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Effect Of Drilling Parameters On Quality Of The Hole

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ABSTRACT

This paper is based on an experiment with an aim to analyze the effects of drilling parameters on the quality of holes in aluminum alloy 2024-T3. Six variables are considered for analysis: the rotational speed of the bit, feed rate, the length and the state of the bit, the use of lubricant and the use of a pilot hole. Two metrics were measured to define the quality of the hole – the surface roughness and the hole conicality. The results obtained show that the improvement of the quality of the hole corresponds at a high rotational speed with a low feed rate. In addition, the use of new bit reduces the roughness value 3 to 4 times compared to an old one and reduces the conicality of the hole upto 2 times. Long bit increases the roughness value of 2.36 to 3.39 times according to the selected drilling speed, it also increases the angle of the hole conicality to 42%. The study results reveal that the use of a pilot hole will significantly improve the conicality of the hole and reduce the roughness value about 6%, while the use of two pilot holes decreases the roughness value to 12 %.

INTRODUCTION

The aluminum alloys are still extensively used today in aeronautical structures, mainly because of their low density and mechanical properties as compared to their weight. The components of the aeronautical structures are generally riveted assemblies of aluminum sheets leading to geometrical discontinuities and stress concentration zones. The risks of initiation and propagation of the fatigue cracks are located close to these zones. Drilling is the machining process used for manufacturing rivet holes, the rotational speed, feed rate, the bit length and state have significant effects on quality of the hole. This quality is a determining factor in the material's fatigue life. (Carter Ralph, 2005) have recently studied the effect of various aircraft production drilling procedures on the quality of the hole, they measured four metrics to define this quality: surface roughness, hole conicality, the number of large gorge marks, and the angle of those marks. They shown that the use of a pilot hole improve the quality of the hole but they did not quantify the impact of the use of two pilots hole and of lubricant on this quality. (Jang DY, 1996) have studied the surface residual stresses due to turning operations as a function of machining speed, feed rate, depth of cut, and tool geometry and coating. They shown that new bit should quickly and easily cut through the workpiece with little plastic deformation and that an old bit would likely expand the hole bore plastically, resulting in larger residual compressive hoop stresses when the stresses relax. No comparison of the quality of the hole between a new and an old bit was done. (Bannantine JA, 1990) have shown that an older bit would be more likely to be damaged, causing scoring of the bore surface and introducing stress concentrations and longer drilling time generate more heat in the bore, which may cause thermally induced plasticity and therefore tensile residual hoop stresses upon cooling, no comparison of surface

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roughness was done. In aeronautical fields where the material used is often an aluminum alloy, there is an advantage to drill at the place of the rivet - a hole of low diameter called a pilot hole - before machining the final diameter. This pilot hole becomes a guide towards drilling the final diameter hole, ensures better cooling and is also a good chip removal of the material which improves machining precision and quality of the hole. However, drilling of two holes obviously need more time and become expensive when thousands of holes need to be drilled. The main objective of this paper is to analyze the effects of drilling parameters, the state and the length of the bit on quality of the hole. This quality will be characterized by measuring the surface roughness and the 'conicality' of the hole.

2. Experiments:

2.1. Material choice:

The material used in this study is an aluminum alloy AERO TL 2024-T3. The mechanical properties of this alloy are given in table 1.

Table 1: Mechanical properties of aluminum alloy 2024-T3

Ultimate strength	476	MPa
Yield strength	378	MPa
Displacement	18.1	%
Elastic Modulus	72.22	GPa
Poisson's ratio	0.33	

The chemical composition is shown in table 2.

Table 2: Chemical composition of aluminum alloy 2024-T3.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	V	Zr	Other
0.09	0.27	4.45	0.61	1.34	0.02	0.17	0.02	0.01	0.00	0.05

2.2. Specimens preparation:

In order to analyze the influence of drilling parameters on the quality of the hole, four batches of specimens containing several different holes were prepared using a 5 KW vertical milling machine. A high strength steel tool (HSS) had been used to make the holes, drilling on rectangular plates of 150 x 50 x 6mm and 150 x 50 x 50mm.

