DETERMINATION OF PARAMETER EFFECTS IN THE DRILLING PROCESS OF ALUMINIUM 5083-H111 MATERIAL BY RESPONSE SURFACE METHOD

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Abstract

Drilling has an essential place in machining processes. Therefore, optimizing the parameter levels used in drilling is valuable regarding process quality. The optimization process can be carried out to minimize the thrust force. An experimental study was conducted to determine cutting parameters' effects on thrust force. This study optimized cutting parameter levels based on the forces that occur during drilling in aluminium AA5083 H111 alloy material. Cutting speed, feed rate, and cooling type were selected as cutting parameters with three levels. These are cutting speeds of 80, 100, and 120 m/min, feed per tooth 0.06, 0.09, and 0.12 mm/tooth, and cooling types are dry, air cooling, and liquid cooling. The optimization process was carried out with the response surface method. The effects of the parameters on the cutting force were found by analysis of variance.

Keywords: Thrust force, drilling, aluminium alloy, response surface method, optimization

1. INTRODUCTION

It is known that aluminium alloys are widely preferred in many areas, such as the aircraft industry, space and aviation, healthcare sector, and computer industry due to their lightness, corrosion resistance, and easy shaping. Therefore, the machinability of aluminum materials is important. By determining the optimum conditions, it will save both energy, time and cost. Some examples of studies conducted in the literature are presented below.

One study investigated the effect of drilling parameters and carbide drill bits on Aluminium 5083 H116 alloy. The study found that increasing feed rate led to a significant increase in thrust force and burr height, while increasing cutting speed adversely affected drill bit temperature [1]. A study used a multi-spindle drill head to perform multi-hole simultaneous drilling on Aluminium 5083. It investigated thrust force, hole quality, burr and chip formation, and post-machining tool conditions under different drilling parameters [2]. An investigation into the effects of cryogenic treatment on the machinability performance of the 5083 aluminum alloy found that cryogenic treatment increased thrust force during drilling but improved surface quality [3]. Techniques such as artificial neural networks, genetic algorithms, and response surface methodology are utilized for predicting and optimizing the machining process [4-6].

Aluminium alloys have become frequently preferred among many new composite and alloy materials due to their lightness, durability, and physical properties. These alloys can be used primarily in the automotive, aircraft industry, maritime, and construction sectors. With the use of aluminium alloys in these sectors, the need for drilling holes in the use of fasteners encountered in the manufacturing phase of these sectors has increased significantly [7].

This study aims to contribute to the insufficient literature on the drilling process of Aluminum 5083-H111 alloy and to contribute to the increase in the use of aluminum alloys, which are defined as lightweight, more machinable, economical, and durable materials.

2. MATERIALS AND METHOD

Aluminium 5083 H111 alloy used in the study is often preferred in the maritime and space sectors because it is light and highly corrosion resistant. Some chemical properties of aluminium 5083 H111 alloy are shown in **Table 1**, and mechanical properties in **Table 2**.

Table 1 The chemical content of the workpiece [8]

Element	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Si**	**Ti**	**Zn**	**Other**
%	0.05-0.25	0.1	0.4	4-4.9	0.4-1	0.4	0.15	0.25	0.15

Table 2 Mechanical properties for the workpiece [8]

Yield Strength	Ultimate Tensile Strength	Elongation	Hardness
228 MPa	317 MPa	16%	85 HB

The experiments were conducted in the CNC vertical machining center of the Taksan TMC-700 V brand model in the SAU Mechanical Engineering Laboratory. This machining center has a FANUC (O-M Series) control panel. Force data was collected with ESIT AX3 load cell, NI cDAQ-9188 data acquisition unit, NI 9237 module and Flexlogger software. The parameters and levels used in the experiments are given in the **Table 3**. TiAlN coated HSSE-Co5 was used as a working tool.

Table 3 Parameters and levels

Parameters	Symbol	Levels		
Cutting speed (m/min)	*Vc*	80	100	120
Feed per tooth (mm/tooth)	*fz*	0.06	0.09	0.12
Cooling type		Dry	Air	Liquid

The technical specifications of the working tool TiAlN coated HSSE-Co5 are as in the **Table 4**.

