JURNAL POLIMESIN
Unit Penelitian dan Pengabdian Kepada Masyarakat (P2M)
Politeknik Negeri Lhokseumawe
ISSN Print: 1693-5462, ISSN Online: 2549-1199
Website: http://e-jurnal.pnl.ac.id/index.php/polimesin

Study on process parameters of CNC milling machine effecting to burr height in drilling Alumunium 6061 alloy sheet

Dinh Tien Dung[1], Nguyen M. Huy[1], Nguyen V. Thanh[1], Nguyen V. A. Duy[2], A. Jannifar[3], Nguyen H. Tho[2*]
[1]Faculty of Mechanical Engineering and Technology, Ho Chi Minh City University of Food Industry, 140 Le Trong Tan Street, Tay Thanh Ward, Tan Phu District, Ho Chi Minh City 760310, Vietnam
[2]Department of Fundamentals of Mechanical Engineering, Faculty of Engineering and Technology (FET), An Phu Dong Campus, Nguyen Tat Thanh University (NTTU), Ho Chi Minh City 729800, Vietnam
[3]Department of Mechanical Engineering, Lhokseumawe State Polytechnic, Lhokseumawe, Indonesia
*corresponding author: nhtho@ntt.edu.vn

Abstract

Productivity and quality of drilling are also of interest, have been paid more attention on the size of burr through the cleaning process. The presence of burr on drilled workpieces creates problems not only in the processing but also in the assembly line, affecting the accuracy of the assembly. Many factors have significant impacts on the burr height such as spindle speed, cutting feed and drill bit diameter. In this paper, the experiment investigation of those process parameters to burr height is implemented, then Taguchi-based approach is used to determine the influence density of each factors. Moreover, artificial neural network model is applied to predict the burr height based on the three input factors. The experiment results showed that the two most important factors affecting the burr are the speed of the spindle and the feed rate. The factors realized to be significant for burr formulation such as an 8 mm drill bit diameter, a CNC spindle speed of 2500 rpm, and feed rate of 70 mm/rev, which will result in the smallest output in terms of the height of the obtained burr is 0.12792 mm.

Keywords: Drilling; Optimal parameters; CNC machine; burr height; Experiments.

1. Introduction

Drilling is a cutting process designed to create holes primarily using twisted drill bit. When drilling, the cutting tool will perform knife movement and cutting motion. If the hole is be drilling on automatic machine, then the workpiece will perform a cutting motion. Drilling is an important operation in creating holes for the assembly process. Productivity and quality of drilling are also of interest, have been paid more attention on the size of burr through the cleaning process. The presence of burr on drilled workpieces creates problems not only in the post-processing but also affects the accuracy of the assembly [1]. Burr processing is time-consuming and it affects the productivity and performace of production. Therefore, the elimination of burr formation at the edges of the workpiece during drilling operation is essential to increase product quality and productivity of this stage [2]. Therefore, understanding the mechanism of formation of burr during drilling to reduce the burr is extremely important in justification of machining parameters. This study identifies the process parameters for the drilling operation, especially drilling Aluminum 6061 to reduce the burr for manufacturing enterprises. Some of the tasks performed in this study such as definition and survey of burr size parameters of the drilling operation, experimental identification, evaluation, analysis of the results of the processing parameters for the 6061 aluminum alloy drilling process with the aim of reducing the burr height size, considering the two modes of dry and wet drilling.

2. Related works

Drilling is a common hole-making operation and the majority of workpieces are drilled holes before they are shipped [1]. However, the presence of burr on the drilled workpiece creates problems not only in the processing, but also in the assembly line. Burrs are unwanted features attached to the edge of the hole. They are determined to be significantly larger on the exit side than the input side. Therefore, reducing the height of the burr on the exit side is a necessary requirement of the mechanical engineering industry. Many researchers have worked on issues related to burr in the process of drilling and others as well as have been studying the mechanisms of burr formation. Control and predict burr height during drilling of various metal materials needed.

