

Effect of Drilling Parameters on Hole Quality

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Abstract— The present paper is an experimental study aiming to analyze the effects of drilling parameters on hole quality in aluminum alloy 2024-T3. Six variables are considered: 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 hole quality: surface roughness, hole conicality. The results obtained show that the hole quality improving 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 hole conicality to 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 hole angle conicality of 42%. The study results reveal that the use of a pilot hole will significantly improves conicality and reduces the roughness value about 6% while the use of two pilot holes decreases the roughness value of 12 %..

Keywords— Drilling; rotational speed; feed rate; bit length; hole quality.

I. INTRODUCTION

THE aluminum alloys still massively used today in the aeronautical structures mainly because of their low density and their mechanical properties compared to their weights. 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 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 estate have significant effects on hole quality. This quality is a determining factor in the material fatigue life. Drill bit has a complex geometrical helical shape and is relatively flexible along its axis[1]. New bit should quickly and easily cut through the work piece with low plastic deformation, with no burs nor notches or other damage and thus it gives a good surface finish of rivet hole[2]. A used drill bit would likely expand the hole plastically resulting in higher residual compressive stresses[3]. In the aeronautical field where the material used is often an aluminum alloy, it is advantageous to drill in 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 for the drill of the

final diameter hole ,it ensures better cooling and a good chip removal of the material which improves machining precision and hole quality. However, drilling of two holes need obviously more time and excessive cost which is a great preoccupation when thousands of holes are to be drilled. In this regards, the main objective of this paper is to analyze the effects of the drilling parameters, the state and the length of the bit on hole quality. This quality will be characterized by measuring the surface roughness and the hole ‘conicality’.

II. EXPERIMENTAL CONDITION

A. Material properties

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 I 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

B. Specimens preparation

In order to analyze the influence of drilling parameters on hole quality, four batches of specimens containing several different holes were prepared using a 5 KW vertical milling machine. A high strength steel tool (HSS) has been used to perform the holes drilling on rectangular plates of 150x50x6mm and 150x50x50mm.

- 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 rateand variable rotational speed. The objective is to show and quantify the effect of the rotational speed and feed rate variation on hole quality.
- 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 hole quality.
- The specimens of the third batch contain holes drilled with and without lubricant. All the holes were drilled with new short drill. The objective is to quantify the improvement of roughness by using lubrication.

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The specimens of the fourth batch contain holes drilled with and without the use of the pilot hole. The goal is to quantify the effect of the pilot hole on hole quality. Figure 1 shows an example of drilled holes.

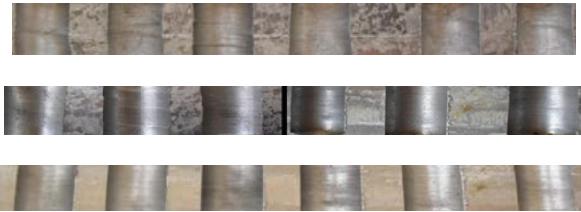


Fig. 1 Drilled holes

C. Criterion choice of surface quality

Surface qualities are related to the irregularities due to 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 irregularities such that the distance between two peaks which should lie between 0 and 0.5mm. According to the ISO standards [4], 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.

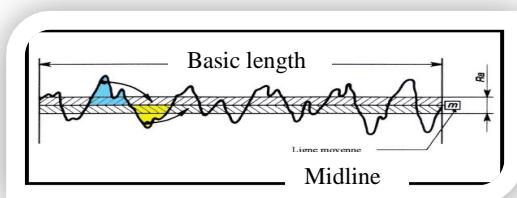


Fig. 2 Average arithmetic deviation "Ra"

This parameter is expressed mathematically by equation

(1).[5].

$$R_a = \frac{1}{L} \int_0^L |Y| dx = \frac{|Y_1| + |Y_2| + \dots + |Y_n|}{n} \quad (1)$$

III. EXPERIMENTAL RESULTS

A. 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 in following the surface profile using a 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 makes 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 taken measurements taken on four generating lines located at 90° from one another. We use at each time a different section for measurement according to two generating lines.

