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LOCALIZED INJECTION OF CUTTING FLUID IN TURNING OPERATION

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ABSTRACT

The choice of lubricant type and the technique for applying lubricant are very important for machining economics, environmental and health issues as well as the workpiece machinability. In this study, a new lubrication technique which is the localized injection of cutting fluid (LIF) is presented and examined when turning different materials (Steel, Brass and Aluminum) at different cutting conditions. Different cutting fluid viscosities were used and compared to dry and wet conditions. Compared to other techniques, the reduction in the quantity of cutting oil in the machining process when using LIF technique is more than 99 % in relation to wet flooding technique that leads to lower machining cost. This small percentage is localized continually at the cutting zone. Experiments showed that machinability was inhanced when using LIF technique. It is found that the volumetric flow rate and viscosity of fluid plays an important role in the evaluation of cutting force, surface roughness and tool wear.

KEYWORDS

Machining, Metal cutting, Machinability, Cutting fluid, localized Injection, cutting fluid, Cutting force, Surface roughness, Tool wear.

INTRODUCTION

Presently, there is a consideration of the use of the metalworking fluids (MWFs) in machining. Industry is looking for ways to reduce the amount of lubricants in metal removing operations due to ecological, economical and most importantly occupational pressure. Respiration and skin problems are the main side affects of MWF, however, the types of occupational risks associated with MWF becoming airborne and behave aerosol-like are numerous and widespread. Other new techniques have been developed recently to reduce the ammount of lubricant, improve productivity and reduce costs. Sreejith, [1] stated that minimum quantity lubrication (MQL) technology is still new. When MQL condition is applied to machining, the process gets economic advantage. He stated that the cutting forces were found to be dependent on the coolant system and that for improving the quality of the workpiece surface, coolant is necessary. He concluded that when MQL condition is applied, the tool wear was found to be less.

Dhar et al., [2] concluded that MQL technique has reduced flank wear and hence is expected to improve tool life. Surface finish and dimensional accuracy improved, mainly due to reduction of wear and damage at the tool tip by the application of MQL. Such reduction in tool wear reflects either on improving tool life or enhancing of productivity, and allowing higher cutting velocity and feed.

Sharma et al., [3] concluded that with the MQL/NDM (Near to dry machining) technique, there can be a remarkable reduction in machining cost, quantity of lubricant and surface roughness, by properly orienting the nozzle on flank face of the tool. Khan et al., [4] concluded that the significant contribution of MQL jet is the reduction in flank wear, which would enable either remarkable improvement in tool life or enhancement of productivity material removal rate (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. They also concluded that MQL reduces deep grooving, which is very detrimental and may cause premature and catastrophic failure of the cutting tools.

On the other hand, not all researchers signaled MQL benefits especially on tool wear. Bruni et al., [5] found that the MQL lubrication-cooling technique does not significantly affect the tool wear, whilst wet cutting produces the highest surface roughness. They concluded that the MQL technique does not provide advantages in comparison to dry cutting in terms of tool wear and surface roughness values. Diniz et al., [6] found that in dry and minimum volume of oil (MVO) cuttings, most of the time, similar values of flank wear, always smaller than the values for wet cutting which did not present better values of surface roughness compared to MVO and dry cutting, but in most of the time, presented similar roughness values. Based on that, the best cooling/lubrication system for this kind of machining operation is dry cutting.

Aoyama et al., [7] stated that in the MQL technique, a large volume of oil mist is discharged to the environment. Also, Yue et al., [8] studied the airborne emissions resulting from a variety of manufacturing processes for safety, health, and environmental concerns. During turning operation, a model is presented for the amount of cutting fluid mist produced by the interaction of the fluid with the rotating cylindrical workpiece. The model predictions and experimental results show that the number distribution of droplets within the control volume is dominated by small droplets because of the settling and evaporation phenomena. Marksberry, [9] stated that long chips and swarfs created in machining processes directly influence NDM performance, since the surface area of continuous curled chips provide greater blocking ability than small broken chips.