Pilny et al. [2] conducted an experimental investigation on Al99.7Mg0.5Cu-H24 forged aluminum alloy plates of 2 mm thickness, using drills diameters of 1.6 and 2 mm. Cutting data, clamping conditions and drilling geometry have been changed to optimize the process and achieve the desired quality. This optical system provides a contactless measurement, aimed at avoiding damage to the burr surface and the measurement results are much less faulty. Reddy Sreenivasulu et al. [3] conducted a burr size modeling, simulation, and validation test when drilling aluminum alloy 6061. Finite Elements Analysis (FEA) is effective for understanding physical behavior in the process. Burr height is found for optimal drilling thrust solution by Taguchi technique. A mathematical model for thrust and burr formation in drilling operations was developed. Therefore, confirming these models, experiments are conducted by changing different process parameters. The values obtained from the experiment were compared to the simulation results developed in Deform3D [4, 5].

Dhote et al. [6] analyzed the burr size during drilling for various alloys using image processing techniques. Removing and controlling burr are two possible ways to deal with burr. One of the main concerns of manufacturing industry in burr removal technology focuses on how to predict their size and shape to ensure uniform removal. This issue encourages them to think about timely and accurate solutions of burr analysis. Matsumura et al. [7] presents a force analysis model presented to simulate the force and direction of the flow during drilling. Three-dimensional flow is considered as the piling of orthogonal cutting parts in planes containing cutting velocity and chip flow velocity. The direction of the chip flow is determined to minimize the cutting energy. Simulation is made to discuss the effect of the burr formation on the back of the plate. The burr formation is associated with thrust and direction of the flow of the chip. The curved blade drill is checked to reduce thrust and control the flow of the blade with the orientation and curvature of the blade. Counter-clockwise orientation with small curvature is effective in reducing the formation of burr in simulation. A drill is designed to have a curved shape counter-clockwise. The groove is designed to escape to the top to prevent the chip from being clogged during stable drilling. Then, the curved shape at the end controls the chip flow in the direction of the tool's center to reduce the burr formation with thrust around the end point of the cut trace.

Preś et al. [8] have studied and modeled the formation of chip edges during orthogonal cutting. The goal of the study was to examine material deformation at the edge of the workpiece during the C45E steel orthogonal cutting process and to develop a two-dimensional model of the process, using the finite elements method. Based on the examination of the mechanical properties of C45E Steel and the results obtained, and the parameters of the constituent model of the material have been matched.

Mondal et al. [9] conducted experiments and learned conditions for minimal burr formation. These experiments were carried out on radient drills (Make-Energy Limited, India) in dry and wet (water-cooled) conditions. The low-alloy steel specimen was used for experiments, using a 14 mm diameter drill. Conclusions were conducted as follows.

Normally, drilling in dry conditions shows large burr formations at the exit edge. Using water as cutting fluid does not bring noticeable results in reducing burr height. No backup support plates or beveled edges during tool escapes may have led to the formation of burr large both in dry and wet conditions.

The study of formation and reduction of burr has not been of much interest. Currently, there are only a few short articles about burr removal tools manually or advertising measuring devices [10-12]. This study presents the experience verification, evaluating, analyzing and validation for the optimal parameters for the 6061 aluminum alloy drilling process in the duration of operation with the goal of reducing the burr height considering two dry and wet drilling modes.

3. Research methodology.

3.1 Introduction

Much research has been done on the formation and removal of burr so far. Previous works have linked burr shapes to test cutting parameters. Several mathematical models based on experiments have been presented to determine cutting parameters. The burr control flowchart is also proposed to optimize the cutting parameters by taking into the formation of burr. Today, 3D modeling of metal cutting processes is a common technique. The main advantage of the proposed approach is to reduce the cost and time to predict parameters such as pressure, deformation rate, thrust experimentally. The goal of the study was to decrease the burr height at the edge of the hole during aluminum drilling.

