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INFLUENCE OF MINIMUM QUANTITY LUBRICATION ON CUTTING TEMPERATURE IN DRILLING OF PLAIN CARBON STEEL (EN8 STEEL)

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Abstract: In the present work the effect of MQL on cutting temperature in drilling of plain carbon steel (EN8 steel) has been investigated. The main objective of this work is to compare the performance of the flooded and MQL conditions provided better results as compare to dry condition in the drilling of plain carbon steel (EN8 steel). The drilling trials were conducted using HSS drill tool on the EN8 steel with a diameter and thickness of 10cm and 30mm respectively under the dry, flooded and MQL conditions. Holes were drilled at a depth of 25mm at the constant feed 60mm/min and the cutting speed 17.3m/min, 30m/min and 53.7m/min. It is observed that the MQL significantly increases the number of drilled holes and reduction in the cutting zone temperature as compare to dry drilling conditions. In addition, the MQL effectively eliminates remaining chips and burrs to enhance the quality of drilled holes.

Keywords: Minimum quantity of lubrication (MQL), tool tip temperature and hole temperature.

1. INTRODUCTION

In highly competitive manufacturing industries nowadays, the manufactures ultimate goals are to produce high quality product with less cost and time constraints. To achieve these goals, one of the considerations is by optimizing the machining process parameters such as the cutting speed, feed rate and depth of cut [1]. Heat generation and friction between tool and chip usually limit machining performance in metal cutting operations. Coolants and lubricants are therefore used in high quantities to reduce the temperature and friction in the cutting area [2]. The use of cutting fluid is important in a machining process to cool and lubricate tool and workpiece, making tool life longer and guaranteeing the workpiece quality. Besides that, in some operations such as drilling, for example, cutting fluid is important to remove the chips from inside the holes, thus preventing drill breakage [3]. The cutting fluid applied to the cutting zone is believed to enhance the lubricity of the tribological system. It is believed that smooth sliding and low friction were obtained due to the reaction between metal oxide layer and the fatty acid. The molecular thin film present during the drilling process under coolant- lubricant conditions helped reduce the friction and heat generation, and consequently improved the tool wear [4]. Due to the multiplicity of negative effects the cutting fluid wastes produce on mankind and our environment, in modern production there has been an increasing attention to carefully select efficient cutting fluids that would in addition to being efficient be also environment-friendly [5]. Applying cutting fluids in metal cutting is an important approach to enhance machining performance. However, the use of cutting fluids has caused some problems such as high cost, pollution, and hazards to operator's health. All the problems related to the use of cutting fluids have urged researchers to search for some alternatives to minimize or even avoid the use of cutting fluids in machining operations. So far various alternatives have been offered. Some of these alternatives are minimal quantity lubrication and cooling gas cutting [6]. The MQL is a recent technique introduced in machining (in particular, in drilling) to obtain safe, environmental and economic benefits, reducing the use of coolant lubricant fluids in metal cutting. As reported by some authors, metal-working fluids cost ranges from 7 to 17% of the total machining cost, while the tool cost ranges from 2 to 4%.Therefore, using MQL technique, a remarkable reduction of machining costs can be obtained reducing the quantity of lubricant used in machining. In MQL, a very small lubricant flow (ml/h instead of l/min) is used [7].The MQL is process in which the lubricant must adequately cover the contact areas, i.e., tool–chip and tool–work interfaces. Particularly, droplet size and distribution in terms of nozzle distance and air pressure have to be considered because the smaller droplet, which can provide better penetration into the cutting surface, are more preferable especially for micro-machining applications where the cutting surface is relatively small [8].

