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Drilling of 6061 Aluminium Alloy with MQL, Dry and Flooded Cooling-Lubricant Conditions

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Abstract
In the present study, the effect of minimum quantity lubrication (MQL) on cutting forces (Torque and Thrust force) and surface roughness is analyzed under drilling with dry, flooded and pure MQL conditions of aluminium 6061 alloy by using HSS drill tools of 6mm diameter. In pure MQL method oil supply rate is fixed at 250 ml/hr and air pressure is fixed at 7 bar. The experimental results shows that in MQL, the number of drilled holes significantly increases and thus reduces the cutting torque and thrust force. The surface roughness of the drilled holes is also improved under MQL condition as compared to dry and flood condition. Analysis of experiments reveal that if MQL is properly employed, it can replace the flooded coolant environment which is presently employed in most of the cutting/machining applications, thereby not only making machining environment friendly but also improving the machinability characteristics.

Keywords
Drilling, MQL, Cutting Forces and Surface Roughness

I. Introduction

The machining process will shape the workpiece as desired and it is usually done using machine and cutting tools (Yusup et al., 2011). The growing demands for high productivity of machining require high material removal rates, which require high cutting speed and feed rate. Such high material removal rates inherently produce high cutting temperature (Meena and Mansori, 2011). During cutting operations one of the most important problems is tool wear, caused by the normal load generated by the interaction between tool and workpiece and by the relative motion between tool-chip and tool-workpiece (Kendall, 1998). The use of cutting fluid is important in a machining process to cool and lubricate tool and workpiece. Besides that, in some operations such as drilling, for example, use of cutting fluid helps to remove the chips from inside the holes, thus preventing drill breakage (Nandi and Davim, 2009). Petrochemical and synthetic based cutting fluids create many negative effects (Ozcelik et al., 2011). Due to the several negative effects they cause, when inappropriately handled of disposal, cutting fluids may damage soil and water resources because of their toxic effects. As machine operators are constantly at the same ambient with cutting fluids, they are primarily under impact of toxic fluids, which cause serious health problems like lung cancer, respiratory diseases and genetic diseases(Dhar et al., 2007). Several researchers state that the costs related to cutting fluids are frequently higher than those related to cutting tools, so cost also effected with cutting fluids (Dhar et al., 2006). Enormous efforts to reduce the use of lubricant in metal cutting are being made from the viewpoint of cost, ecological and human health issues. Minimal quantity lubrication (MQL) can be considered as one of the solutions to reduce the amount of lubricant or cutting fluid (Itoigawa et al., 2006).

Dry operations would be the best solution for the environmental issues involving metal machining. In reality, they are sometimes less effective when higher machining efficiency, better surface finish quality and severe cutting conditions are required (Sutherland and J.W, 2000). For these situations, semi dry operations utilizing very small amounts of cutting lubricants, such as MQL systems are expected to become a powerful tool (Hiesel et al., 1994). MQL is a method of supplying lubrication in machining to achieve both environmental and economic benefits. Typically, an MQL system supplies 0.3-0.5 ml/min of a cutting oil with pressurized air or other supplemental gases, where as a conventional system supplies about several thousand ml/min of MWF. The conventional flood supply system demands more resources for operation, maintenance and disposal, and results in environmental and health problems.

II. Experimentation

In this experiment, Aluminium (6061) was used for drilling operation. A vertical machining centre (INDIAN TOOLS CORPORATION INDIA) with 1 kW motor power and maximum spindle speed of 2850 RPM was used to drill holes of diameter 6 mm on 28 mm thick aluminium plate. The depth of the drilled hole was 25 mm. The machining tests were conducted using the HSS drills bits of 6 mm diameter which consists of two flutes with helix angle of 30° and point angle of 118°. A new drill bit was used for each experiment. The drill bit with the same geometry was used for each test performed using dry, pure MQL, and flood coolant-lubricant drilling condition. The MQL set-up is shown in fig. 1.