The response surface method is created with the help of model regression. It helps determine the main effect of a factor and the extent to which its interaction with other factors affects the response. Today, this method is used in many areas [9].The experimental study data were processed with the Minitab 19 program and RSM results were given. In the response surface method **equation (1)**is used [9].

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} {X_i}^2 + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

Y: the corresponding response; X_i, X_j: process parameters; β_0: a constant; β_{ii}, β_{ij}: the first and the second-degree coded input parameters and parameters interactions of linear, quadratic, and second order terms; *k*: the number of independent parameters; *ε*: the error term.

3. RESULTS AND DISCUSSIONS

The force measurements taken during the experiments were later processed through Excel, and the maximum forces are given in the **Table 4**.

Table 4 Experimental results

Exp. no.	***Vc*** (m/min)	***fz*** (mm/tooth)	**Cooling type**	F_{max} (N)	**Predicted force results** (N)
1	80	0.06	Dry	428	497
2	80	0.09	Dry	848	751
3	80	0.12	Dry	1029	1005
4	80	0.06	Air	430	495
5	80	0.09	Air	772	749
6	80	0.12	Air	1026	1003
7	80	0.06	Liquid	314	272
8	80	0.09	Liquid	486	526
9	80	0.12	Liquid	744	780
10	100	0.06	Dry	814	709
11	100	0.09	Dry	900	882
12	100	0.12	Dry	971	1054
13	100	0.06	Air	772	707
14	100	0.09	Air	913	879
15	100	0.12	Air	981	1052
16	100	0.06	Liquid	441	484
17	100	0.09	Liquid	556	657
18	100	0.12	Liquid	905	829
19	120	0.06	Dry	763	790
20	120	0.09	Dry	855	881
21	120	0.12	Dry	930	971
22	120	0.06	Air	774	788
23	120	0.09	Air	923	878
24	120	0.12	Air	929	969
25	120	0.06	Liquid	517	565
26	120	0.09	Liquid	714	656
27	120	0.12	Liquid	841	747

All statistical calculations in the study were carried out through the MINITAB program. According to the force values measured in the experiments, a mathematical relationship based on the cutting parameters is derived. Maximum force prediction was developed using multiple regression equations. Regression equations for maximum force are given in **Table 5** below.

Table 5 Regression equations according to cooling type

Cooling Type	**Regression Equation**
Dry	$Fmax = -2826 + 48.3 \times Vc + 19350 \times fz - 0.1643 \times Vc^2 - 136.1 \times Vc \times fz$

Air	$Fmax = -2829 + 48.3 \times Vc + 19350 \times fz - 0.1643 \times Vc^2 - 136.1 \times Vc \times fz$
Liquid	$Fmax = -3051 + 48.3 \times Vc + 19350 \times fz - 0.1643 \times Vc^2 - 136.1 \times Vc \times fz$

(R^2: 91.66, R^2_{adj}: 89.16)

Table 6 shows the analysis of variance. It is seen that *fz* is the most effective parameter with 48.4%, the cooling type comes in second place with 27.07%, and *Vc* comes in third place with 9.15%. The error rate is 15.38%.

Table 6 ANOVA Table

Source	**DF**	**Seq SS**	**Contribution**	**Adj MS**	**F-Value**	**P-Value**
Vc	2	101424	9. 15%	50712	5.95	0.009
fz	2	536519	48.40%	268259	31.48	0.000
Cooling type	2	300042	27.07%	150021	17.60	0.000
Error	20	170456	15.38%	8523		
Total	26	1108441	100%			

(DF: Degree of freedom, Adj MS: Adjusted mean of squares)

The desirability function method was used to determine optimum parameter levels. With this function, the measured quality characteristics of the predicted response are converted into a dimensionless desirability value. Its value is between 0 and 1. Since the aim of this study was to reduce the force during drilling, the smaller, better quality characteristic, according to **Equation (2)**, was chosen.

$$d_i = \begin{cases} 1 & y_i < T \\ \left(\frac{U - y_i}{U - T}\right)^w & T \le y_i \le U \\ 0 & y_i > U \end{cases} \qquad (2)$$

T: target value of the i_{th} response y_i; *L*: the allowable lower limit value; *U*: the acceptable upper limit for this response; *W*: the weight [10]. The optimum levels (*Vc* = 80 m/min, *fz* = 0.06 mm/tooth, cooling type= Liquid) were obtained from the analysis, results shown in **Figure 1**.