Other techniques have been developed such as micro-flood technique (MF) and direct oil drop supply system (DOS). In MF technique, a conceptual tooling design is used. Uniform and continuous MWF is applied through a single oil passage hole that is directed at the chip-tool interface without obstruction from fast moving chips. Marksberry, [9] concluded that water-miscible MWFs can decrease machining performance (tool-wear) at high MWF rates. Overall, MF technology can be recognized

as a coolant-less and occupational health friendly technology capable of providing improved machining performance without creating undesirable spray mist entropy. MF technology is a positive step towards a coolant-less machining environment that supports the ISO14001 standard, which aims to prevent pollution in balance with socio-economic needs. MF technology, like other sustainable manufacturing processes, will continue to be increasingly significant in reducing the environmental footprint of MWFs. Aoyama et al., [7] mentioned that the DOS technique can supply a very small oil drop directly to the cutting edge without making oil mist, and the DOS shows almost same machining performances compared to the MQL technique. They concluded that the amount of oil mist floating in the workspace can be considerably reduced be using the proposed DOS lubrication technique instead of the existing MQL mist supply technique. They found that in the case of the DOS technique, the oil drop shot must be accurately focused on the cutting point and when compared with the existing MQL technique, the proposed DOS technique has the possibility of further reductions in the total amount of oil consumption by decreasing the injector diameter.

This paper presents a new technology for minimizing the use of metalworking fluids (MWFs) during the machining process that is atomization-less and occupational friendly by using localized injection cutting fluid. Different cutting fluids having different viscosities were injected using different volumetric flow rates. The contribution of volumetric flow rate and viscosity of fluid in the evaluation of cutting force, surface roughness and tool wear were investigated.

EXPERIMENTAL

Experiments are carried out on (16K20) center lathe of 10 KW shown in fig. (1), using cutting tool of type Sandvik Corona TB S 3/4× 5 Square high speed steel tool of Coromant Grade C45. The cutting conditions used were cutting speeds ranged from 60 to 135 m min^{-1}, feed ranged from 0.1 to 0.25 mm rev^{-1}, and depth of cut ranged from 0.5 to 1.125 mm. Cutting force was measured using a dynamometer attached to strain meter (digitaler dehnungsmesser). The surface roughness was measured using surface roughness measuring unit surtronic 10. Tool wear was measured using 20x power measuring tool macker microscope of type (CARL ZEISS, JENA) of accuracy 0.01 mm as shown in fig. (2). Repeatability studies were performed to increase the overall confidence of the work.

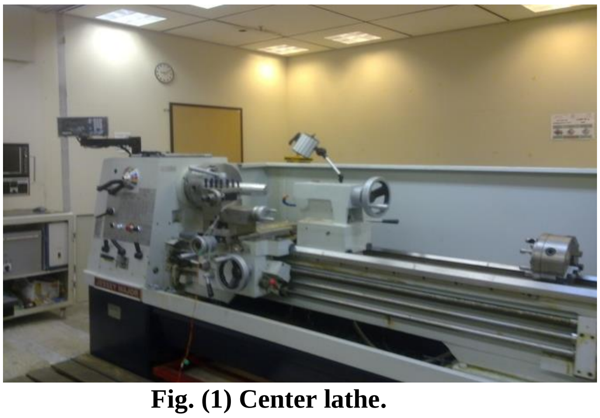


Fig. (1) Center lathe.

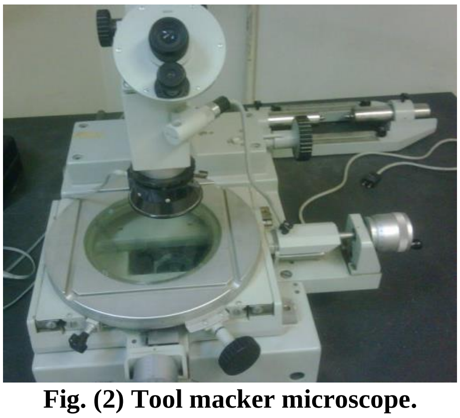


Fig. (2) Tool macker microscope.

Three different materials were used in this work; High strength low alloy steel, 60/40 Brass, and Aluminum alloy 6082. The workpiece properties having a profound effect on mechanics of metal cutting are microstructure, chemical composition, and physical properties. The major material property affecting machinability is the hardness property as demonstrated by Li et al., [10] who mentioned that the machinability of the materials may be connected with the decrease of Vickers hardness.

The properties of the three different materials used in this research are measured under repeatability on an Instron Universal Testing Machine of Model 1197 (500 KN full load capacity) and Microhardness tester of type Bohler Hardness tester (Max. load of 1000 gm). The results are shown in Tables 1, 2, 3, and 4.