B. 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.

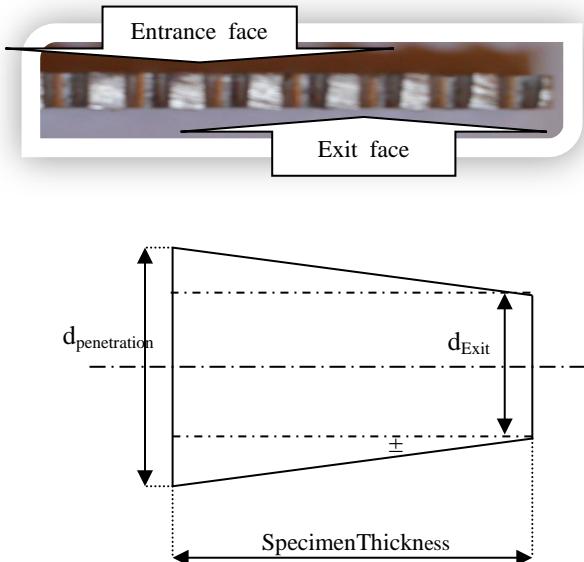


Fig. 4 Holes conicality

Using the S.E.M for measuring the entrance and the exit diameters of the bit as shown in figure 5, the holes conicality can be calculated by the following equation [6]:

$$\tan \alpha = \frac{(d_{\text{entrance}} - d_{\text{exit}}) / 2}{\text{thickness}} \quad (2)$$

C. Effect of rotational speed and feed rate

The experimental tests carried out on holes of the first batch allowed to plot the curves of the roughness variation according to rotational speed and federate as shows it 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 can be observed that the increase in the rotational speed reduces the roughness values. Inversely the feed rate increase generates higher roughness values because the higher applied pressure likely causes more

deflection of the tip of the bit. Although the bit does cut through the work piece more quickly with a high feed rate. Thus 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.

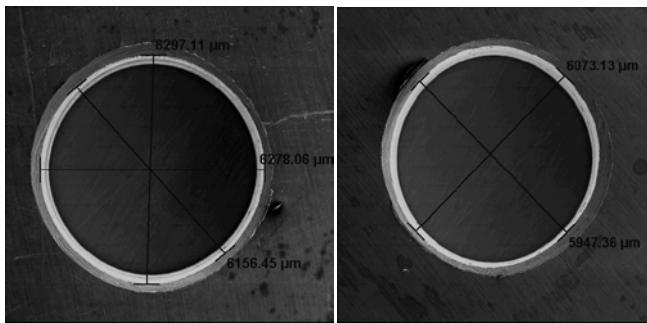


Fig. 5 Entrance and exit diameters measurement (SEM)

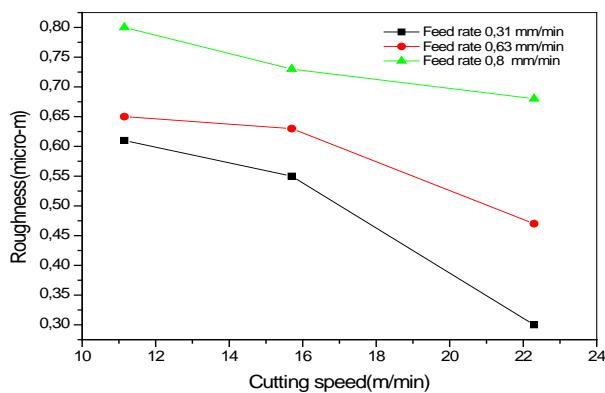


Fig. 6 Roughness variation according to the cutting speed and to the feed rate.

D. Length and state effects

In order to show the length and state effects, two groups of holes have been drilled respectively with new and used short tool having 13.5 cm in length. The rotational speeds used were (11.47m/min; 15.7m/min; 22.29m/min) and a constant feed rate equal 0.16mm/min. Another set of holes were drilled with respectively 13.5 and 20 cm in length. Figures 7 and 8 show a comparison roughness values. According to figure 7 the state effect analysis shows that for 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, table 3 show the calculated holes conicality values. We can observed that the short bit decreases the conicality of 42%.