3.2 Sample preparation

Experimental samples of 120 × 60 × 8 (Sheet of Aluminum Alloy 6061) each drilled up to 6 holes (Figure 1). To assess the factors affecting the burr size when drilling, the research procedure follows the diagram as shown in Figure 2. First of all, through the overview of the drilling process and the burr, its formation mechanism and its size through the mathematical model of analysis are constructed. This model shows the relationship between the burr and the parameters of the drilling process.

Next, we perform a raw drilling simulation process based on CAD/CAE systems such as DEFORM 3D to identify the influencing factors in this process. Analytical and simulation models are verified through experimental use of second-tier planning methods. To do this, the screening experiment aims to identify and tolerance of the factors affecting the burr when drilling, the experiment planning table is proposed according to the Taguchi approach. The determination of the dimensions of the burr through experimental drilling of holes with a diameter of 12 mm based on the different drilling conditions. Measurement of burr dimensions thanks to the CMM device and experiment planning table.

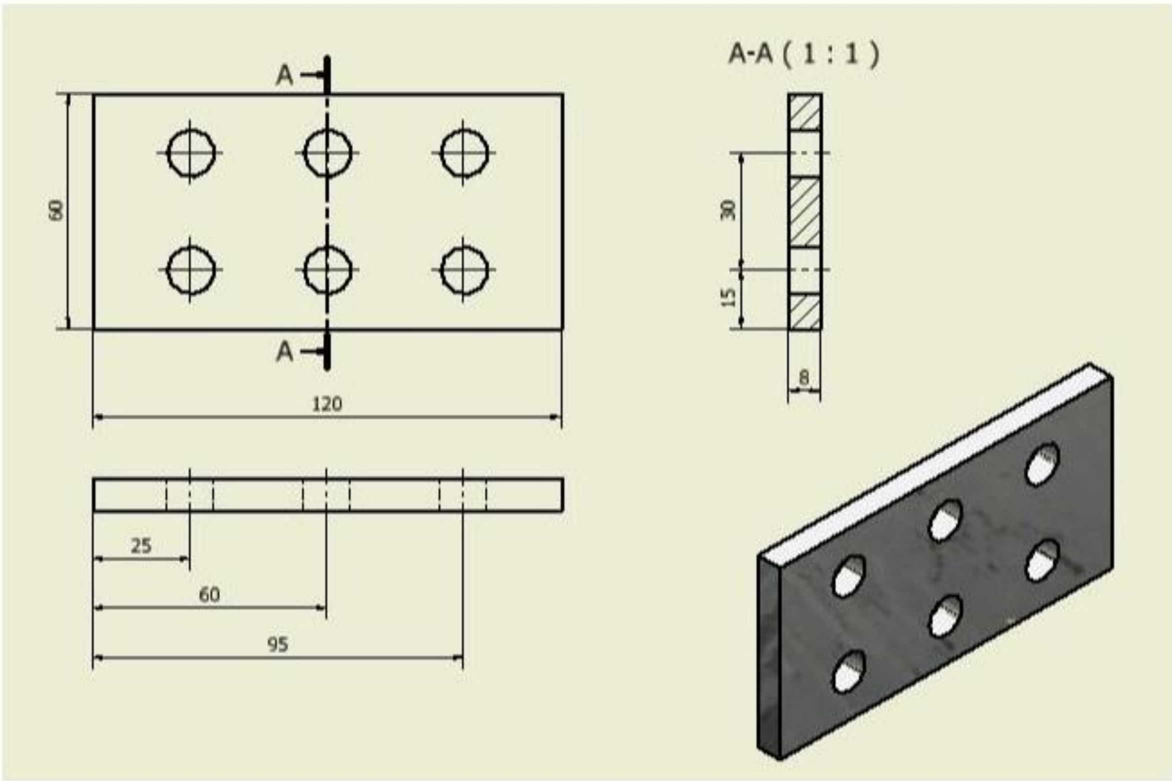


Figure 1. CAD model sample for drilling operation

3.3 Research flowchart

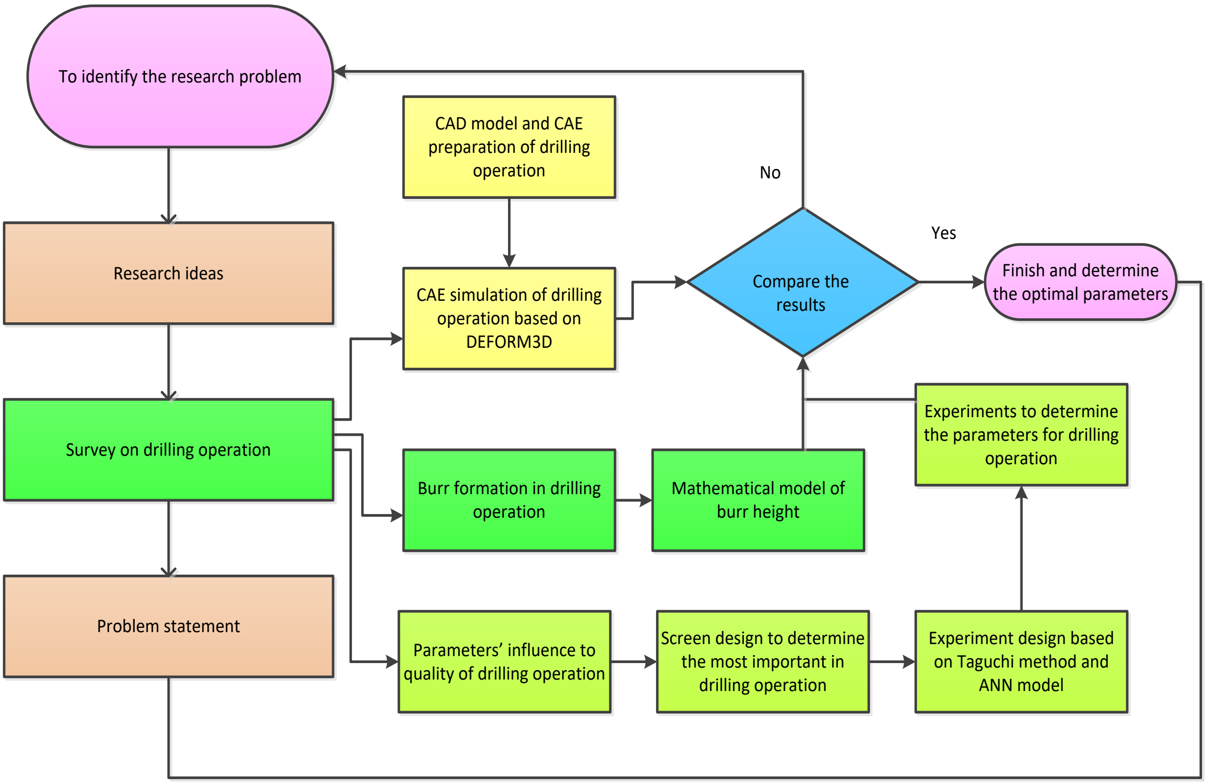


Figure 2. Research flowchart of drilling operation to understand the burr height