- The specimens of the first batch contain holes drilled using a new short tool (13.5 cm in length) with constant rotational speed and a variable feed rate. It comprises also other drilled holes with constant feed rate and variable rotational speed. The objective is to show and quantify the effect of the rotational speed and variation of the feed rate on quality of the hole.
- The specimens of the second batch include holes drilled with new short and long tools (13.5 cm and 20 cm in length). It also contains other holes drilled using new and used bits. The objective is to analyze the effects of the bit length and state on the quality of the hole.
- The specimens of the third batch contained holes drilled with and without lubricant. All the holes were drilled with a new and short drill. The objective was to quantify the improvement of roughness by using lubrication.
- The specimens of the fourth batch contained holes drilled with and without the use of the pilot hole. The goal was to quantify the effect of the pilot hole on quality of the hole.

Figure 1 shows an example of drilled holes.

Fig. 1: Drilled holes.

2.3. Criterion choice of surface quality:

Surface qualities are related to the irregularities due to the machining process. These irregularities can be classified into three categories:

- Geometrical deviation: flatness, straightness, circularity and conicality.
- Waviness: geometrical irregularities such as the distance between two tops.

- Roughness: geometrical irregularity was such that the distance between two peaks should be between 0 and 0.5mm.

According to the ISO standards (ISO 4288, 1998), the selected standard criterion of surface quality is the arithmetic roughness value R_a. It is the most used parameter; it corresponds to the arithmetic mean of all the distances y_n between the midline and the profile as shown in figure 2.

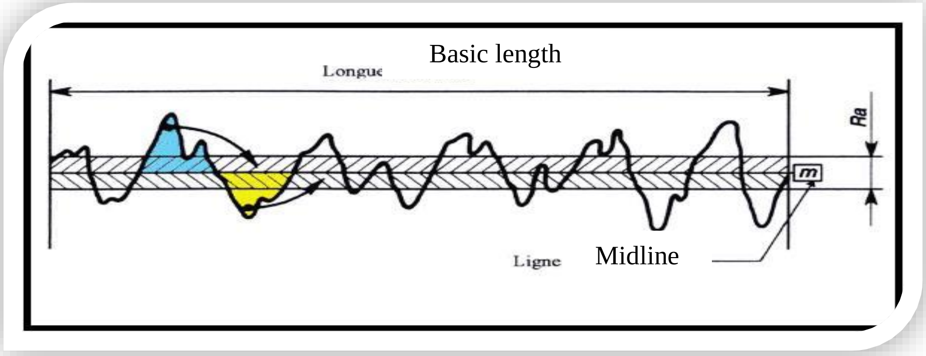

Fig. 2: Average arithmetic deviation "Ra".

Using the user's manual of surftes Sv-400 (Mitutoyo, 2006), this parameter is expressed mathematically by equation (1).

$$R_a = \frac{1}{L}\int_0^L |Y| dx = \frac{|Y_1| + |Y_2| + \ldots + |Y_n|}{n} \tag{1}$$

2.4. Roughness measurements:

The surface roughness apparatus used is a surftest Sv-400 shown in figure 3. This apparatus uses control by palpation. This method consists of the following - the surface profile is done by bringing the pin in contact with the measured surface, the oscillations are transmitted to a recording device which will transform them into a direct reader on a digital dial and make it possible to trace the profile-grams on the tapes.

Fig. 3: Surface roughness apparatus (surftest Sv-400)

All the roughness values given in this study represent an average of three measurements taken on four generating lines located at 90° from one another. We used different section for measurement each time, according to two generating lines.

2.5. Holes conicality measurements:

Based on experimental observation it is shown that the drilled holes are not cylindrical but have a conical form as shows it figure 4.

