. Tool wear values, failure modes (SEM images of wear) and surface finish were recorded and used to assess the performance of MQF techinique.

2. EXPERIMENTAL PROCEDURE

Machining trials were carried out using a CNC lathe with 10 HP motor driver. The workpiece material used in this investigation is a commercially available AISI 1047 steel grade with the following dimension: 130mm diameter x 250 mm long. Coated cemented carbides insert with ISO tool designations SNMA 120408 was used for the machining trials (Tab. 1).

Cutting conditions employed in this investigation are shown in Tab. 1. Cutting speed and feed rate values were selected based on the tool manufacturer's recommendation and industrial practices. Depth of cut was kept constant.

The MQF technique needs to be supply at high pressure and impinged at high speed throughout the nozzle at the cutting zone. Considering the conditions required for the present research work and uninterrupted supply of MQF at constant pressure over reasonably long cut, a MQF (ITW system) was used. The MQF jet in this work was conduct to rake surface using a pressure of 0.6 MPa, through two nozzles, to protect too the auxiliary flank to enable better surface finish. During MQF application the distance between the nozzles and cutting zone was kept in 30mm.

The tool life rejection criterion for this investigation was maximum flank wear, $V_{BBmax} \geq 0.6$ mm. Tool wear measurement of maximum flank wear was carried out at various intervals using a Profile Measurement Machine PJ300H at the end of each pass. Relevant images of the worn tools were selected and captured on a computer connected to the SEM.

Surface roughness (Ra parameter) of the machined surface were recorded after each pass using a Surftest Mitutoyo portable stylus type instrument with sampling length of 0.8mm for all conditions investigated. Measurements were carried out in three different regions (R1, R2 and R3) of workpiece as schematically illustrated in Figure 1. Three measurements were realized on each region and the average of three readings represents the surface roughness value of the machined surface for each region.

Table 1. Summary of the experimental tests carried out when turning AISI 1047 steel grade at a constant Depth of Cut of 2 mm.

Machine tool	CNC Lathe machine (10hp)	
Workpiece material	AISI 1047 steel (C = 0.44%, Mn = 0.73%, Si = 0.19%, P = 0.016%, Cu = 0.067%, S = 0.015%, Cr = 0.027%, Ni = 1.037%)	
Dimension	∅130 mm x 250mm long	
Cutting insert designation	Cemented carbide inserts ISO SNMA 120408 (without chip breaker)	
Tool holder designation	PSDNN2525-M12	
Coating material	TiAlN monolayer (low Al, less than 30 wt.%)	
Cutting parameters		Conditions (C)
Cutting speed (m/min)	220, 300	C 1. Vc = 220m/min; f = 0.22mm/rev
Feed rate (mm/rev)	0.22, 0.28	C 2. Vc = 220m/min; f = 0.28mm/rev
		C 3. Vc = 300m/min; f = 0.22mm/rev
		C 4. Vc = 300m/min; f = 0.28mm/rev
MQF supply	Pressure: 0.6 MPa, Flow rate: 20ml/h and 60ml/h	
Environment	Dry and minimum quantity lubrication (MQF)	
Cutting fluid	Vegetable oil with additives and anti-oxidants constituents	

