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Experimental Investigation of Cutting Fluid Influence on Drilled Aluminum Part Quality

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Abstract. In the present study, an attempt has been carried out to investigate the effect of cutting fluid applications including dry, mist and flood drilling on the part quality during drilling of 6061-T6 aluminum alloy. The part quality criteria include the surface finish and burr size. A multi-factorial experimental design (DOE) and analysis was used. It has also been found that dry machining and mist machining can produce parts with quality comparable to those obtained in wet machining when using the optimal cutting conditions.

Introduction:

Statistical design of experimental method (DOE) is widely known as an efficient experimentation technique which has been applied to enable the designers to determine simultaneously the individual and interactive effects of a number of factors which might affect the output results in any design. Cozzens *et al.* conducted a similar cutting fluid study focused on single point boring. They study the role of cutting fluid, tool, and cutting conditions during boring process. The results indicated that the cutting fluid conditions (on, off, varied concentration and contamination) had no significant effect on surface texture, forces or built-up edge. Experimental research and analytical modeling was conducted to the effect of cutting fluid on thermal deformation and surface error [[1]]. The cutting fluid was found to have a significant effect on the predicted surface error. Sreejih [[1]] reported on the effect of dry machining, minimum quantity lubricant, and flooded coolant conditions during turning process of 6061 Al alloy with respect to cutting forces, surface roughness of machined workpiece and tool wear. It was found that if MQL properly employed can replace the flooded coolant. There are reports, which indicate that MQL in an end-milling process is very effective [1]. Davim et al. [1] studied the dry drilling of commercial purity aluminum (AA1050) compared with MQL drilling, for which an emulsion oil was applied at a rate of 250ml/h, and flooded drilling using the same fluid at a rate of 1200 l/h. No difference in hole surface roughness was observed between MQL and flooded drilling. Klocke and Eisenblaetter [1] reported the effect of MQL on drilling of a cast aluminum-9% silicon alloys (380Al) using a synthetic fluid supplied at rate of 10ml/h. They found that the holes displayed less surface roughness (25µm) with MQL when compared to dry drilling (45µm).

This paper presents an investigation into various methods of cutting fluid application with the objective of deriving the optimum cutting condition during drilling of 6061-T6 Al-alloys. The effect of dry machining, mist (*also called MQL*), and flooded coolant condition will be analyzed with respect surface roughness, hole quality and burr formation.

Experimental procedures

An experiments was performed to investigate the effect of different coolant application methods in drilling of aluminum alloy 6061-T6 plate with of 95BHN. Drilling experiments were carried out on HURON high speed 3-axis CNC vertical machining center using high speed steel twist drills. It should be mentioned here that a group of drills with the same batch were used throughout the tests to ensure uniformity of geometry and properties for the cutting tools. Drilling tests were done at different cutting speed and feed rates for various methods of coolant application modes, as shown in Table 1.

Table 1-Machining conditions

Type of machining	**Quantity and description of lubricant**
Dry	0 ml/h (without any form of lubrication and coolant)
MIST lubrication	Delivery pressure is 6 bar gauge; lubrication rate, 50 ml/h. the lubrication used was a vegetable oil
Flood lubrication	Water miscible mineral oil, Blasocut R, at concentration of 5% was used at flow rate of 5000 ml/h.
	Cutting Parameters
Material	6061-T6 (plate 200x40x3mm)
Tool	High speed twist drill-3/8 Stub drill bright Finish-118 point angle
Speed (m/min)	30, 60, 120, 180,240, and 300m/min
Feed rate (mm/rev)	0.15, 0.25, 0.35mm/rev.
Depth Of Cut	3mm

The surface roughness of holes under different cutting conditions was evaluated using R_a, R_q and R_t parameters using Mitutoyo SJ 400. These values were calculated at three places within each hole. Four holes of each set were measured to validate the values in each condition. The average value was used for analysis purpose in the present study. The sample from last holes drilled for each condition was sectioned in parallel to feed direction. These samples were ultrasonically cleaned in ethanol bath in order to investigate the surface texture of drilled hole using SEM for each case. The burr height has been obtained using Mitutoyo Height Gages. To measure the burr height, the gage indictor was put first on the datum surface at hole exit and then on the top of the burr. Hence, the distance between the two measurements is the burr height. At the same condition the measurements were done four times and then take the average value. The burr form was investigated using optical microscopy.

A 3^3 experimental design (DOE) concept has been used for experimentation. The factors and their levels are shown in Table 2. A total of 27 trials were carried out.