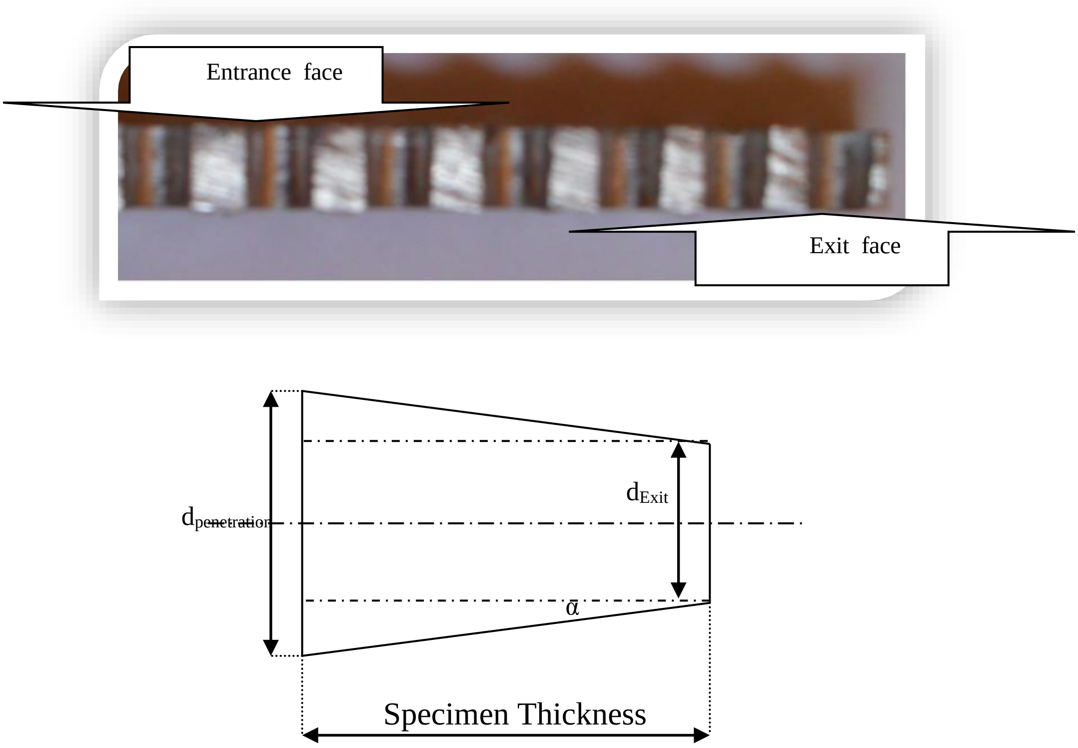

Fig. 4: Holes conacality

Using the S.E.M we measured the entrance and the exit diameters of the bit as shown in figure 5. (Elajrami, 2007) have shown that the hole drilling process affect the hole conicality. He compared results of fatigue life for different drilling process, he found that the residual stress induced by the drilling process and the hole conicality affect significantly the fatigue life but drilling parameters were not taken into consideration. He proposed the following equation to calculate the holes conicality:

$$tg\alpha = \frac{\left(d_{entrance} - d_{exit}\right)/2}{thickness} \tag{2}$$

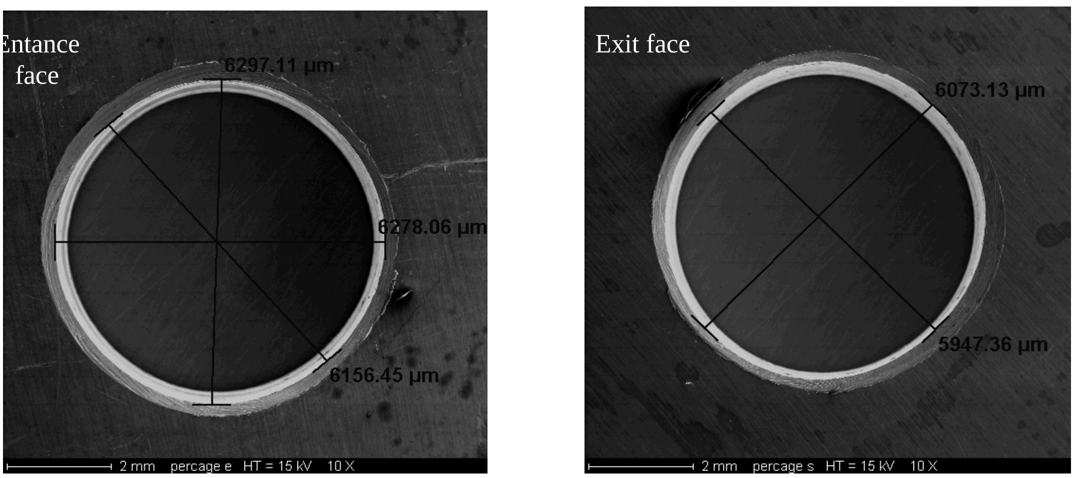

Fig. 5: Entrance and exit diameters measurement (SEM)