Next, we perform the experimental analysis using JMP software to identify the influencing factors and determine the machined set of process parameters to reduce the minimum burr size when drilling. The experimental results is drawn to better support the actual implementation of the correctness of created burr during drilling process.

3.4 Process parameters in drilling operation of Aluminium alloy 6061 sheet

+ Drilling sample material: Aluminum alloy 6061 is one of the most widely used types of aluminum alloys in the 6XXX series. Application of this material for industrial automation and mechanical components, food processing molds, and molding, etc. Aluminium 6061 is the most commonly used as an aluminum alloy sheet like aircraft and aerospace components, marine accessories, transportation, bicycle frame, camera lens, wheels; electrical accessories and connectors, braking components, valve, and connecting tubes, etc.
+ Cutting tool material (Drill bit): 2 types of HSS-R drill (R: Roll forged) and HSS-G drill.
+ Specifications of CNC milling machine (Figure 3): DEM 4000 Model, manufacturer of Korea Doosan, control System of FANUC, Desk in size 650 × 400 mm, distance from spindle barrel to machine table: 120÷570 mm, X=550 mm axis journey; Y= 400mm; Z=450 mm, spindle speed: 8000 rpm, machine size: Length of 1875 mm, Height of 2317 mm, and Width of 2200 mm, volume of 3210 kg, Year of production is 2019.