Table 2- Cutting parameters and their levels

No.	Factor	Notation	Unit	Level					
				Original			Coded		
				Low	Central	High	Low	Central	High
1	Cutting Speed	A	m/min	60	180	240	-1	0	1
2	Feed Rate	B	mm/rev	0.15	0.25	0.35	-1	0	1
3	Cutting Fluid	C		dry	mist	wet	1	2	3

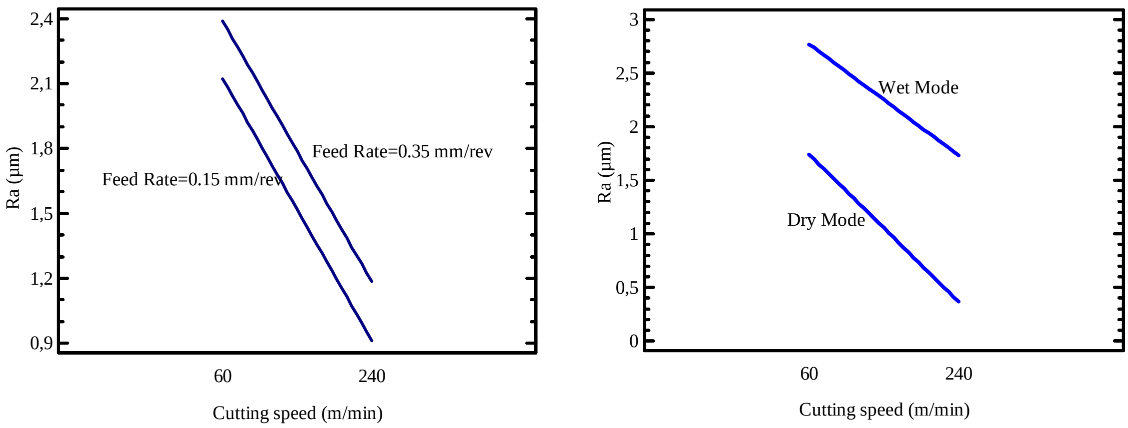
Results and Discussions

Surface roughness. Table (3) shows the ANOVA analysis for the surface roughness (Ra) data having a confidence level of 95%. In this table the most significant effects was correspond to the cutting speed (A) and cutting fluid (C) i.e. dry, mist, and wet drilling application modes. However, The effect of the feed rate (B) and two-level interaction effect of cutting speed and cutting fluid (AC), feed rate and cutting fluid (BC), cutting speed and cutting fluid (AB) as well as the three-level interaction effect of cutting speed, feed rate and cutting fluid (ABC) were all found to be insignificant.

Figure 1(a) exhibits the surface roughness (R_a) values of drilled hole measured parallel to the feed direction. From this figure, it is evident that with increase of the cutting speed, surface roughness (Ra) values decreases with all values of the feed rate. It was found also that the surface roughness increases with increasing the feed rate. However, it is very important that wet application was found to be have an adverse effect in the surface finish of hole with the all values of speed and feed given in this study since the surface roughness values of holes drilled in the wet drilling are almost one-and-half more than those drilled with mist and dry conditions, as shown in figure 1(b).

Table 3 Analysis of Variance (ANOVA) for surface roughness parameter (Ra) values

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*	Remakes
A:Cutting speed	6.5522	1	6.5522	53.36	0.0000	Signifiant
B:Feed Rate	0.32535	1	0.325356	2.65	0.1192	Not signifiant
C:Cutting Fluid	6.44405	1	6.44405	52.48	0.0000	Signifiant
AB	0.0000333	1	0.000033	0.00	0.9870	Not signifiant
AC	0.0867	1	0.0867	0.71	0.4107	Not signifiant
BC	0.0456333	1	0.0456333	0.37	0.5490	Not signifiant
Total error	2.45589	20	0.122795			
Total (corr.)	15.9099	26				
R-squared = 84.5637 percent R-squared (adjusted for d.f.) = 79.9328 percent						