The fluid was mixed with water by the ratio 1/3 as recommended. Experiments were conducted in lab for determining the viscosity for both fluids using the terminal velocity of a sphere falling in the viscous fluid. Assuming the flow is laminar, Stokes's law can be applied, [11]. The resulting Viscosity for both fluids gulf and Betromen oils are as follows:

Viscosity of Gulf = 22.6 kg/ms & Viscosity of Betromin = 14 kg/ms

Table 1: Properties of the three different materials

Material to be machined	Hardness HV	Yield stress σ_y (KN/mm^2)	Ultimate tensile stress σ_{ult} (KN/mm^2)
High strength low alloy steel	191	226	521
60/40 Brass	148	197	407
Aluminum alloy 6082	113	164	353

Table 2: High strength low alloy steel JIS G 3128 SS400 chemical analysis

Element	C	Si	Mn	P	S	Ni	Cr	Cu	Fe
%	0.19	0.181	0.452	0.0142	0.0119	0.026	0.047	0.076	Balance

Table 3: Brass 60/40 JIS H3250 C3604 BE chemical analysis

Element	Cu	Pb	Fe	Fe+Sn	Zn
%	58.54	3.17	0.1	0.21	37.98

Table 4: Aluminum alloy 6082 chemical analysis

Element	Mg	Al	Si	Mn	Fe
%	1.1911	97.039	1.0225	0.4529	0.2942

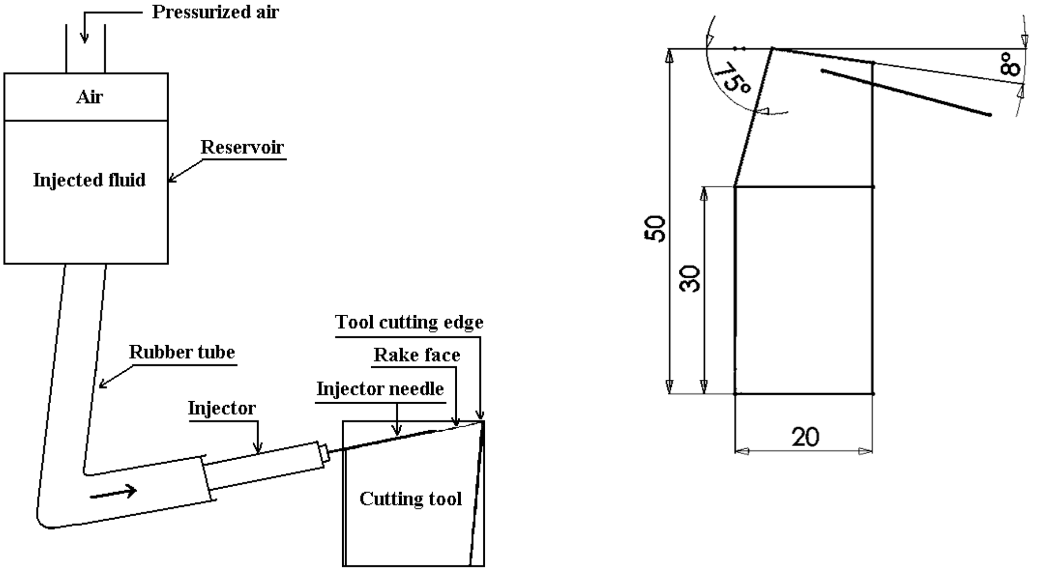
LOCALIZED INJECTION TECHNIQUE

Localized injection cutting fluid technique (non-atomizing spray) was accomplished by a simple injector as shown in the schematic sketch in Fig. (3-a). The injector tip is positioned approximately 10 mm past the cutting edge to prevent unnecessary clogging from dirt or debris from the cutting zone. The injector tip is better to be perpendicular to the cutting edge as shown in Fig. (3-b). The cutting fluid is to be fed from a large reservoir by a pressurized air as shown in Fig. (4). The fluid is supplied to the injector

through a rubber tube. The LIF technique can supply a very small oil stream directly to the cutting edge without making oil mist as presented in Fig. (5). A patent (no. 2011101799 (2011/1799)) was filed for this tool in the patent office, Academy of Scientific Research and Technology, Ministry of Scientific Research, Cairo, Egypt.

Two groups of experiments were planned. The first group of experiments was performed using different cutting fluids flow rates. The volumetric flow rate for both fluids at different injector inside diameters (D1 = 0.7 mm, D2 = 1.25 mm) were measured and recorded in table 5. These experiments were conducted for studying the effect of different flow rates on cutting force, surface roughness and tool wear for different materials (Al-alloy, Steel, and Brass) and injected fluids (B and G) at the zero level of cutting conditions (V = 90 m/min., f = 0.15 mm/rev., d = 0.75 mm.).