2. EXPERIMENTATION PROCEDURE

2.1. Work-piece material and cutting tool

The work material was EN8 steel with the chemical composition of 0.376% C, 0.151% Si, 0.453% Mn, 0.033% P, 0.035% S, 0.111% Cr, 0.019% Mo, 0.085% Ni, 0.023% Al, 0.0003% B, 0.001% Co, 0.076% Cu, 0.0002% Pb, 0.001% Ti, 0.004% V, 0.000% W and bal: Fe, and it was prepared in circular plate of diameter 10 cm and thickness 30 mm. EN8 steel is widely used in many steel industries for making various products such as shafts, studs, bolts, connecting rods, screws, rollers etc. The machining tests were conducted using the High speed steel (HSS) tools of diameter 6 mm. The tool was produced by ITI Company {helix angle: 25°-31°, point angle: 118° and lip clearance angle: 8° (minimum)}. The same drill tool with the same geometry and properties were used for all tests performed using dry, MQL and flooded drilling conditions. For each experiment new drill bit was used. Tool life is evaluated by counting the total number of holes drilled and according to the tool flank wear for dry, flooded and MQL drilling. Drilling is continued until 50 holes. However drilling experiments were stopped after 50 holes in all case of drilling. A schematic representation of the uncoated HSS twist drill and the term used in describing its geometry are shown in Fig. 1.

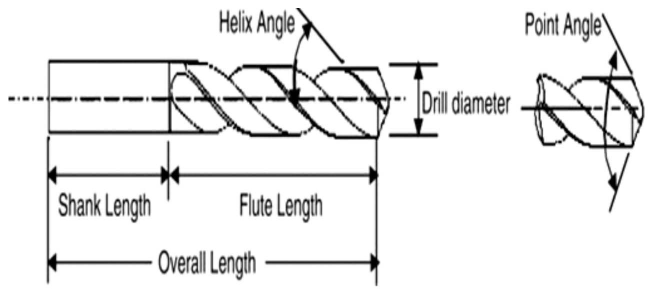

Figure 1: Geometry of twist drill consists of two flutes.

2.2. Drilling test

The drilling experiments were carried out using 1HP 1440 rpm drilling machine (four spindle speed: 510-920-1590-2850 rpm) and manufactured by INDIAN TOOLS CORPORATION INDIA (ITCO).The temperature was measured by means of a non-contact, infrared thermometer from one side of the workpiece- 3mm away from the first row of holes (50holes) being drilled. A detailed explanation of the measurement technique using an infrared thermometer can be found in Ref. [9].The variation in cutting temperature (°c) values with the number of holes produced in different drilling conditions is noted. The cutting temperature of the drilled holes and drill tip was measure after every 10 holes in every case. For flooded and MQL drilling servo-cut S (INDIAN OIL) lubricant was used with Kinematic Viscosity, cSt @ 40°C (Typical): 20 and Flash Point (COC), ºC Min: 40.In this study 1:10 cutting fluid-water ratio was used and fresh cutting fluid is used for each experiment. In MQL drilling, the MQL is applied to the drill tip under different coolant-lubricant conditions at different speeds. Drilling experiments for dry, MQL and flooded conditions are conducted using a constant feed of 60 mm/min.A schematic diagram of MQL drilling is shown in Fig. 2.The drilling tests were performed under different drilling conditions, as shown in Table 1.

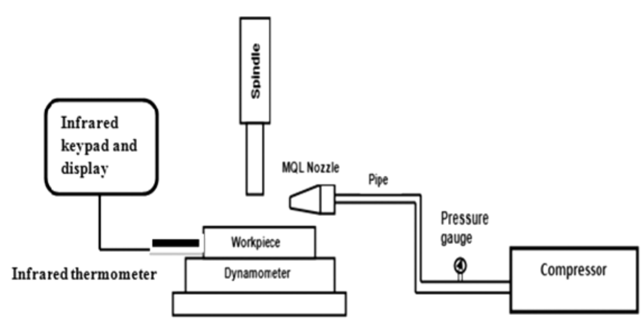

Figure 2: Schematic diagram of MQL drilling

Table 1
Drilling Conditions

1.	Spindle speed (m/min)	17.3, 30 and 53.7
2.	Machining	Dry, Flooded and MQL
3.	Pressure for MQL (Psi)	60 and 110
4.	Feed (mm/min)	60
5.	Depth of hole (mm)	25
6.	Cutting fluid for MQL (ml/hr)	60 and 250

3. RESULTS AND DISCUSSION

3.1. Tool tip temperature

The analysis of tool tip temperature (°c) during dry, flooded and MQL drilling at 17.3 m/min, 30 m/min and 53.7 m/min speed is presented in Fig. 3 to Fig. 5 respectively. Fig. 3 shows the effect of the coolant – lubricant conditions on the tool tip temperature when performing MQL drilling of EN8 steel at the cutting speed of 17.3 m/min and constant feed of 60 mm/min. As can be seen from this figure, the flooded and MQL conditions provided better results as compare to dry drilling with respect to tool tip temperature; however, flooded condition has given the best results. From Fig. 3 it is observed that the MQL (250 ml/hr at 110 psi) condition significantly reduce the tool tip temperature and improve the tool life as compare to dry drilling and other MQL conditions.