Figure 3. CNC Milling Machine Doosan DEM4000

+ Experimental parameters are described as follows.
The first run of Screen design of experiments with three factors as follows.

Table 3. Four selected factors with 3 levels for screening design of experiments in drilling operation.

Factor	Level 1 (min)	Level 2 (medium)	Level 3 (max)
Velocity	70 m/min	80 m/min	90 m/min
Feed rate	80 mm/min	90 mm/min	100 mm/min
Drilling mode	Dry	Wet (water and Emunxi with mixture of oil and water 1:20)	
Drilling	Φ8	Φ10	Φ12

The second run of Screen design of experiments with three factors as follows.

Table 4. Three selected factors with 3 levels for screening design of experiments in drilling operation.

Factor	Level 1 (min)	Level 2 (medium)	Level 3 (max)
Velocity	1500 rpm	2000 m/min	2500 m/min
Feed rate	70 mm/min	90 mm/min	110 mm/min
Drilling type	Φ8	Φ10	Φ12

Experiment setup of CNC milling machine
- Preparation work: Aluminum alloy 6061 sheet, HSS steel drillbit of all kinds, CNC Milling Machine Doosan DEM 4000 - Korea, watches, oil brushes, Emunxi cooling water, jigs, clamp heads, plastic hammers, steam hoses, scabies wipes, and sample containers. The fixturing process is shown in Figure 4.

- Experimental process:
Step 1: The workpiece is fixed on the machine desk and using the nape to create a clearance to exit the cutting tools as in Figure 4.

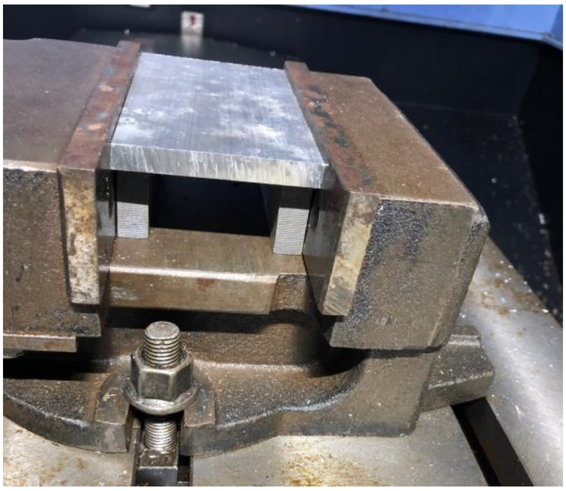


Figure 4. Fixing the workpiece

Step 2: Fixing the cutting tools.
The HSS steel drill bit is located with a self-centered elastic collet, attached to the BT40 end of the spindle. We create good rigidity and concentration.
Step 3: To get the workpiece center.
Step 4: To get the cutting tool's height. The process is available as in Figure 5.

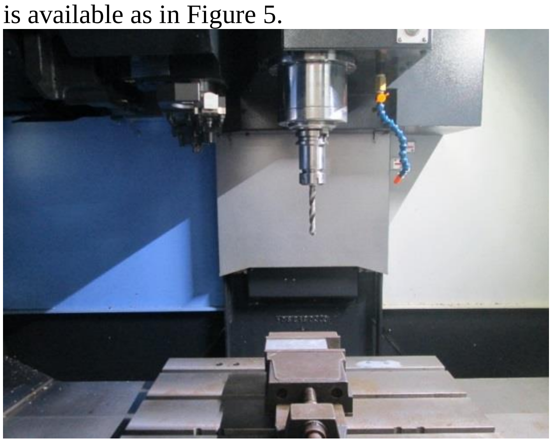


Figure 5. Insert the drill bit into the spindle

Step 5: Take the shallow hole drilling program with the G81 cycle to drill holes on the specimen (Figure 6). Enter the parameters for each hole to drill into the program wrote. Each specimen drills up to 6 holes.
Step 6: We starting to drill the holes based on the data of this study
Step 7: To remove the sample and arrange the specimen into a foam box to avoid impact on the burr.
Step 8: To measure the burr height and filling the results into the experimental planning table.