The second group of experiments was performed at constant flow rate at injector inside diameter D1 using different cutting conditions and applied to different materials. The independent variables are evaluated and coded as given in table 6. The design values of three levels for the independent variables are selected from Machining Data Handbook, [12].



(a)

(b)

Fig. (3). Localized injection (LI) technology design concept (a patent was filed for this tool, no. 2011101799, by the Academy of Scientific Research and Technology, Ministry of Scientific Research, Cairo, Egypt).

By comparing the volumetric flow rate of LIF with MQL and wet techniques, the reduction of the quantity of cutting oil in the machining process when using MQL technique is approximately 95 % in relation to wet flooding technique, [13]. Experiments were conducted for measuring the cutting fluid volumetric flow rates for different injector diameters and their percentages related to wet flooding technique were presented in Table 5. It is obviously shown that the reduction in the quantity of cutting fluid in the machining process when using LIF technique is more than 99 % in relation

to wet flooding technique, which implies lower machining cost. This small percentage of fluid is localized at the cutting zone which affects cutting force, surface roughness and tool wear.

Fig. (4) Experimental set-up.

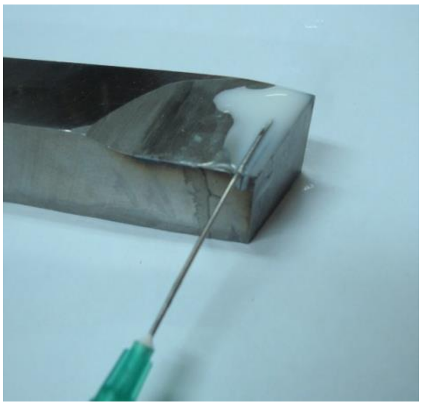


Fig. (5) Injector application.

Table 5: Volumetric flow rates (in ml/hr.) related to wet technique

	Fluid B	**Fluid G**	**Wet**	**% Fluid B Injection : Wet**	**% Fluid G Injection : Wet**
D1	**923**	**632**	**150000**	**0.006**	**0.004**
D2	**1333**	**900**	**150000**	**0.009**	**0.006**

Table 6: Levels and coding of independent variables.

Independent Variables	**-1**	**0**	**+1**
Cutting speed (V, m/min)	**60**	**90**	**135**
Feed (f, mm/rev)	**0.1**	**0.15**	**0.25**
Depth of cut (d, mm)	**0. 5**	**0.75**	**1.125**
Material hardness (HV)	**113**	**148**	**191**

EXPERIMENTAL RESULTS

Figs. (6-11) show a comparison between the two injected fluids at different volumetric flow rate compared with dry and wet cutting conditions. It is shown that dry cutting results in higher cutting force and deteriorates surface roughness followed by wet technique. Injection fluid technique shows better force and surface roughness results than wet cutting. This is due to the injected fluid is localized at the tool-chip interface. Graphs also show that the cutting force and surface roughness decrease with the increase of the fluid volumetric flow rates for all material used. The lower viscosity cutting fluid B shows better influence on cutting force and surface roughness than the higher viscosity fluid G. The lower viscosity fluid has better effect for the low viscosity property gives the chance for the fluid to get within the tool-chip interface. Increasing volumetric flow rate gives better results for all material used.

Figs. (12-15) show the effect of injecting different cutting fluid with different volumetric flow rates using different workpiece materials on cutting force and surface roughness. Steel results show highest cutting force values followed by Brass material, due to the fact that steel possesses higher material hardness than Brass and Aluminum Alloy as shown in Table 1. It can be also shown that Steel has the best surface roughness using injection technique followed by Brass. This is because the higher material hardness results in improved surface roughness as demonstrated by Chen, [14]. This result is clear for all cutting conditions used. Figs. (6-15)

shows that the fluid flow rates, and its viscosity have a valuable effect on the cutting force and surface roughness.

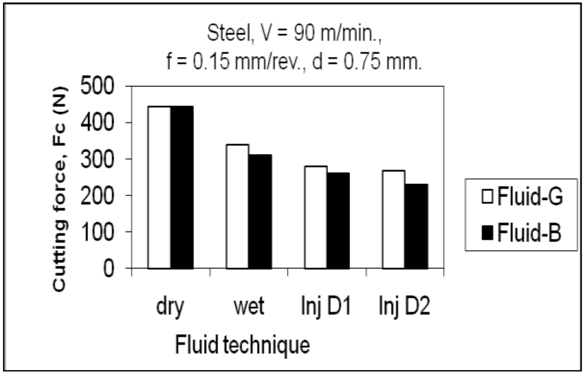


Fig. (6) Comparing cutting force for the two fluids (Steel).

