Optimisation of Drilling Parameters of Rivet Holes with the Design of Experiments Method

Mohamed ELAJRAMI, Ramzi MILOUD, and Farouk. B. BOUKHOULDA

Abstract— much of the structural loading in an aircraft is transferred through fuselage skin panels by way of riveted fastener holes at lap joints. The most popular material for this application is aluminum. The rivet holes produce regions of concentrated stress where cracks can form and grow. The drilling parameters of rivet holes such as the rotational cutting speed, feed rate and the length of the bit affect significantly the holes roughness. In this paper, we utilise the experimental design method to investigate the effect of these parameters in order to achieve an optimisation of the machining parameters to obtain a good holes surface quality. A mathematically model for the minimisation of the holes roughness values will be proposed.

Keywords— Machining; rotational speed; feed rate; bit length; design of experiments method.

I. Introduction

THE method of experimental design has been used in industry for determining factors that are most important in achieving useful goals in a manufacturing process [1]. These factors, under the designer's control, are varied over two or more levels in a systematic manner. Experiments are then performed, according to an orthogonal array to show the effects of each potential primary factor; thus allowing us to perform an analysis that will reveal which of the factors are most effective in reaching our objective and how these factors should be adjusted to optimize it. In this work we apply the method of experimental design for the optimisation of drilling parameters in order to obtain a good holes surface quality. 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 e state have significant effects on hole quality [2]. This quality is a determining factor in the material fatigue life. For example, 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 [3]. A used drill bit would likely expand the hole plastically resulting in higher residual compressive stresses [4]. The purpose of this study is optimise the drilling parameters in order to achieve a good surface finish. We will take into consideration the following parameters: The rotational cutting speed, feed rate, the length of the bit. The effects of each parameter on surface roughness will be shown.

Mohamed.ELAJRAMI, Laboratry of Mechanical Solids and Structures, University of SidiBel Abbes –BP 89 BenM'Hidi City- SidiBel Abbes 22000 - Algeria . phone:+213556158110; fax:+21348575412; (e-mail:eladjrami_mohamed@yahoo.fr)

Ramzi MILOUD, Laboratry of Mechanical Solids and Structures, University of SidiBel Abbes –BP 89 Ben M'Hidi City- SidiBel Abbes 22000 -Algeria (e-mail: mamiloud@yahoo.fr).

Farouk.BOUKHOULDA, Laboratry of Mechanical Solids and Structures, University of SidiBel Abbes,–BP 89 Ben M'Hidi City- SidiBel Abbes 22000 -Algeria (e-mail: boukhoulda_22000@yahoo.fr).

II. Experiments Condition

A. 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 I.

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. Method

In order to analyze the influence of drilling parameters on holes roughness, 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. We will consider that the variation of the roughness as a function of three parameters: the rotational cutting speed, feed rate and the length of the bit. Our objective is to minimize the roughness values of holes surfaces. The method of experimental design is suitable method that can rapidly optimise the varying parameters to get a desired outcome. Two values of rotational speed, of feed rate and two lengths were used in the drilling process.

C. Criterion choice of surface quality

Surface qualities are related to the irregularities due to machiningprocess. 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 [5], 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 1.

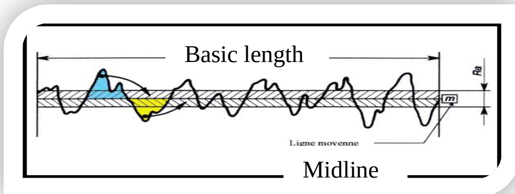

Fig. 1 Average arithmetic deviation "Ra"

This parameter is expressed mathematically by equation (1). [6].

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

D. Roughness measurements

The surface roughness apparatus used is asurftest Sv-400 shown in figure 2.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. 2 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.

III. Results And Discussion

Table II represents the matrix of the studied phenomena.

It contains all the possible combinations obtained with the three parameters (rotational speed, feed rate and the length of the bit), each one of them with two levels. In table III, we have the coefficients of the factors and their interactions.