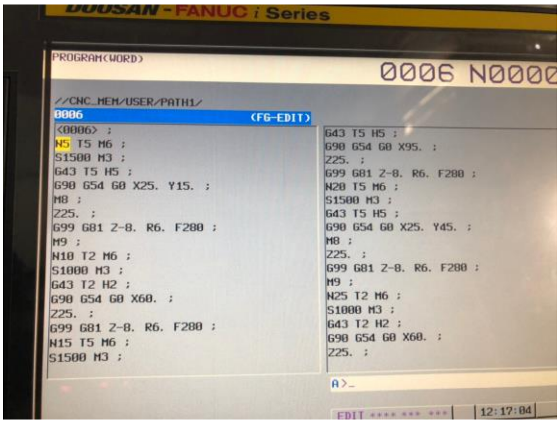


Figure 6. Hole Drilling Program

3.5 How to measure burr dimensions

The specimen was cooled to the contact surface for increased accuracy during the test.

- 1st experiment screen design:

The specimen were left on the cheekbones, using a 0.01 mm precision compared meter to measure the burr height. We have the probe touch the standard face and rotate the clock hand back to 0 as in Figures 7 and 8.

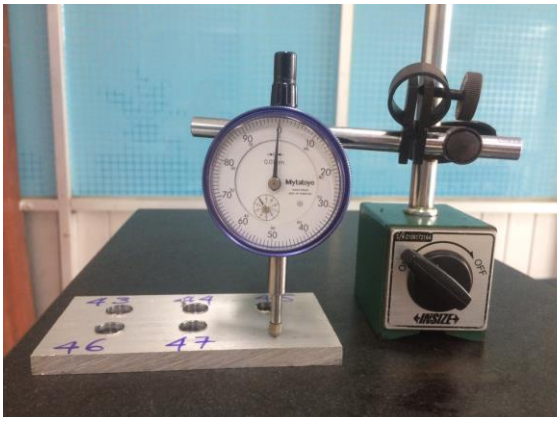


Figure 7. Adjust the clockwise to 0

Move the sample and check multiple positions/locations to determine the highest for optimization burr design

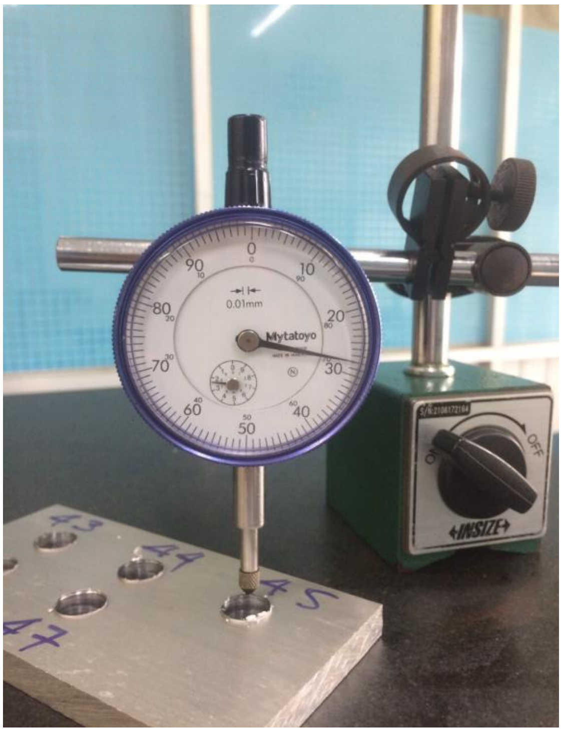


Figure 8. Burr height measurement

- 2nd experiment design:

The specimen was left on the cheekbones, using Mitutoyo's CMM meter with an accuracy of 0.001 mm to measure the burr height (Figure 9).