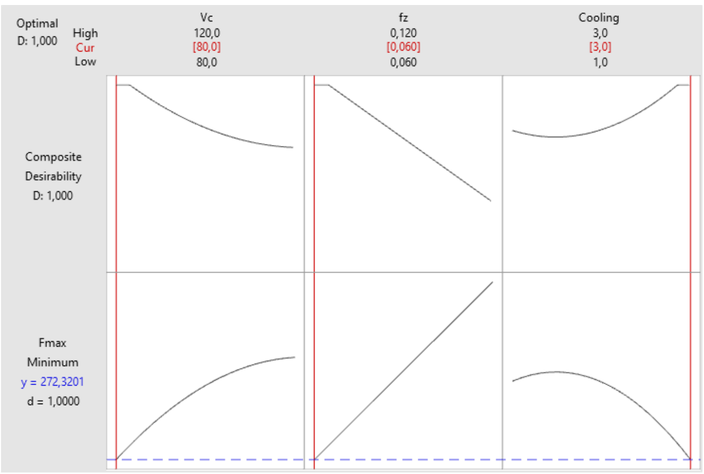

Figure 1 Response optimization plot

Contour plots are drawings used to show the effects of parameters on the result in two dimensions. **Figure 2a** shows the effect of changing *Vc* and fz on the maximum force. An increase in force values is observed with increasing levels of *fz.* Similarly, as *Vc* values increased, the force increased, but it was not as sharp as the increase with the change in *fz*, which is consistent with the results in the ANOVA table. **Figure 2b** shows the variation of the maximum force value according to *Vc* and cooling type. The lowest values were observed in experiments using the liquid cooling type, which was already found to be optimum by desirability analysis. There was also an increase in the force with increasing *Vc* values. **Figure 2c** shows the effect of cooling type and *fz* variation on the force. It is seen that the force increases with increasing *fz* values. Again, it is seen that the liquid cooling type is most suitable for obtaining low force.