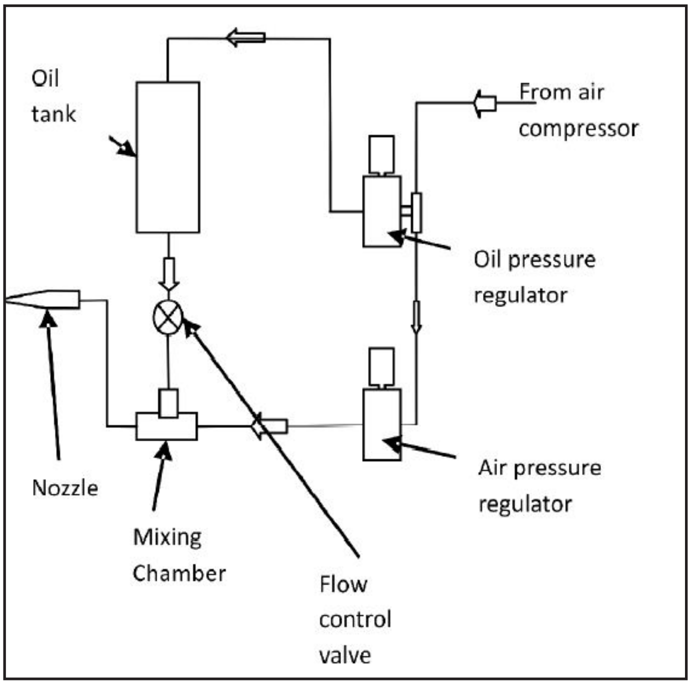

Fig. 1: MQL set-up

In MQL conditions the vegetable oil (Refined soya bean oil) was used. The drilling dynamometer was used to measure the thrust force and torque after every 15 holes. Surface roughness of machined work piece was measured using Talysurf (Mitutoyo SJ-201), surface roughness tester. The objective of the present study was to analyse the effect of dry and coolant-lubricant environment on, cutting forces and surface quality of work piece during drilling of aluminium under different lubrication conditions. The process parameters are given in Table 1.

Table 1: Process Parameters and Drilling Conditions

Machining environment	Dry, Flooded, MQL
Cutting fluid flow rate for MQL (ml/hr)	250
Drill bit diameter (mm)	6
Depth of drilling hole (mm)	20
Cutting speed (RPM)	1500 and 2500
Feed rate (mm/min)	60
Pressure for MQL (bar)	7

III. Results and Discussion

A. Drilling Torque and Thrust Force

The drilling torque and thrust force are measured after every 15 holes and shown graphically versus the number of drilled holes. Fig. 2 shows the thrust force at the speed of 1500 rpm and feed rate of 60 mm/min. In case of dry drilling; the drill failed due to adhesion at 27th hole and higher thrust forces is observed after 15 holes. Due to dry machining, tremendous pressure and high temperature generated by the process cause the adhesion of work material to the tool if the bonding energy is stronger than the cohesive energy of the work piece. Pure MQL produces lower thrust force than flood condition as micro droplets of the cutting oil at high pressure in pure MQL condition are able to reach the cutting zone easily, where it performed its lubrication effect and minimized the friction (Zhang et al., 2012). The higher thrust force of 32 N-m is recorded for the flood condition. Fig. 3 shows the torque generated at the speed of 1500 rpm. Lowest torque is produced during the MQL condition.

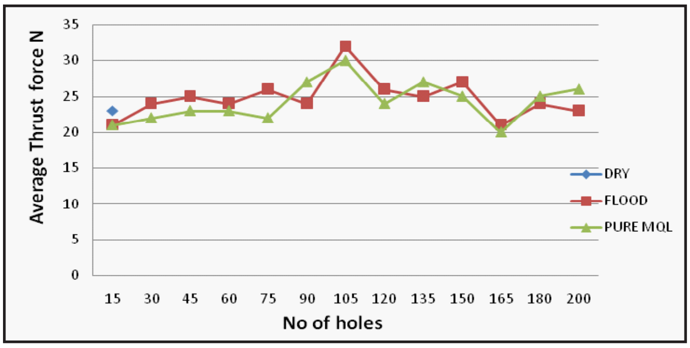

Fig. 2: Thrust Forces Generated During Dry, Flooded and MQL Drilling at the Speed of 1500 rpm.