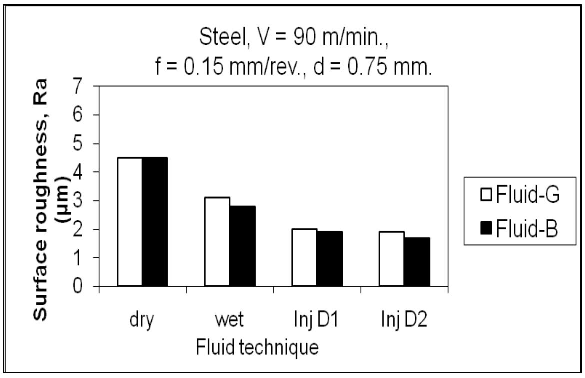


Fig. (7) Comparing surface roughness for the two fluids (Steel).

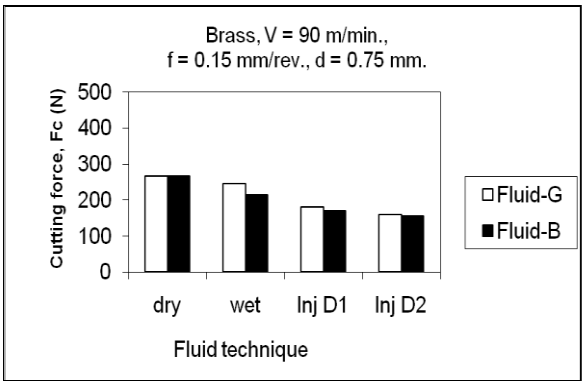


Fig. (8) Comparing cutting force for the two fluids (Brass).

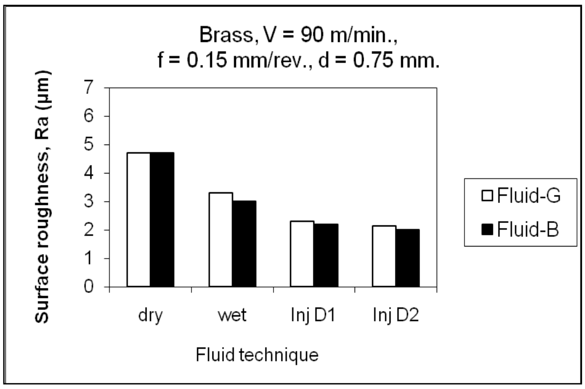


Fig (9) Comparing surface roughness for the two fluids (Brass).

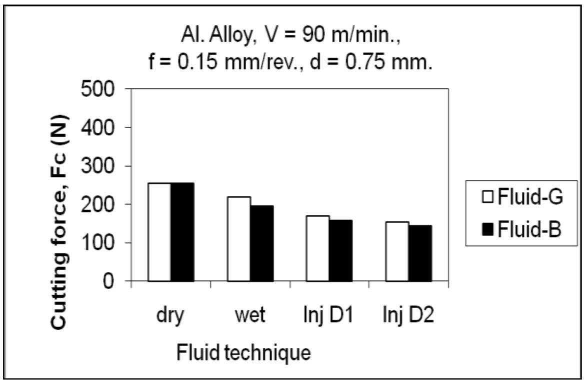


Fig. (10) Comparing cutting force for the two fluids (Al. Alloy).

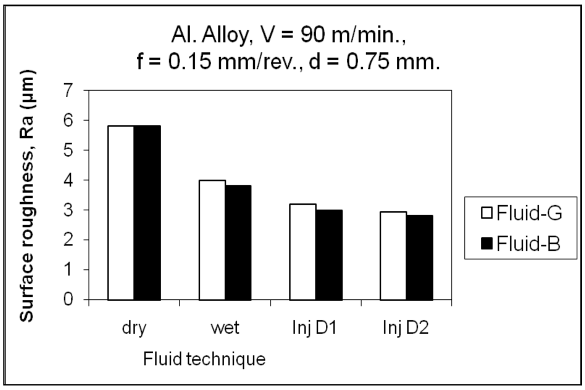
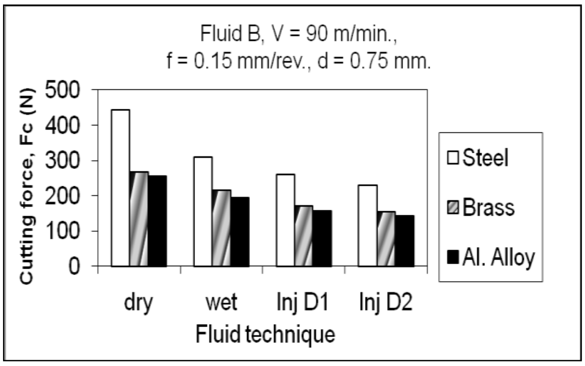


Fig. (11) Comparing surface roughness for the two fluids (Al. Alloy).