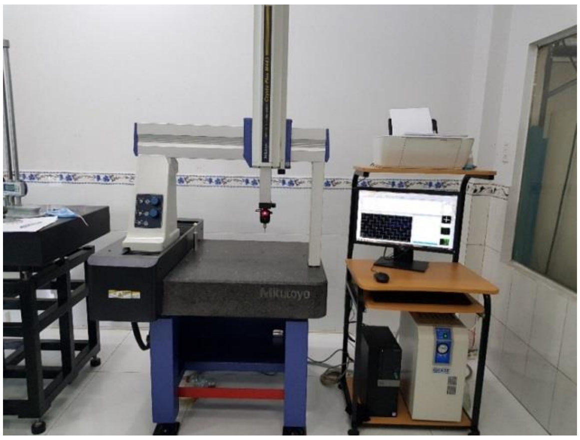


Figure 9. Mitutoyo CMM meter

The probe of the move machine to touch the specimen in 4 positions to create the standard plane to take the basis of the burr height comparison (Figure 10).

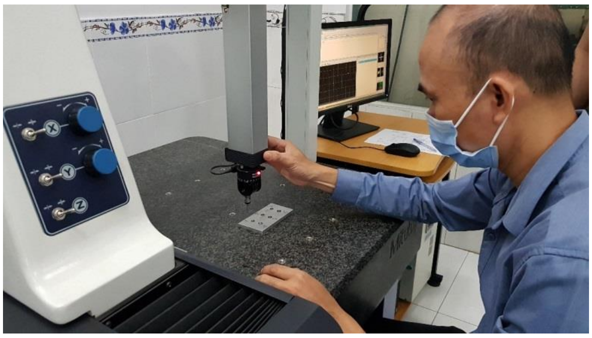


Figure 10. Determination of a datumn plane

Continue for the probe of the moving machine to touch the highest part of each hole to determine the burr height (Figure 11) and the measurement results is taken as in Figure 12.

Figure 11. Measure the burr height of each borehole

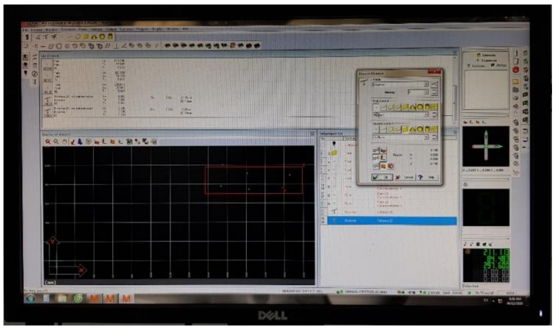


Figure 12. The burr height results of each measurable hole

4. Results and discussions

4.1 Taguchi-based approach

After setting up the machine, drill bit, and fixing the workpiece, we operate the CNC milling machine according to the experiment data and collect the 52 hole samples for the first time of screen design and 27 hole samples for the second time as described in Figures 13 and 14.

For the screen design of experiment during the first time, Table 6 presents the evaluation of data between drill bit and cooling mode in Table 5. It can be concluded that through the screening noticed with the type of drill bit 1 (HSS-G) and the cooling mode Emunxi solution 5%, height burr is the smallest so we take this parameters as the input for the next experiment.