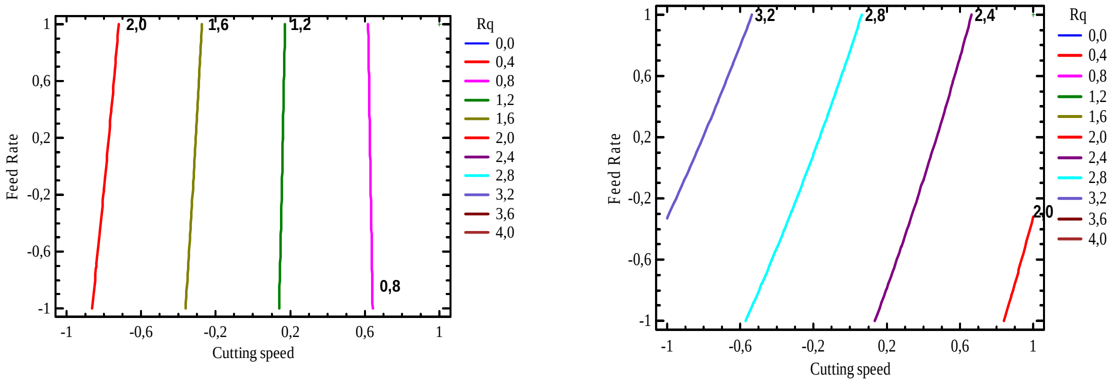


(a) **(b)**

Figure 1 Two-way diagram of the significant two-factor interaction between: (a) cutting speed and feed rate; and (b) cutting speed and cutting fluid modes on the surface roughness values (Ra in µm).

The contour plots of the surface roughness in feed rate-cutting speed plan for dry and wet drilling applications are shown in Figures 2(a) and (b), respectively. These figures clearly show that a best surface finish can be achieved for any level of feed rate when cutting speed is high (i.e. 240 m/min) and dry mode application (Fig. 2(a)). The final response surface equation for quadratic model of surface roughness was shown in the following equations:

Ra (in µm) = 1.419 – 0.603*Cutting speed + 0.134*Feed Rate + 0.35*Cutting speed^2 (1)



(a) **(b)**

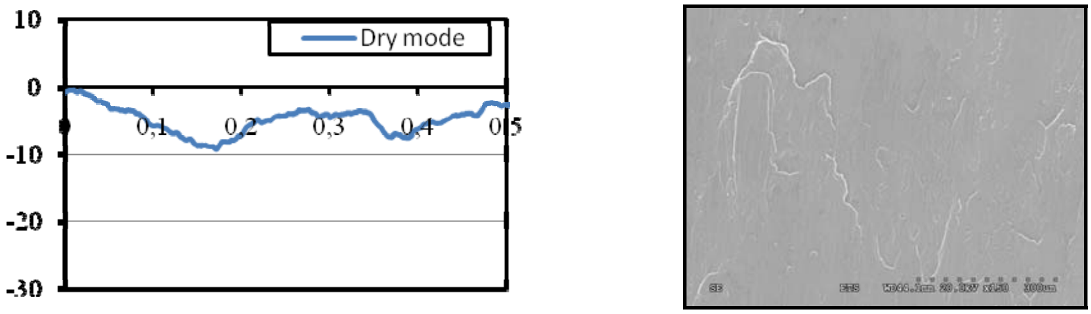
Figure 2 Surface roughness contours in cutting speed and Feed rate plan for (a) dry; and (b) wet drilling.

In order to explain the effect of cutting fluid applications on the finish quality of the hole surface, the surface textures of these surface were investigated using SEM. Figures 3(a), (b), and (c) show SEM photographs of typical sectioned drilled hole surface and corresponding surface traces for all three drilling conditions with the same cutting speed (120m/min) and feed rate (0.25mm/rev). As shown clearly, the dry and mist drilled holes exhibit smoother surface while the wet conditions produce heavily deformed zones on the side-wall with significant feed marks resulting in increased roughness.

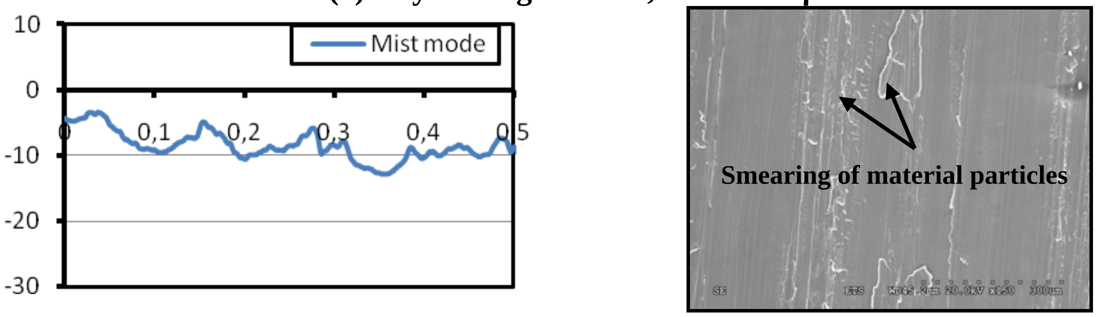
The adverse surface effects was found with wet drilling application may by explained in the following two possible ways: the first one is linked with post cut (drill removal) occurrences , such as chips dragging against the side-wall of the hole as the drill was being retracted. The surface textures clearly indicate that the surface was impaired during drill removal [2]. While the post cut phenomena were present with or without the cutting fluid, the severity of this effect was high with pressurized cutting fluid. The second effect may be attributed to the increased flow-ability of the work material at high temperatures under dry drilling condition and may have contributed to easier chip formation and thus improved the surface finish under dry conditions.