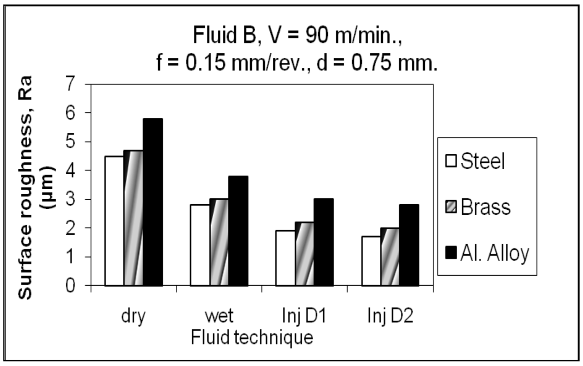
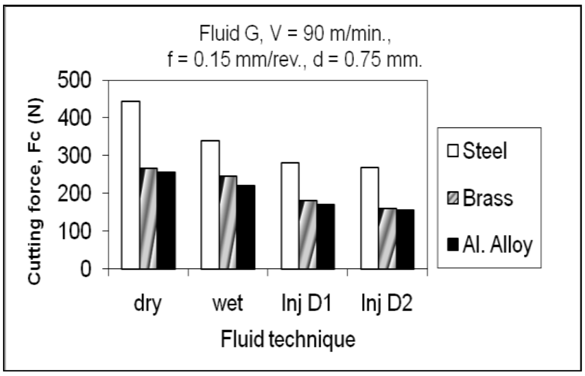


Fig. (12) Effect of volumetric flow rate on cutting force (Fluid B).

Fig. (13) Effect of volumetric flow rate on surface roughness(Fluid B).



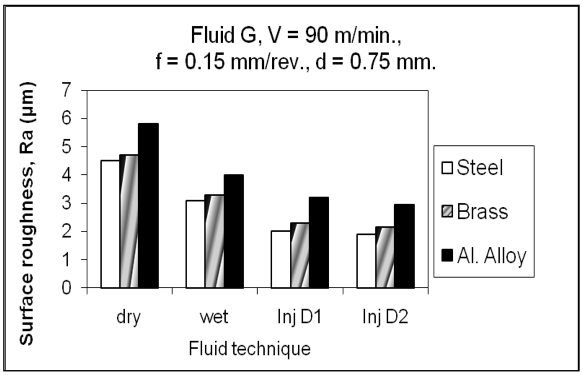


Fig. (14) Effect of volumetric flow rate on cutting force (Fluid G).

Fig. (15) Effect of volumetric flow rate on surface roughness(Fluid G).

Fig. (16) shows tool wear results by applying different techniques. It is clear that dry cutting results in the highest tool wear followed by wet cutting with flooding fluid. Injecting cutting fluid technique shows lower tool wear values than dry and wet cutting and decreases with increasing the volumetric flow rate reached by increasing the injector diameter as presented experimently in Table 5.

Fig. (17) shows a comparison between the two injected fluids (B & G) at the same injecting diameter (D1) compared with dry and wet conditions. Curves show that tool wear values are high when cutting dry, decreased when using wet cutting and reduced by injection technique. The cutting fluid B with lower viscosity has better influence on tool wear than fluid G. This is due to two reasons; cutting fluid B delivers more volumetric flow rate than fluid G and cutting fluid B possesses lower viscosity which gives the chance for the fluid to get inside the tool-chip and tool-work interfaces. Higher volumetric flow rate gives more cooling effect at the cutting zone which leads to better tool wear results.

Fig. (18) shows the effect of using different workpiece materials on tool wear when injecting fluid B using injector diameter (D1). The highest tool wear values results when machining steel followed by Brass material due to the fact that steel possesses higher material hardness than Brass and Aluminum Alloy as presented in Table 1.

Figs. (19-21) present the effect of cutting conditions (cutting velocity, feed and depth of cut) on tool wear when machining Al. alloy and injecting fluid B with injector diameter (D1). These curves obviously show that increasing cutting velocity, feed and depth of cut increase tool flank wear.