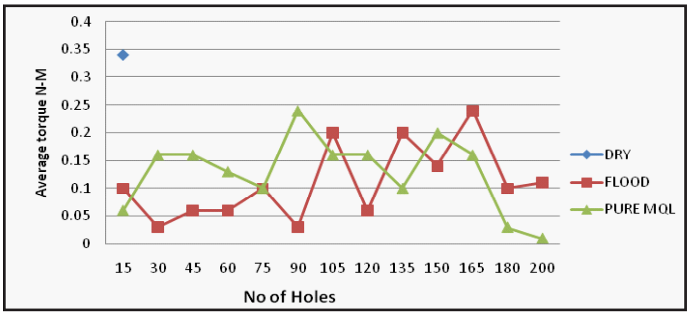

Fig. 3: Torque Generated During Dry, Flooded and MQL Drilling at the Speed of 1500 rpm.

As shown in fig. 4. It can be depicted that for a constant feed rate (60 mm/min) the thrust force involved in the drilling process reduces with the increase in the speed of the spindle. As the speed increases from 1500 to 2500 rpm, thrust force decreases in all the cooling lubrication conditions (Rahim and Sasahara, 2011). It reveals that the lowest thrust force is achieved in MQL condition. Pure MQL gives the lower thrust force as compared to flood condition. Overall the MQL condition is more effective than other lubrication conditions at higher speed.

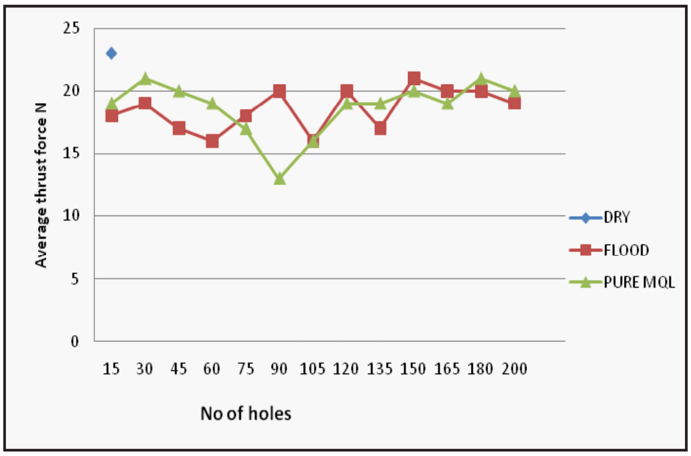

Fig. 4: Thrust Forces Generated During Dry, Flooded and MQL Drilling at Speed of 2500 rpm.

Fig. 5 shows that the MQL is effective in drilling with respect to torque at cutting speed of 2500 rpm. Highest torque is produced during the flood condition which is 0.13 Nm. Overall, the resultant cutting forces (thrust force and torque) are highest under dry cutting condition. The higher cutting forces are due to the effect of adhesion of the work material in drill flutes and on the tool face (Sreejith, 2008). Where as in all other cases (flood, MQL), no drill failure occurred and 200 holes generated successfully. Therefore, it can be concluded that flood lubrication, pure MQL conditions could significantly increase the number of drilled holes with the single drill.

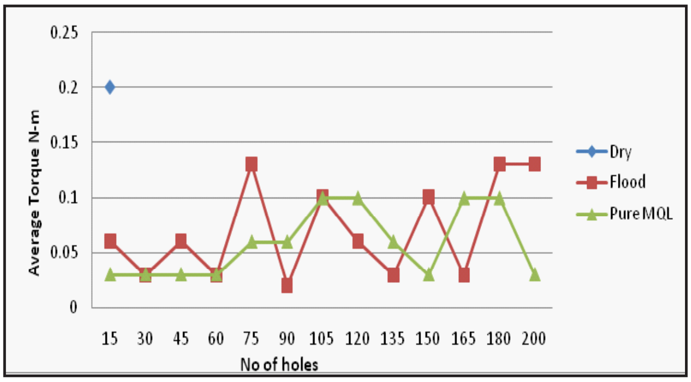

Fig. 5: Torque Generated During Dry, Flooded and MQL Drilling at the Speed of 2500 rpm.