Similarly at cutting speed of 30 m/min. and 53.7 m/min the MQL (250 ml/hr at 110 psi) condition reduced the tool tip temperature as compare to dry and other MQL conditions as shown in Fig. 4 and Fig. 5 In case of dry condition at cutting speed of 53.7 m/min the tool failure occurred after 20th hole. In this experiment, the MQL and flooded drilling

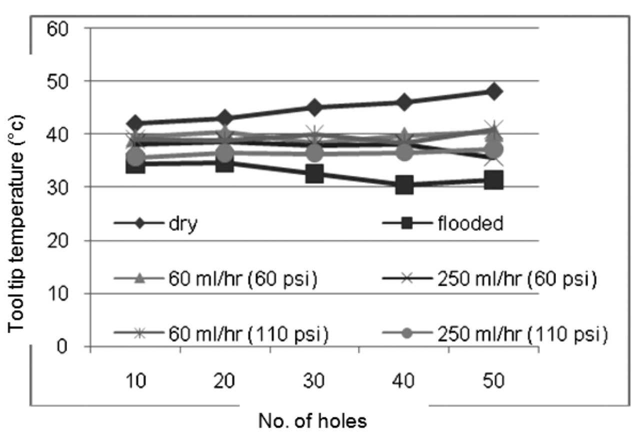

Figure 3: Tool tip temperature generated during dry, flooded and MQL drilling at speed of 17.3 m/min.

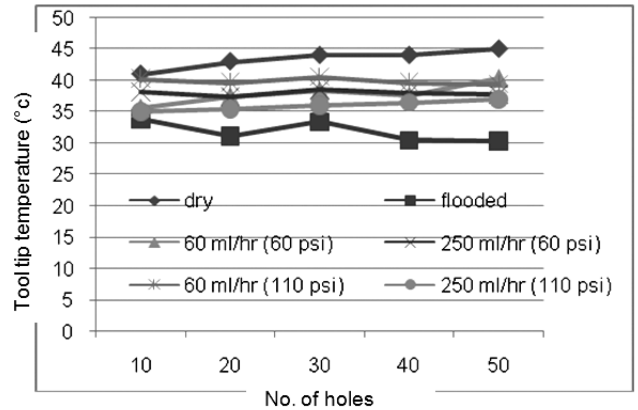

Figure 4: Tool tip temperature generated during dry, flooded and MQL drilling at speed of 30 m/min.

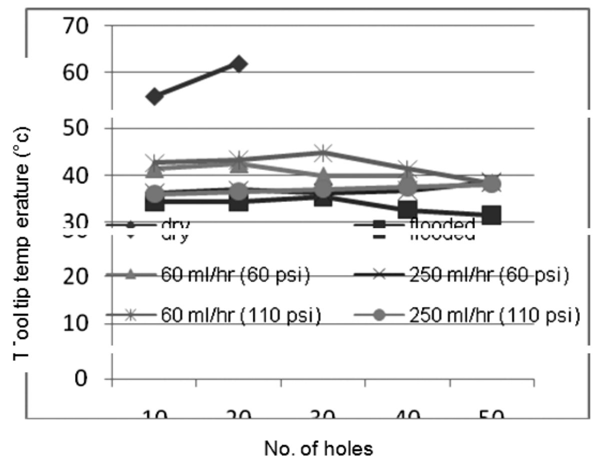

Figure 5: Tool tip temperature generated during dry, flooded and MQL drilling at speed of 53.7 m/min

conditions have sufficient cooling effect on the marching process, thus prolonging the tool life. It can be reasonably expected that a very small amount of oil is capable of reducing the friction between the tool–workpiece interfaces, and subsequently suppressing the temperature rise [4].