TABLE II
Combinations Obtained With The Three Parameters (Rotational Speed, Feed Rate And Length Of The Bit)

Rotational cutting speed (S_1) (m/min)	Feed rate (S_2) (mm/min)	The length of the bit (L) (cm)	Roughness (R_a) (µm)
11.147	0.31	13.5	0.61
22.29	0.31	13.5	0.3
11.147	0.8	13.5	0.8
22.29	0.8	13.5	0.68
11.147	0.31	20	1.1
22.29	0.31	20	1.03
11.147	0.8	20	1.75
22.29	0.8	20	1.8

TABLE III
Coefficients List Of The Considered Drilling Parameters

	1	2	3
1	rugosité	Coeff. SC	Std. Err.
2	Constant	0,99375	0,02375
3	S1	-0,07125	0,02375
4	S2	0,23375	0,02375
5	L	0,39625	0,02375
6	S1*S2	0,0237499	0,02375
7	S1*L	0,0362499	0,02375
8	S2*L	0,09125	0,02375
9			
10	N = 8	Q2 =	0,841
11	DF = 1	R2 =	0,998
12		R2 Adj. =	0,983
13			

We can see that the most influent factor is the length of the bit (0.39625) followed closely by the feed rate (0.23375). The coefficient of the rotational speed is (-0.07125). Then come in decreasing order the length of the bit/feed rate interaction (0.9125), the rotational speed/length of the bit interaction (0.0362499) and finally the rotational speed/feed rate interaction (0.0237499). These results are comforted by figure 3 and 4.

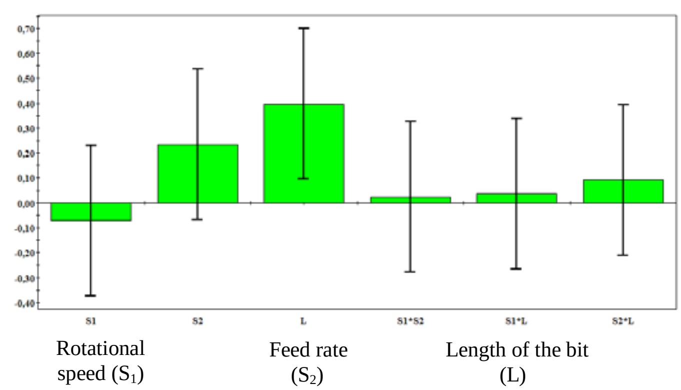

Fig. 3 Effect for roughness (R_a)

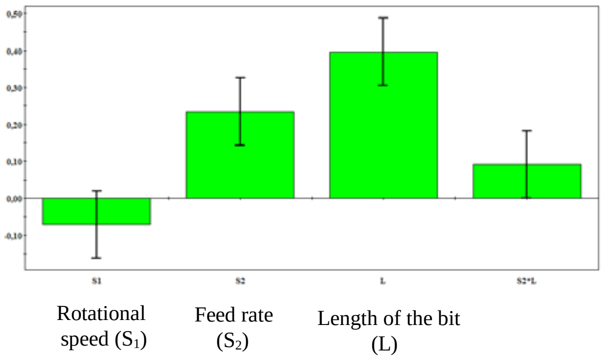

Fig 4 Interaction effect of feed rate and length on roughness

To further our investigation we consider the prediction plot (Figure 5) which displays the variation of the roughness (R_a) with respect to the considered factors while they vary from one level to another.

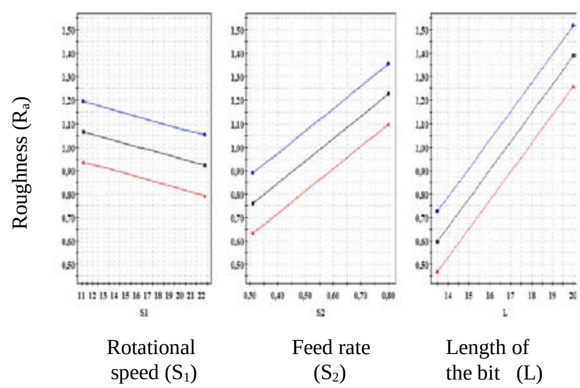

Fig. 5 Prediction plots for the two levels

It can be seen that roughness is a decreasing function of the rotational speed while it is an increasing one with respect to feed rate and to the length of the bit. These results are quite interesting compared to the one obtained by varying only one parameter at a time; as they take into consideration the interactions and this an originality of this work. Once we have performed the parameters analysis, we can tackle the optimisation problem which is our main objective. This will be achieved through the use of the contour plots shown in Figure 6. To minimize the values of roughness (R_a) we should choose the rotational speed of level 2, while those of the feed rate and of the length of level 1.