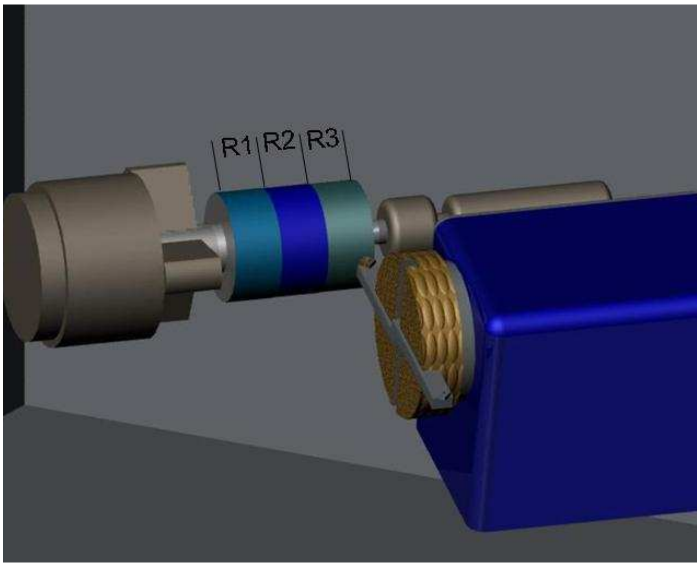


Figure 1. Schematic illustration of machining tool-workpiece-roughness device system showing workpiece regions (R1, R2 and R3) used for monitoring of surface roughness

3. RESULTS AND DISCUSSIONS

During machining operation the quantity of heat generated is due the interaction of tool/chip/workpiece. The heat generated in the primary shear zone is due to shear and plastic deformation and the heat generated at the chip/tool and work/tool interfaces are due to sliding and rubbing, respectively. All heat sources lead to generation of elevated temperatures at the chip/tool interface, which substantially influence the chip formation mode, cutting forces and tool life.

Therefore, attempts are made to reduce this detrimental cutting temperature. Conventional cutting fluid application may cool the tool and workpiece but can not efficiently cool and lubricate the chip/tool interface. However, it was observed that the MQF technique enabled reduction of the average cutting temperature by about 5-10% depending upon the levels of the process parameter (Dhar et al., 2006).

Figures 2, 3 and 4 show the evolution of maximum flank wear, V_{Bmax}, with length when turning AISI 1047 steel grade under dry, MQF 20 and MQF 60 conditions, respectively, as previous indicated in Tab. 1.

From these Figures can be observed gradual growth of $V_{Bmax,}$ with increase of length of cut in all conditions investigated.

From Figure 2 can be observed that lower flank wear value was generated under condition 2, i.e., at lower cutting speed of 220 m/min and higher feed rate of 0.28 mm/rev, whereas condition 1 (lower cutting speed of 220 m/min and lower feed rate of 0.28 mm/rev) generated higher flank wear.

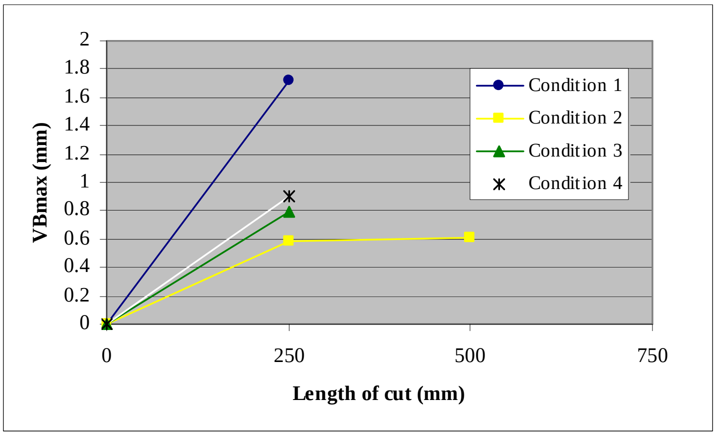


Figure 2. Flank wear curves when machining AISI 1047 steel at various cutting lengths and different conditions (combination of cutting speed and feed rates) under dry situation.

Figure 3, machining with MQF technique with flow rate of 20 ml/h, shows that again condition 2 (lower cutting speed and higher feed rate) gave least flank wear value. Machining at conditions 1, 3 e 4 presented similar flank wear values. Best performance of condition 2 may be attributed to improved lubrication conditions and efficient cooling achieved with MQF technique, which lead to reduction of abrasive wear by retaining tool hardness and also adhesion and diffusion wear mechanisms which are highly sensitive to temperature.