3.2. Hole Temperature

Better results by the MQL (250 ml/hr at 110 psi) condition reduced the values of hole temperature(°c) as compared to other MQL conditions and dry drilling at the cutting speed of 17.3 m/min, 30 m/min and 53.7 m/min shown in Fig. 6 to Fig. 8 respectively. However, it can be seen that dry drilling increased the temperature of the material adjacent to the hole surface, and caused to a notable decrease in the hardness of the material and generation of large plastic strains in the vicinity of the hole. But the

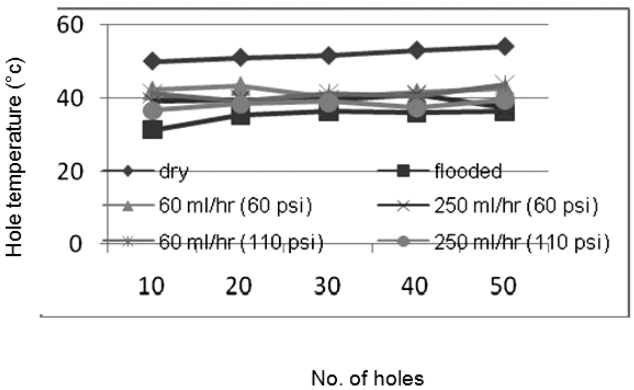

Figure 6: Hole temperature generated during dry, flooded and MQL drilling at speed of 17.3 m/min.

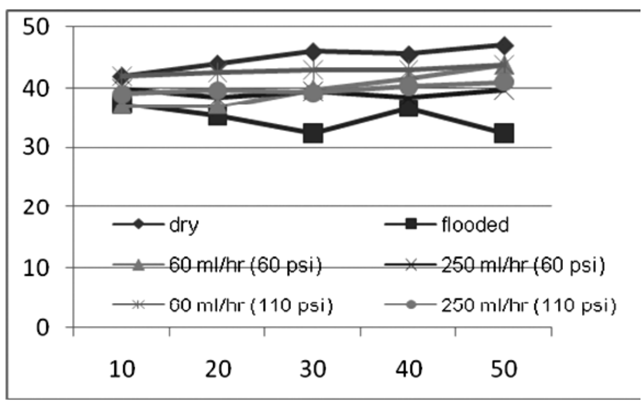

Figure 7: Hole temperature generated during dry, flooded and MQL drilling at speed of 30 m/min.

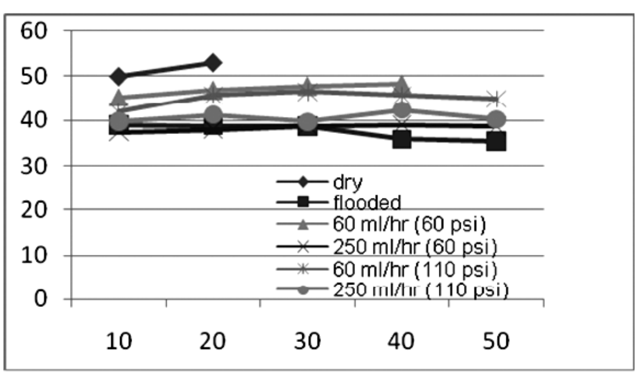

Figure 8: Hole temperature generated during dry, flooded and MQL drilling at speed of 53.7 m/min.

MQL was no softening of the material around the holes during the course of drilling. In turn, the amount of steel transferred to the drill flutes and BUE (built-up edge) formation at the drill's cutting edge were both significantly reduced shown in Fig. 9 to Fig.11. Similar results of better performance by MQL condition as compare to other coolant-lubricants conditions were also reported by [9].