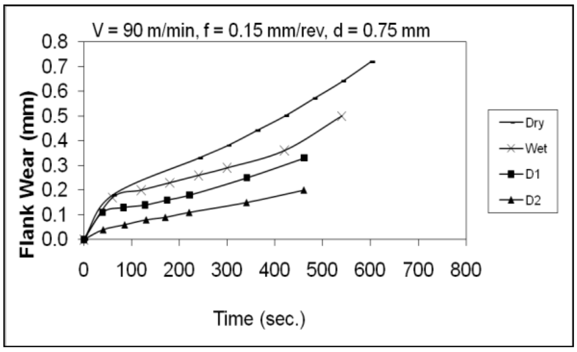


Fig. (16) Effect of fluid technique on tool wear (Al. alloy, Fluid B).

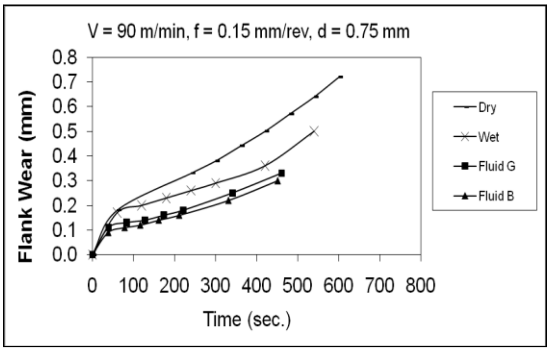


Fig. (17) Effect of cutting fluid type on tool wear (Al. alloy, D1).

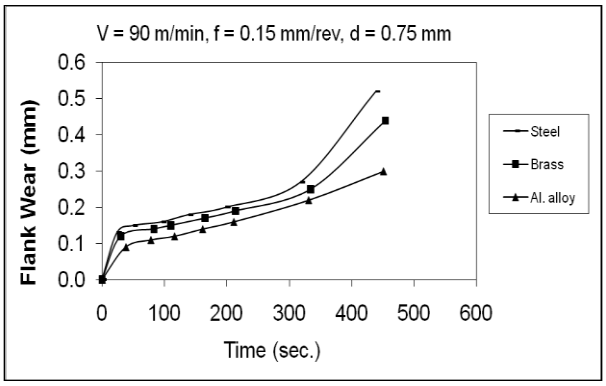


Fig. (18) Effect of workpiece material on tool wear depth of cut on (Fluid B, D1).

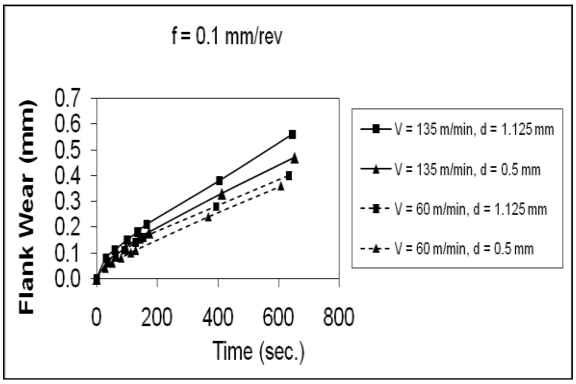


Fig. (19) Effect of cutting velocity and tool wear (Al. alloy, Fluid B, D1).

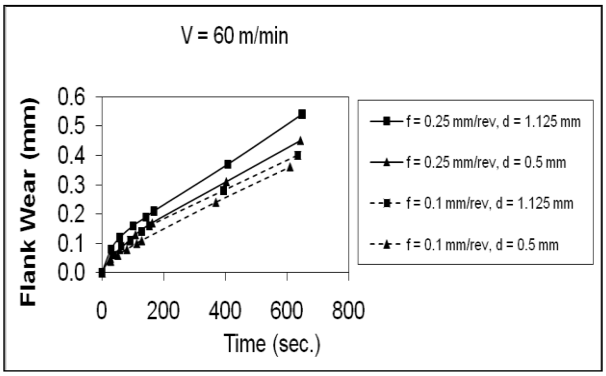


Fig. (20) Effect of feed and depth of cut on tool wear (Al. alloy, Fluid B, D1).