Burr Formation. The effect of different lubrication modes on the burr formation was quantified using optical microscopy. Figures 4(a) and (b) show two types of burr forms obtained on the exit of the drilled holes for 6061-T6 Al alloys using dry, wet, and mist lubrication modes. It was observed that the two types of burr form namely the transient and the uniform burrs. The transient type was obtained for dry condition with low cutting speed and cutting feed (Fig. 4(a)). The uniform burr was found also at low cutting speed and feed rate for wet and mist lubrication modes (Fig. 4(b)).

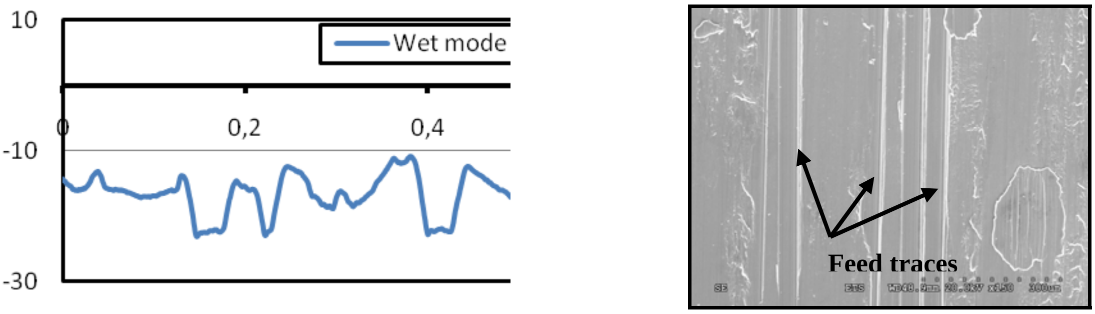
Figure 5(a) shows that the burr height decreases significantly with increase the cutting speed and feed rate. The burrs height is not influenced under various methods of cutting fluid applications at high cutting speed i.e. 240m/min as shown clearly in figure 5(b). However, at lower and moderate speeds, lubricated machining application (mist and wet) produces small size burrs compared to dry machining.



(a) Dry cutting at 150X; Ra= 1.353µm

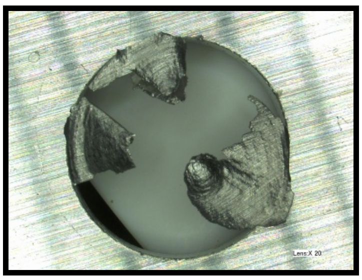


(b) Mist Cutting at 150X; Ra = 1.56 µm

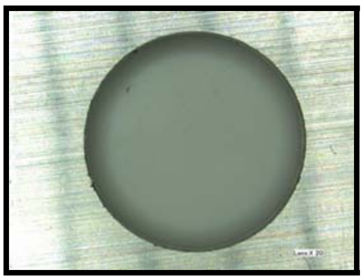


(c) Wet Cutting at 150X; Ra = 2.36 µm

Figure 3 Scanning electron microscope (SEM) of surface texture observed on the side walls of holes drilled with various methods of cutting fluid application with the same cutting speed (120m/min) and feed rate (0.25mm/rev).



(a)



(b)

Figure 4 Optical microscopy images showing burr form of 6061-T6 Al alloy with the same cutting conditions (speed 30m/min and feed =0.15mm/rev) for (a) dry mode; (b) wet mode application.