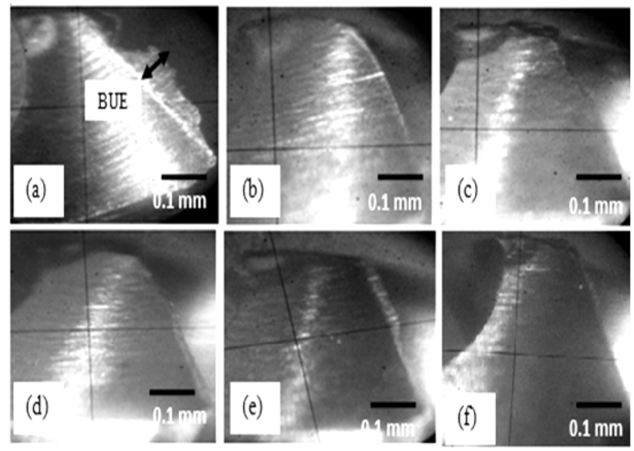

Figure 9: Optical micrographs showing the BUE (built-up edge) formation at the drill's cutting edge under different coolant-lubricant conditions at cutting speed 17.3 m/min. (a) Dry condition (b) Flooded condition (c) MQL {60 ml/hr at 60 psi} (d) MQL {60 ml/hr at 110 psi} (e) MQL {250 ml/hr at 60 psi} (f) MQL {250 ml/hr at 110 psi}.

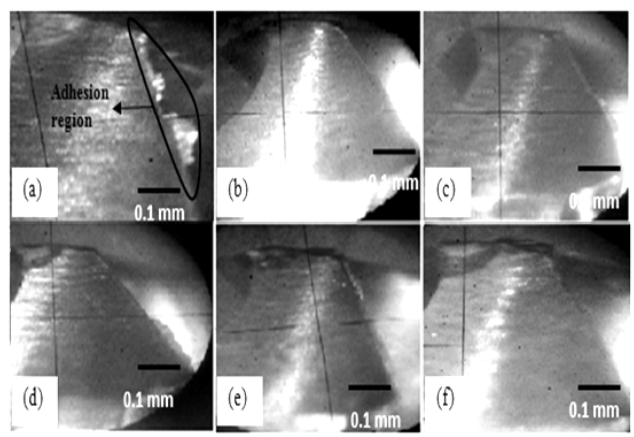

Figure 10: Optical micrographs showing the BUE (built-up edge) formation at the drill's cutting edge under different coolant-lubricant conditions at cutting speed 30 m/min. (a) Dry condition (b) Flooded condition (c) MQL {60 ml/hr at 60 psi} (d) MQL {60 ml/hr at 110 psi} (e) MQL {250 ml/hr at 60 psi} (f) MQL {250 ml/hr at 110 psi}.

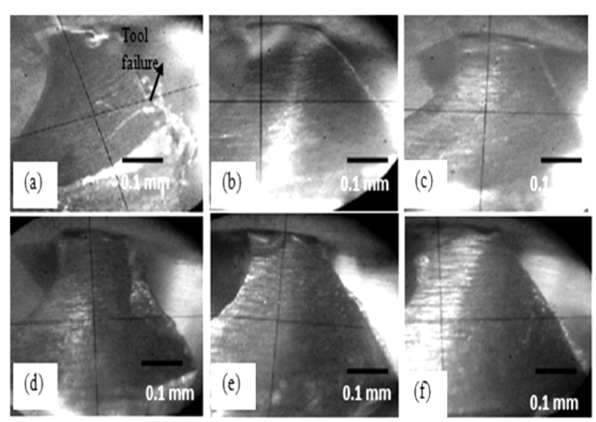

Figure 11: Optical micrographs showing the BUE (built-up edge) formation at the drill's cutting edge under different coolant-lubricant conditions at cutting speed 53.7 m/min. (a) Dry condition (b) Flooded condition (c) MQL {60 ml/hr at 60 psi} (d) MQL {60 ml/hr at 110 psi} (e) MQL {250 ml/hr at 60 psi} (f) MQL {250 ml/hr at 110 psi}.

4. CONCLUSIONS

Experiments and analyses were conducted to assess the efficiency of MQL drilling when applied to EN8 steel. The following conclusions can be drawn from the results presented:

- The maximum temperature generated in the workpiece during MQL drilling was lower than that observed in dry drilling, and comparable to flooded condition. The mechanical properties of the material adjacent to drilled holes, as evaluated through plastic strain and hardness measurements near the holes, revealed a notable softening in the case of dry drilling, but not for MQL drilling.
- MQL drilling provided a stable drilling performance, which was evident from the uniform torque and force patterns throughout the drilling cycles and also resulted in desirable machining characteristics, including a smooth hole surface and short chip segments
- The low COF (coefficient of friction) under MQL conditions restricted the temperature increase, which limited steel adhesion and no significant drill wear occurred.

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