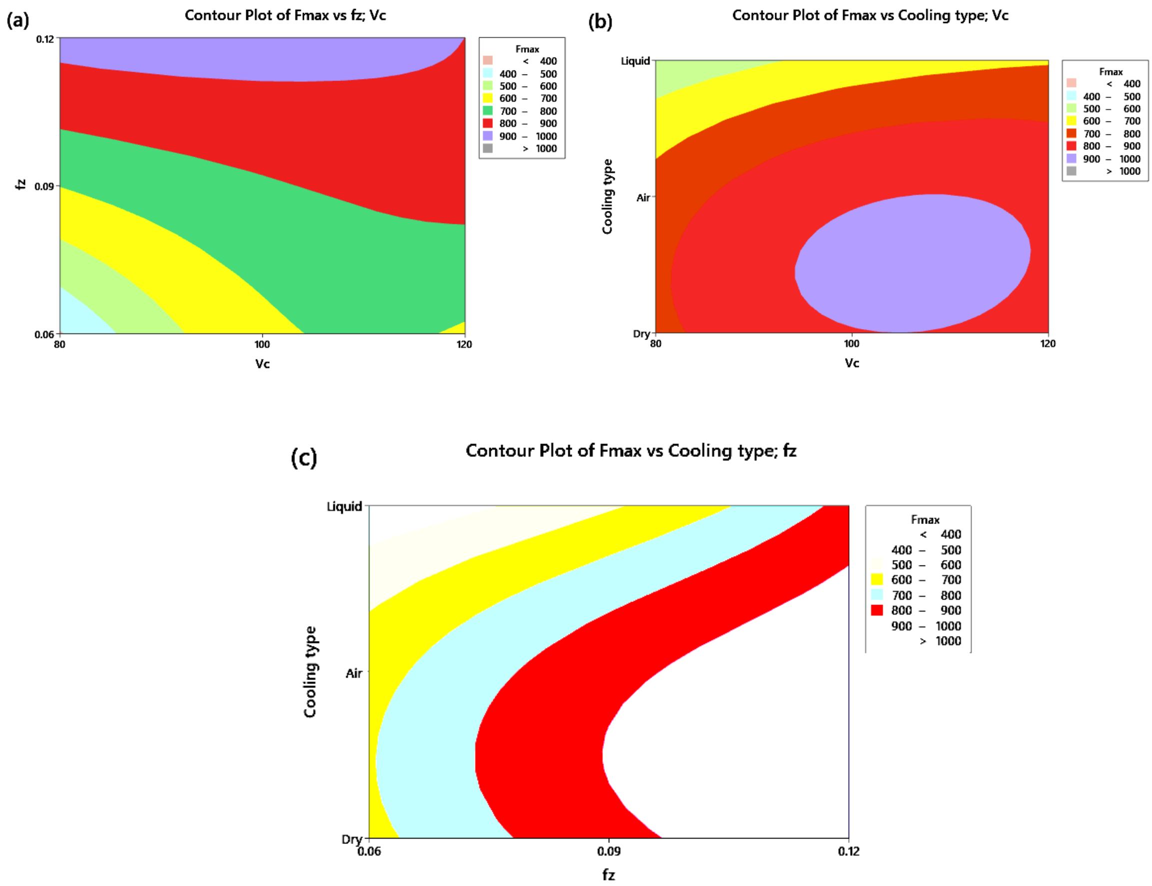

Figure 2 Interaction of parameters and their effects on the F_{max}

The comparison of the force values predicted by the regression equations and the force values measured in the experiments is given as a column chart in **Figure 3**. The estimated value rate is 84.97%.

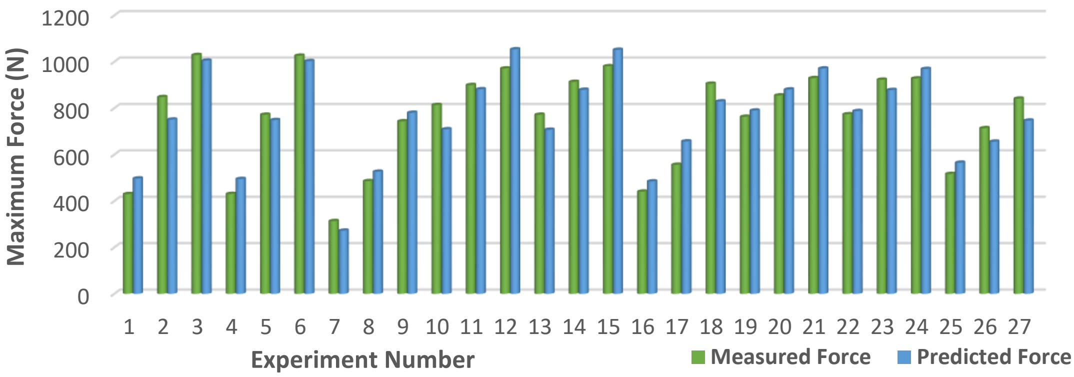

Figure 3 Comparison of experimental data and RSM predictions

4. CONCLUSIONS

In this study, cutting force measurement was carried out during drilling into Al5083-H111 alloy. In the experiments, three different cutting speeds (80, 100, 120 m/min), three different feed rates per tooth (0.06, 0.09, 0.12 mm/tooth), and 3 different cooling types (dry, air-cooled, and liquid-cooled) were used. Hole drilling operations were carried out with a TiAlN-coated HSSE-Co5 drill. As a result of the study, the following results were obtained:

The optimum values were determined as 80 m/min for cutting speed, 0.06 mm/tooth for feed rate per tooth, and liquid cooling method.

According to ANOVA, *fz* was the most influential parameter with 48.4%, the cooling type came in second place with 27.07%, and *Vc* came in third place with 9.15%.

Thanks to the equation obtained by regression analysis, force values can be predicted with an accuracy rate of 89.16%.

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