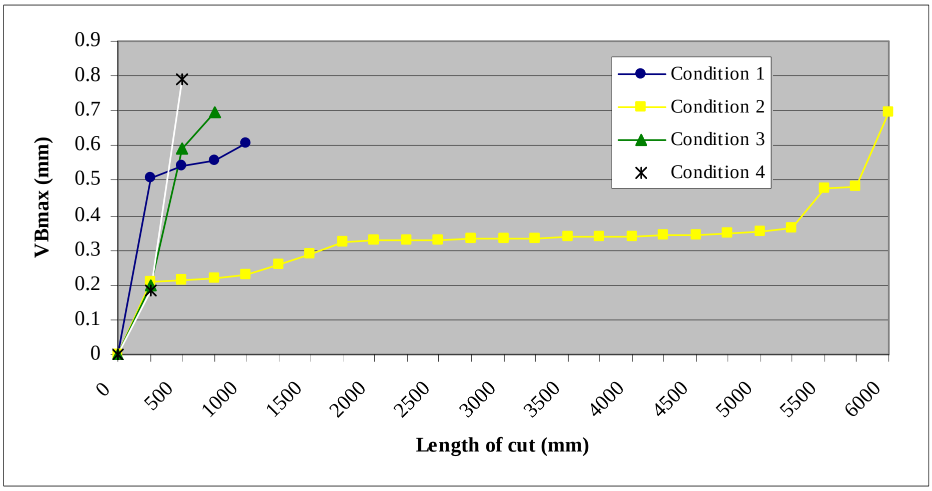


Figure 3. Flank wear curves when machining AISI 1047 steel at various cutting lengths and different conditions (combination of cutting speed and feed rates) with MQF technique at a flow rate of 20 ml/h

Figure 4, machining with MQF technique with flow rate of 60 ml/h, shows that again condition 2 (lower cutting speed and higher feed rate) gave least flank wear value. Machining at condition 1 (lower cutting speed and lower feed rate) also produced relatively lower flank wear value compared to conditions 3 and 4. Flow rate of 60 ml/h showed an important role when machining with MQF technique at lower cutting speed of 220 m/min. From this Figure can be observed that feed rate can also influence in wear. For a same cutting speed of 220 m/min, highest feed rate of 0.28 mm/rev generated lower flank wear value (condition 1) then when machining with least feed rate of 0.22 mm/rev (condition 1). Best performance of condition 2 again in Figure 4 may be attributed to improved lubrication conditions and efficient cooling achieved with MQF technique, which reduced negative effects of thermal related mechanism existing when machining at conditions investigated. It is known that increase in feed rate directly causes increase areas of primary and secondary shear zones, length of contact between chip and tool and consequently increase of heat generation. Increase in heat generation contributes to easy shearing of the work material. Also, when a length of contact between chip and tool is increased, more heat is dissipated from cutting zone and in some cases heat transfer rate to cutting tool is decreased. This phenomenon may explain the best performance of condition 2 verified when machining AISI 1047 steel.

By comparing Figure 3 and Figure 4, it can be observed that machining with MQF technique at flow rate of 60 ml/h (Figure 4) cutting tool reached maximum flank wear value of 0.6 mm faster, i.e. length of cut was nearly 50% smaller than that length of cut machined with MQF technique at flow rate of 20 ml/h, hence indicating that a flow rate of 20 ml/h may be the optimum flow rate for machining AISI 1047 steel under cutting parameters investigated.