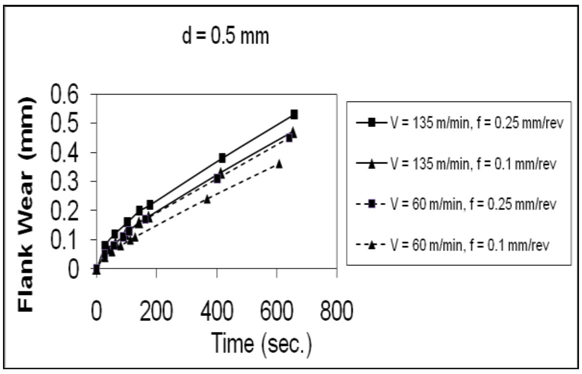


Fig. (21) Effect of cutting velocity and feed on tool wear (Al. alloy, Fluid B, D1).

COMPARING LIF WITH OTHER TECHNIQUES

When LIF is compared with other techniques, NDM oil mist lubrication is a technique that continuously delivers fresh clean oil, provides better productivity, minimizing lubrication and cost. Improvements in tool-wear can contribute to effective MWF penetration at the cutting zone. But NDM technique using a nozzle to create a localized

spray mist always has the inherent disadvantage of MWF obstruction between the nozzle and the cutting tool. Nozzle applications in NDM using an atomized spray mist will always have the possibility to become obstructed and segmented with newly created chips. Beneficial cooling and lubrication stops when the MWF spray mist can no longer reach the cutting tool. On the contrary, localized injection technology utilizes the same or less amount of MWF more efficiently compared to NDM due to the direct contact between the cutting fluid and the cutting zone as in the case of conventional flooding technique but with less oil dissipation compared with the NDM technique.

The improvement in machining performance using LIF technology can be attributed to that of Micro-Flood technology: (1) pool cooling and lubrication characteristics, (2) MWF penetration into the cutting zone, and (3) a decrease in local chip hardening by overcooling of the chip. It has been demonstrated that a small localized pool of MWF on the cutting tool near chip formation can provide optimal cooling and lubrication characteristics as mentioned by [9]. It can be speculated that this small pool of MWF will grow or shrink depending on the amount of heat generation encountered in the cutting process. The pool acts as a reservoir that is depleted at high heat exchanges and is continuous to allow backwall sliding between the chip and the cutting tool. Micro-flood technique needs designing and manufacturing this conceptual tooling as it is not easy manufactured for it is not a straight hole, in addition to the predicted contamination which can block this fluid passage hole and needs continuous maintainance which is difficult as the oil passage is not a straight hole. Whilst in Localized injection technology, it is easy to replace the injector without consuming a valuable time, effort or cost.

CONCLUSIONS

In addition to cutting force and surface roughness, tool wear behaviour was investigated when applying new cutting fluid technique of localized injection cutting Fluid (LIF). This was achieved by investigating the effect of cutting parameters (cutting speed, feed, depth of cut, workpiece hardness, cutting fluid viscosity, volumetric flow rate, and time ellapsed) on these output parameters. Conclusions can be summarized as follows:

1. **By comparing the volumetric flow rate of LIF with MQL and wet techniques, the reduction in the quantity of cutting oil in the machining process when using MQL technique is approximately 95 % in relation to wet flooding technique. Experiments were conducted for measuring the cutting fluid volumetric flow rates for different injector diameters. It is obviously shown that the reduction in the quantity of cutting oil in the machining process when using LIF technique is more than 99 % in relation to wet flooding technique that leads to lower machining cost. This small percentage is localized at the cutting zone which gives efficient effect on cutting force, surface roughness and tool wear.**
2. **Experimental results show that the volumetric flow rate increases as the injector diameter increases. It is obviously shown that the lower viscosity fluid B delivers more volumetric flow rate at the cutting zone than that of the higher viscosity fluid G.**
3. **The cutting fluid B with lower viscosity has the best influence on tool wear followed by fluid G. This is due to two reasons; cutting fluid B delivers more volumetric flow rate than fluid G and cutting fluid B possesses lower viscosity. Low viscosity property gives the chance for the fluid to get inside the tool-chip and tool-work**

interfaces while higher volumetric flow rate gives more cooling effect at the cutting zone. This leads to better tool wear results.

4. When LIF is compared with other techniques, LIF technology utilizes the same or less amount of MWF more efficiently compared to NDM due to the direct contact between the cutting fluid and the cutting zone as in the case of conventional flooding technique but without oil dissipation compared with the NDM technique. Also, the improvement in machining performance using LIF technology can be attributed to that of Micro-Flood technology. But Micro-flood technique needs designing and manufacturing this conceptual tooling as it is not easy manufactured for it is not a straight hole. In addition to the predicted contamination which can block this oil passage hole and needs continuous maintainance which is difficult as the oil passage is not a straight hole. While in Localized injection technology, it is easy to replace the injector without consuming a valuable time, effort or cost.

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