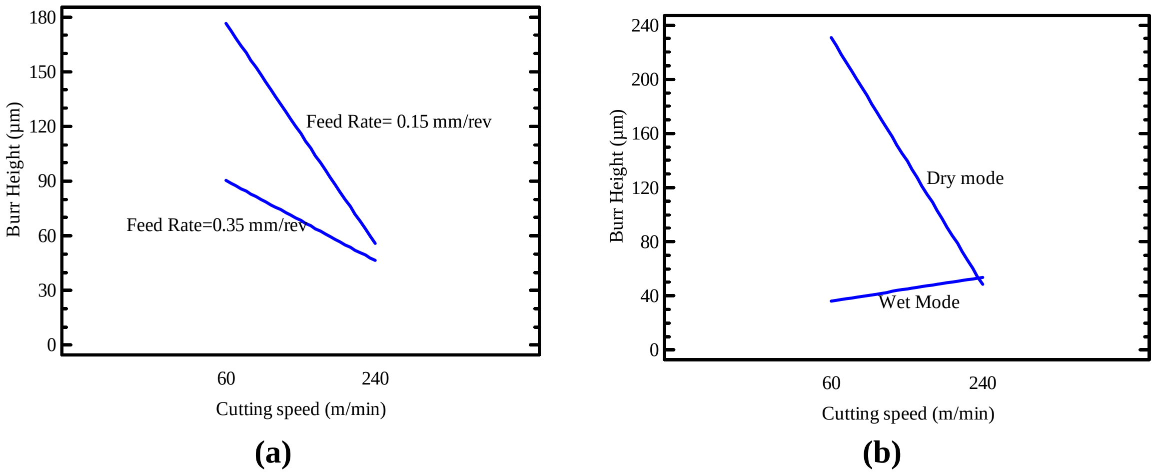


Figure 5 Two-way diagram of the significant two-factor interaction between (a) cutting speed and feed rate ; and (b) cutting speed and cutting fluid modes on the burr height values (in µm).

From the ANOVA results, it was concluded that the cutting fluid (C) and cutting speed (A) are the most significant effect followed two-level interaction effect of cutting speed and cutting fluid (AC) and feed rate (B). Next in significance are two-level interaction effect of feed rate and cutting fluid (BC); cutting speed and feed rate (AB).

The contour plots of the burr height in feed rate-cutting speed plan for dry and wet drilling applications are shown in Figures 6(a) and (b), respectively. These figures clearly show that a best burr formation can be achieved for any level of feed rate when cutting speed was high (i.e. 200 m/min) for both dry and wet mode applications. Contour plots can be used for selecting the cutting parameters for providing the given desired burr height. The final response surface equation for quadratic model of surface roughness was shown in the following equations:

Burr Height = 0.092 – 0.041*Cutting speed – 0.024*Feed Rate + 0.0192*Cutting speed*Feed Rate (2)

The normal probability plot of the residuals (i.e. error = predicted value from model – actual value) for the thrust force was investigated revealing that the residuals lie reasonably close to straight line, providing support that the factors mentioned in the model are only significant [5].

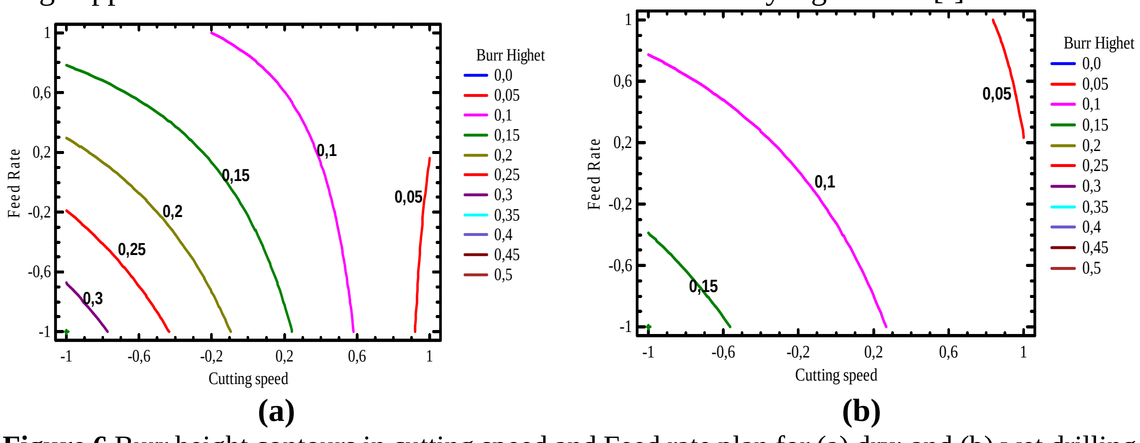


Figure 6 Burr height contours in cutting speed and Feed rate plan for (a) dry; and (b) wet drilling.

Conclusions:

In this work, the effect of lubrication (wet, mist and dry) on the quality of drilled 6061-T6 aluminum alloy was investigated using statistical methods. It is found that

- The use of cutting fluid allows minimizing or eliminating the burr formation but deteriorates the surface roughness. Better surface finish can be achieved for any level of feed rate when cutting speed is high (more than 200m/min) with dry mode application.

- Dry and MQL machining can produce parts with quality comparable to those obtained in wet machining when using the optimal cutting conditions.

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