RESULTS AND DISCUSSION

3.1 Effects of rotational speed and feed rate:

The experimental tests carried out on holes of the first batch allowed us to plot the curves of the roughness variation according to rotational speed and feed rate as shown in figure 6. Three values of feed rate and three values of rotational speed were respectively used (0.31 mm/min; 0.68 mm/min; 0.8mm/min) and (11.47m/min; 15.7m/min; 22.29m/min). It was observed that the increase in the rotational speed reduces the roughness values. Inversely an increase in the feed rate generated higher roughness values because the higher applied pressure causes more deflection of the tip of the bit - although the bit does cut through the workpiece more quickly with a high feed rate. Thus, in order to obtain low roughness values it is necessary to increase the rotational speed and decrease the feed rate. The rotational speed and feed rate effects on holes conicality were found insignificant.

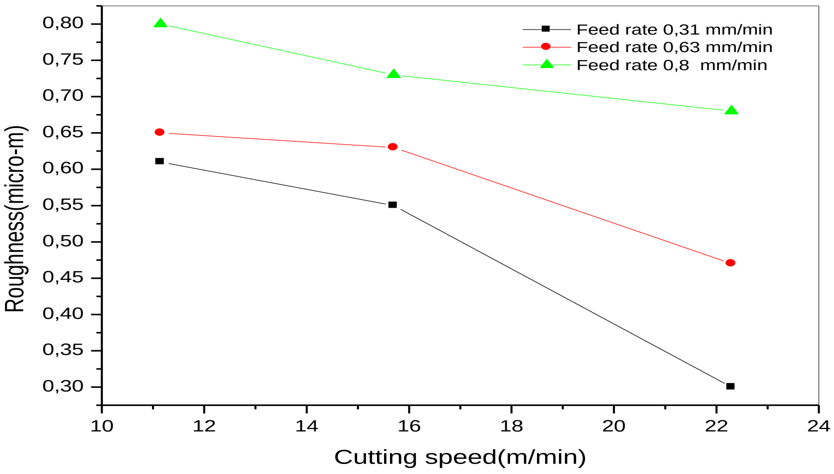

Fig. 6: Roughness variation according to the cutting speed and to the feed rate.

3.2. Length and state effects:

In order to show the length and state effects, two groups of holes were drilled with new and used short tool of 13.5 cm length. The rotational speeds used were (11.47m/min; 15.7m/min; 22.29m/min) and a constant feed rate equal to 0.16mm/min. Another set of holes were drilled with 13.5 and 20 cm in length. Figures 7 and 8 show a comparative roughness values.

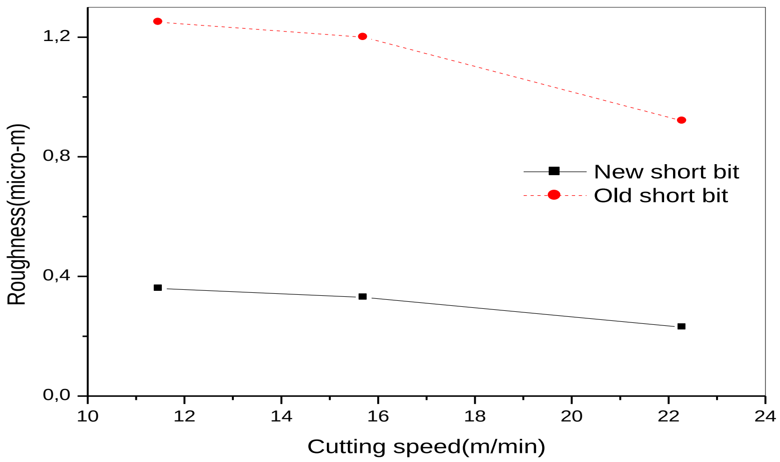

Fig. 7: Comparison of the surface roughness (new and worn bit)