B. Surface Roughness

As shown in fig. the surface roughness value obtained is quite high in dry condition as compared to pure MQL and flood condition. This is attributed due to adhesion which causes high temperature and stresses at the tool tip. The highest surface roughness value recorded is 1.99 µm in 2500 rpm [Fig. 6] and 2.02µm in 2500 rpm [Fig. 7] at the onset of drill adhered and failure during dry drilling. Similar results of poor surface roughness for dry drilling have also been reported by Meena and Monsari 2011.

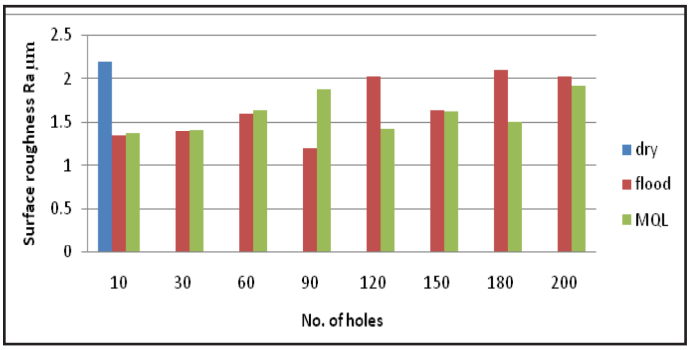

Fig. 6: Comparisons Among Flood, MQL and Dry Drilling With Respect to Drilled Holes for Average Surface Roughness Values at Cutting Speed of 2500 rpm.

In Fig. 6 at the speed of 2500 rpm, higher roughness value of 2.2µm is observed in dry cutting at the 10th hole. It is observed that surface roughness is quite high up to 90 holes in MQL condition as compared to flood condition. The surface roughness value in flood condition increases with the increase in number of holes. Effective lubrication allows the chips to slide more easily over the tool surface and results in a better surface finish.

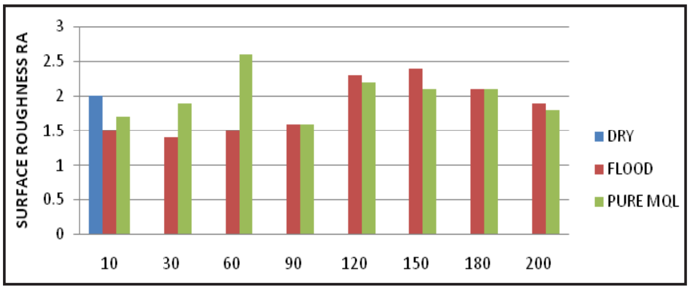

Fig. 7: Comparison Among Flood, MQL and Dry Drilling With Respect to Drilled Holes for Average Surface Roughness Values at Cutting Speed of 1500 rpm.

In fig. 7 at the cutting speed of 1500 rpm, it is observed that high surface roughness value for MQL condition is up to 90 holes. The flood condition seems less effective as the number of holes increase with regard surface roughness when compared to pure MQL condition. The lowest surface roughness value of 0.84 µm is observed for MQL.

IV. Conclusion

MQL technique is very effective and observed best results in drilling as compared to flood cooling and dry cutting in terms of cutting force and surface roughness. The dry cutting condition gave poor results as the tool failed due to adhesion. There is a considerable reduction observed in cutting forces as the cutting speed increases from 1500 rpm to 2500 rpm for all the coolant lubricant conditions. The number of drilled holes was significantly increased when the flooded lubrication, pure MQL used.

Surface roughness obtained in pure MQL is comparable to that of flood cooling, while it is better than that of dry cutting. Whereas pure MQL condition gave better results in terms of tool wear and cutting forces as compare to flood lubrication condition. This experimental research showed that flood lubricant can be replaced by the MQL (VBCFs), thus reducing the occupational health risks associated with petroleum oil based CFs and reducing the waste treatment costs due to the inherently higher biodegradability.

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