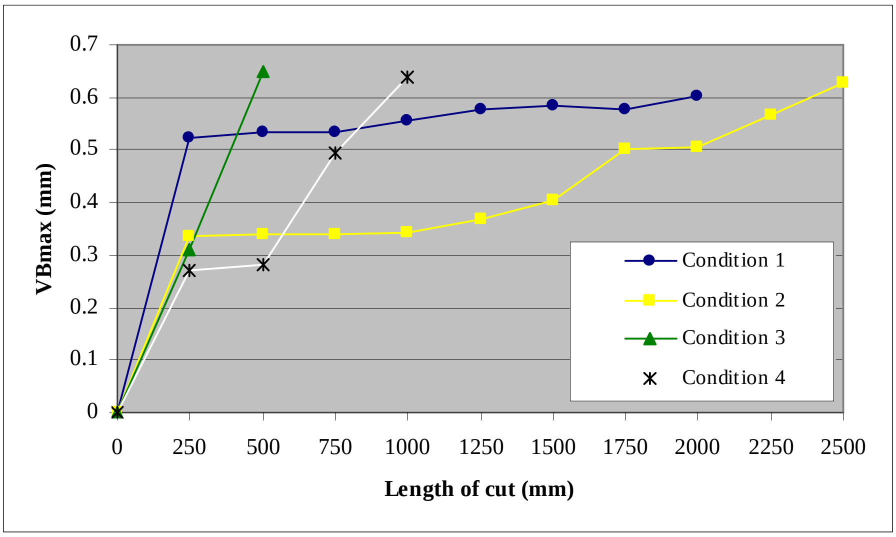


Figure 4. Flank wear curves when machining AISI 1047 steel at various cutting lengths and different conditions (combination of cutting speed and feed rates) with MQF technique at a flow rate of 60 ml/h

Figures 5, 6 and 7 show worn cutting edges obtained after machining AISI 1047 steel at various cutting conditions and different cooling environments (dry, MQF 20 ml/h and MQF 60 ml/h, respectively).

In all the conditions investigated it can be observed presence of abrasive scratch marks on insert flanks and by the examination of the craters, it was observed small scratches on the rake surface of the tool. It was also observed some presence of adhesive wear in the insert. Some plastic deformation and micro chipping were noticed on inserts after machining under dry and MQF environments. Presence of clear delamination of TiAlN monolayer from cemented carbide substrate was observed in cutting inserts after machining under all tested conditions.

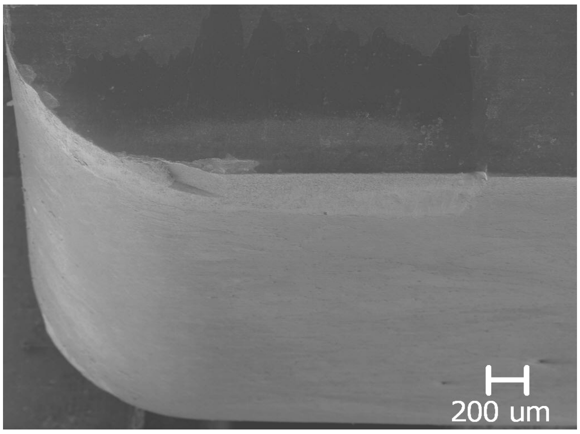


Figure 5. Worn coated carbide insert after machining AISI 1047 steel under dry machining.

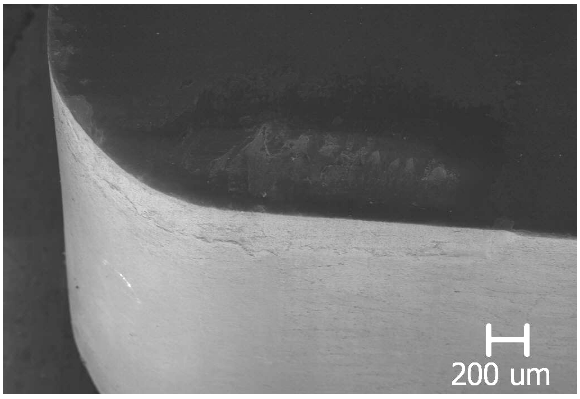


Figure 6. Worn coated carbide insert after machining AISI 1047 steel with MQF technique at a flow rate of 20ml/h.