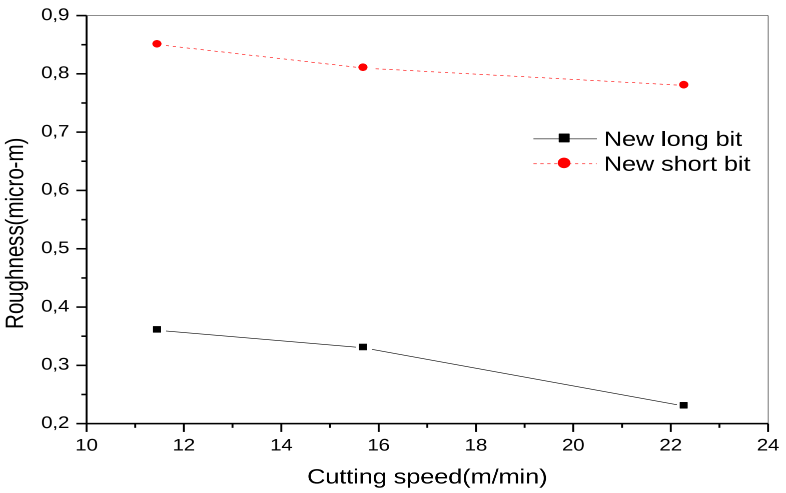

Fig. 8: Comparison of the surface roughness (short and long bit)

According to figure 7 the state effect analysis shows that for a rotational speed of 11.47 m/min, the use of new bit reduces the roughness values of approximately 3.47 times compared to a worn bit, 3.63 times for a rotational speed of 15.7 m/min and of 4 times for the highest rotational speed of 22.29 m/min. The state of the bit produced moderate holes conicality variability. Figure 8 shows the effect of the bit length on roughness. A difference in length of 6.5 cm (from 13.5 to 20 cm) increases the roughness value from 2.36 to 3.39 times according to the selected rotational speed. Therefore, the roughness was significantly affected by the bit length. The bit length also significantly affected conicality. The table 3 shows the calculated values of the conicality of the holes. We observed that the short bit decreases the conicality by 42%.

Table 3: Holes comicality

Drilling bits	Conicality angle
Long bit	1.334°
Short bit without pilot hole	0.560°
Short bit with one pilote hole	0.285°
Short bit with two pilote hole	0.213°

3.3. Lubricant results:

Figure 9 show the improvement of surface quality of the holes. These results were obtained using a rotational speed of 22.29 m/min and a feed rate of 0.16 mm/min.

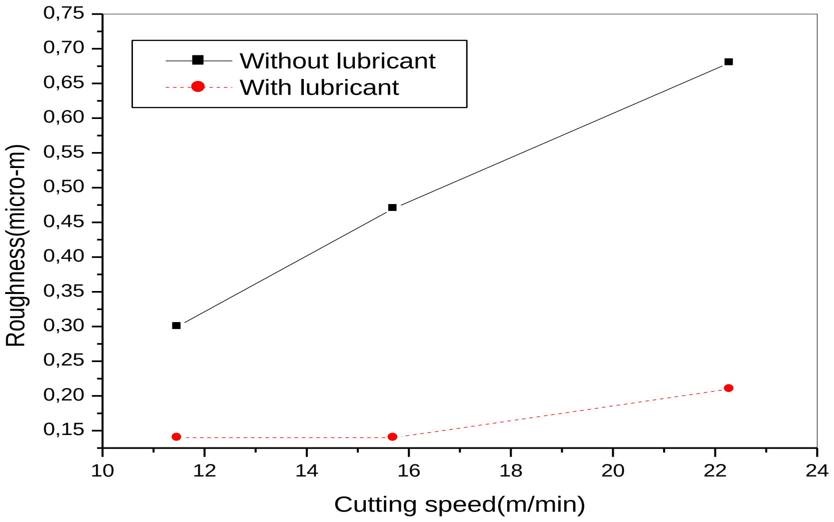

Fig. 9: Comparison of the surface roughness (with and without lubricant).