Finally, these results have allowed us to obtain a mathematical model for the minimisation of the holes roughness values through the optimisation of the choice of the drilling parameters. By equation 2, we can calculate the values of roughness as a function of the drilling parameters (rotational speed (S1), feed rate (S2) and the length of the bit (L)):

$$R_a = 0.99375 + (-0.07125)S_1 + (0.02375)S_2 + (0.39625)L \qquad (2)$$

S_1 : Rotational cutting speed ; S_2 : Feed rate ; L : Length of the bit

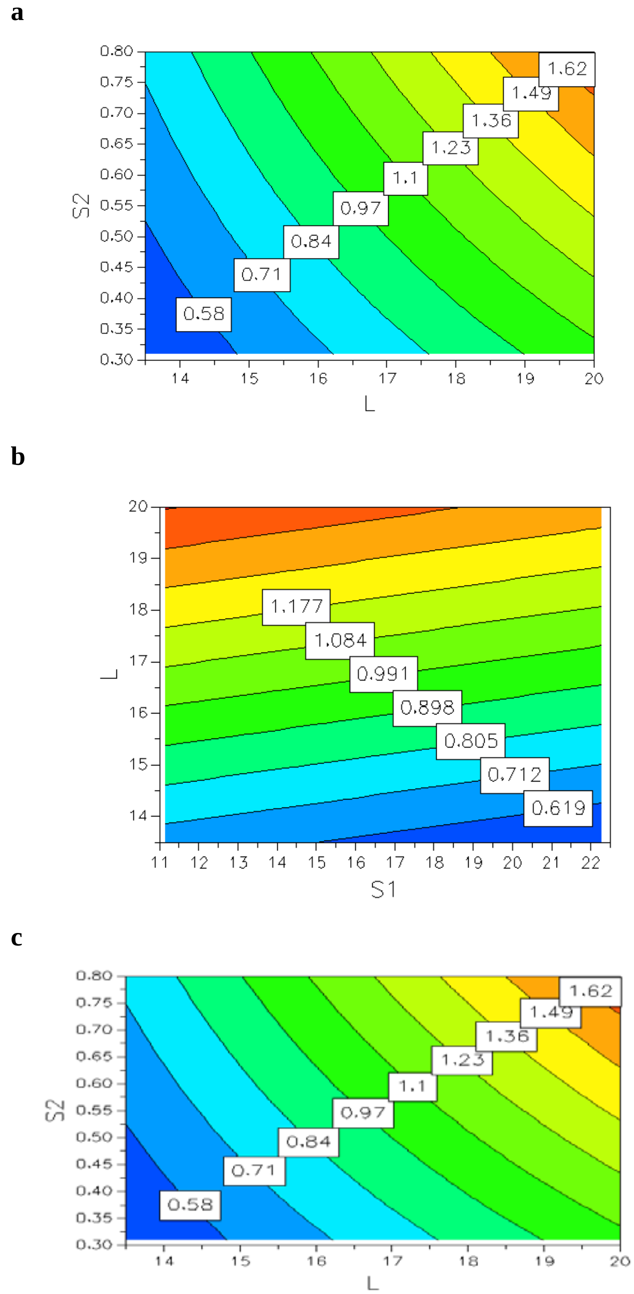

Fig. 6 Contour plots (a) contour plot for interaction effect of rotational speed

(S_1)/feed rate (S_2) (b) contour plot for interaction effect of rotational speed

(S_1)/length of the bit (L) (c) contour plots for interaction effect of feed rate

(S_2)/length of the bit (L)

IV. Conclusion

The main objective of this work was to optimize the drilling parameters to achieve at a good holes quality in 2024-T3 aluminum alloy, especially to minimize the values of surface roughness. The design of experiments method proved again to be power full and judicious method when there is a need to have a whole grasp of a given phenomenon as it takes into account all the drilling parameters and their interactions. In this case it allowed us to quantify the effects of the rotational cutting speed and the feed rate and the length of the bit upon the roughness values. Furthermore, using this analysis, a mathematically model was proposed to optimise the drilling parameters by determining which speeds and length values give a minimum value of the roughness R_a.

REFERENCES

[1] Taguchi G, Konishi S. Othogonal arrays and linear graphs. Tools for quality engineering. Allan Park, MI: ASI , 1987.
[2] Carter Ralph, W., Steven Johson, W., Toivonen, P., Makeev, A., Newman, J.C. Effect of various aircraft production drilling procedures on hole quality. International journal of fatigue – Elsevier, 2005, PP 1-8.
[3] Jang DY, et al. Surface residual stress in machined austenitic stainless steel. Wear 1996; 194(1-2); 168-73.
[4] Bannantine JA, Comer JJ, Handrock JL. Fundamentals of metal tiredness analysis. Englewood Cliffs, NJ: Prentice Hall; 1990.
[5] ISO 4288 1998, Geometrical product specifications. Surface texture: profile method, Rules and Procedures for the Assessment of Surface Textures, 1998, p. 20.
[6] Mitutoyo, surfatestformtracer, user' smaunalseries 2006, No.1178.