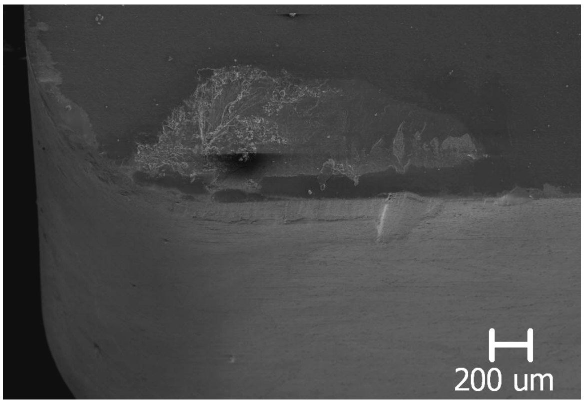
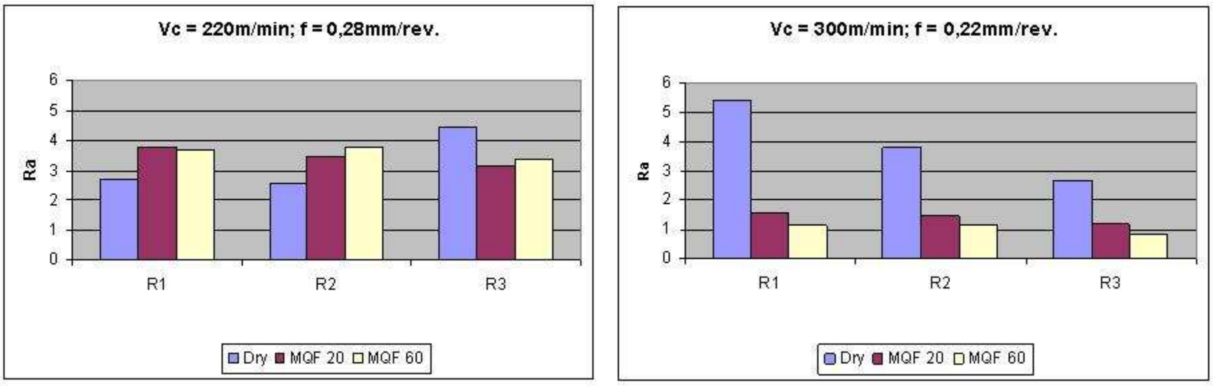


Figure 7. Worn coated carbide insert after machining AISI 1047 steel with MQF technique at a flow rate of 60 ml/h.

Figures 8 (a) and (b) show the surface roughness and recorded at three regions of workpiece after machining AISI 1047 steel at various cutting conditions: (a) condition 1; (b) condition 3. It can be seen from Figures 8 (a) and (b) that the surface roughness values recorded in all the conditions investigated varied between 0.8 and 5.4 µm. Figure 8 (a), however, shows evidence of deterioration of the surface finish when machining with MQF technique for both regions 1 and 2 of workpiece. Machining with MQF technique at both flow rates gave similar surface roughness values in range of 3 to 4 µm at lower cutting speed and higher feed rate; and 0.9 and 1.5 µm values at higher cutting speed and lower feed rate. These results show that combination of higher cutting speed with lower feed rate promotes best surface finish, a part from machining under dry condition. Machining under dry conditions at higher cutting speed and lower feed rate generated the highest surface roughness values.



(a) (b)

Figure 8. Surface roughness recorded at three regions of workpiece after machining AISI 1047 steel at various cutting conditions: (a) condition 1; (b) condition 3

4. CONCLUSIONS

Based on the results of the present experimental work the following conclusion can be drawn:

(1) Turning operation of AISI 1047 steel with MQF technique showed superior performance compared to dry machining under the conditions investigated. Tool life results show that there is not significant difference between MQF at flow rate of 20 ml/h and 60 ml/h. MQF technique provides the benefits mainly by reducing the cutting temperature, which improves the chip/tool interaction and maintains sharpness of the cutting edges.

(2) The surface roughness recorded show that the MQF technique can improve quality of machined component due the reduction of flank wear rate and cutting forces generated during turning.

(3) From the overall results obtained in this work and take into account the economic factors of machining, the best condition for machining AISI 1047 steel is using MQF at a flow rate of 20 ml/h and a cutting speed of 220 m/min with feed rate of 0.28 mm/rev.

5. ACKNOWLEDGEMENTS

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