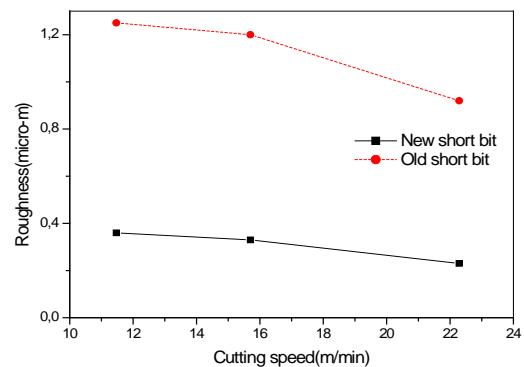


Fig. 7 Comparison of the surface roughness (new and worn bit)

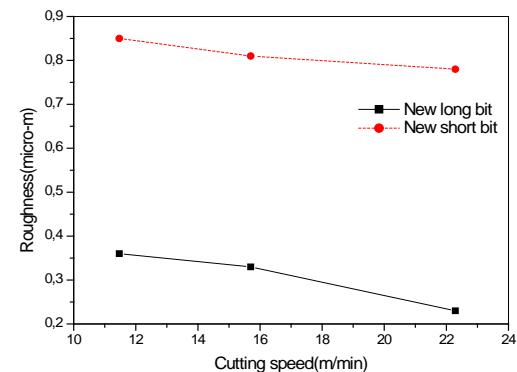


Fig. 8 Comparison of the surface roughness (short and long bit)

E. Lubricant results

Figure 9 show the improvement of holes surface quality. These results were obtained using a rotational speed of 22.29 m/min and a feed rate of 0.16 mm/min. These parameters are selected in order to illustrate very well the lubricant effect. 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.

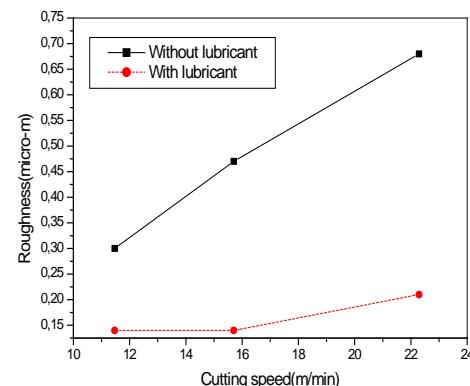


Fig. 9 Comparison of the surface roughness (with and without lubricant)

F. 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 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.

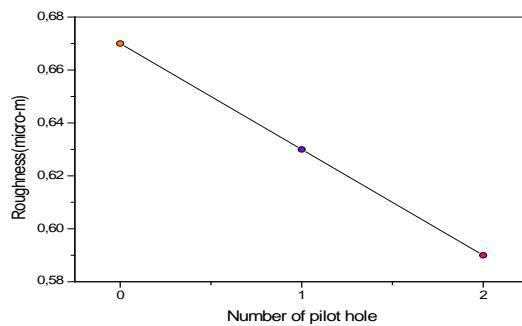


Fig. 10 Roughness values of drilled holes with and without pilot hole

The disadvantage is that the drilling of two holes needs obviously more time which can become a great preoccupation with time and cost when thousands of holes are to be drilled. In addition, the pilot hole significantly improves conicality. In table 4 are shown the conicality values. This effect on conicality is likely due to three factors: the quick biting of the bit into the work piece, the increased forward speed of the bit, and the guiding effect of the pilot hole. When the 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 work piece the pilot hole guides the bit throughout the remainder of the drilling, providing the bit with a predetermined path.

IV. CONCLUSION

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

- A drilled hole is conical, it is not cylindrical.
- In the case of using low feed rate, the surface roughness remains independent to the rotational speed.
- Independently of the rotational speed, the increase in feed rate increases the roughness values.
- The increase in rotational speed leads to a reduction in the roughness values.

- 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 roughness values 3 to 4 times compared to a worn one.
- The bit length produced a significant difference in hole quality. A difference in length of 6.5 cm increases the roughness values of 2.36 times to 3.39 times according to the selected rotational speed and increases the hole conicality of 42%.
- The use of pilot hole improved hole quality. It reduces the roughness values of approximately 6% while the use of two pilot holes reduces the roughness values to 12%.

This conclusions presented here-in may be used to optimizing the hole drilling parameters and improving the fatigue life of rivet holes for future aircraft manufacture.

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