These parameters are selected in order to illustrate the lubricant effect clearly. We can deduce that the lubricant use reduces the roughness value to approximately 53%. This is due to the minimization of the bit friction with hole. The disadvantage in this case lies in the fact that the lubricants pollute the environment and can increase the production cost considerably.

3.4. The pilot hole effect:

From figure 10 we notice that a pilot hole decreases roughness value from approximately 6% while the use of two pilot holes reduces this value to about 12 %. The analysis of these observations shows that the use of the pilot hole is beneficial for the final surface quality due to the guiding of the bit. It ensures a better cooling and a good removal of the material coupons which improve the precision of cut, and the surface quality. The disadvantage is that the drilling of two holes obviously needs more time which can become very time and cost intensive when thousands of holes are to be drilled. In addition, the pilot hole significantly improves conicality (Table 3).

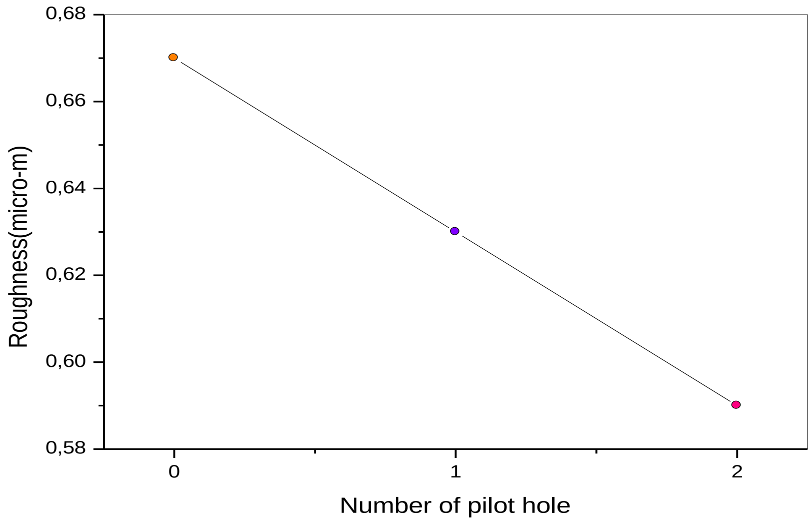

Fig. 10: Roughness values of drilled holes with and without pilot hole

This effect on conicality is likely due to three factors: the quick biting of the bit into the workpiece, the increased forward speed of the bit, and the guiding effect of the pilot hole. When drilling begins, the pilot hole provides a definite starting location for the bit, which can then instantly bite into the edges of the hole. Without a pilot hole the bit can wander across the surface before finding purchase, sometimes in the wrong location. Not only does the cutting start more quickly with a pilot hole, but it also proceeds more quickly because less material must be removed, reducing the opportunity for the bit to wobble at the beginning of the drilling, when the bit is least constrained. Once the bit enters the workpiece the pilot hole guides the bit throughout the remainder of the drilling, providing the bit with a predetermined path.

Conclusion:

The goal of this experimental study was to evaluate the influence of the drilling parameters, of the bit state and length, and of the pilot hole on quality of the hole in 2024-T3 aluminum alloy. The quality of the hole was quantified in two parameters: surface roughness and conicality. The results of the experiment allow us to reach the following conclusions:

- A drilled hole is conical, it is not cylindrical.
- When using a low feed rate, the surface roughness remains independent of the rotational speed.
- The increase in feed rate increases the values of the roughness when independent of the rotational speed.
- The increase in rotational speed leads to a reduction in the value of the roughness.
- Low value of surface roughness corresponds to a high rotational speed and to a low feed rate.
- The bit state affects the roughness surface of the hole. New bit reduce the values of the roughness 3 to 4 times compared to a worn one.
- The bit length produced a significant difference in quality of hole. A difference in length of 6.5 cm increases the values of the roughness 2.36 times to 3.39 times according to the selected rotational speed and increases the hole conicality of 42%.

- The use of the pilot hole improved quality of the hole. It reduces the values of the roughness approximately to 6% while the use of two pilot holes reduces the values of the roughness to 12%.

These conclusions presented here may be used to optimize the parameters of the drilling of holes and thus improve the fatigue life of rivet holes for future aircraft manufacture.

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