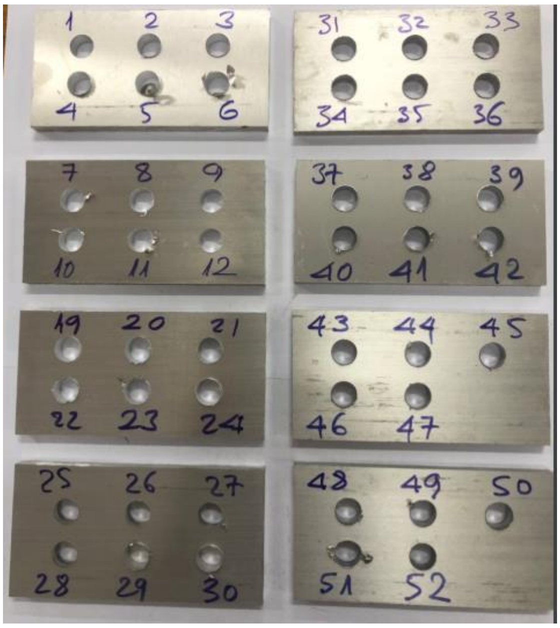


Figure 13. Results on drilling operation of holes in screen design of experiments

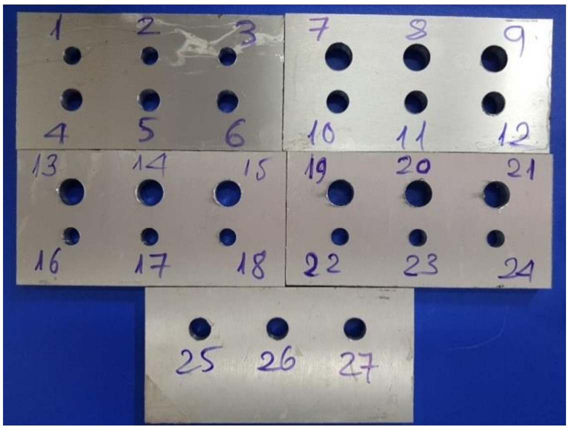


Figure 14. Results on drilling operation of holes in Taguchi design of experiments

Table 5: Comparison of burr height data (mm) between drill bit and cooling mode

Number of order	Drill 1-Cooling 1	Drill 1-Cooling 2	Drill 2-Cooling 1	Drill 2-Cooling 2
1	0.09	3.18	2.75	2.22
2	0.82	0.21	0.35	3.8
3	0.59	2.84	0.31	2.22
4	1.82	1.84	0.85	1.1
5	2.69	0.61	2.54	3.8
6	6.22	0.86	0.51	0.28
7	2.1	0.87	1.54	1.4
8	0.23	0.83	1.7	1
9	0.22	0.76	1.52	2.88
10	0.28	0.64	4.56	2.7
11	6.28	0.58	1.28	0.97
12	0.3	0.6	0.29	3.18
13	4.21	0.68	0.77	0.48
Average	1.99	1.12	1.46	2.00
Min	0.09	0.21	0.29	0.28
Max	6.28	3.18	4.56	3.8

For the second design of experiments, we used the Taguchi-based method to determine the factors' effects to the height of burr during the drilling operation. The Taguchi method has been used to big burr height when drilling aluminum. Taguchi recommends analyzing the average response for each experiment in the experimental planning table. He also proposed analyzing fluctuations using a well-selected signal-to-noise (S/N) ratio. This ratio is given from the second-tier loss function, and the three objectives are considered standard and wide application. These are:

(1) Lower is best
(2) Higher is best
(3) Average is best

The "Signal to noise, S/N" ratio is the main tool used in the concept of design for measuring or dosing quality. The S/N ratio intensity is extremely variable during experimental repetition. The smaller S/N ratio is better used because we need to reduce the burr height in the original 6061 aluminum alloy drilling.

In this study, we use the goal "Lower is the best":

$$\frac{S}{N} = -10\log\left\{\frac{1}{n}\sum_{i=0}^{n} y^2\right\}$$

The lower S/N ratio responds to better productivity. Therefore, the optimal level of process parameters is the level with the lowest S/N value. Analysis of statistical data is carried out by the ANOVA method to study the contribution/role of factors.

Three work parameters are selected as control factors, and each element is designed to have three levels, expressed in cutting feed (70,90,110), speed

(1500, 2000, 2500) and drill bit diameter (8,10,12), and the replication is three, as in Table 6. The experimental design is based on the L27 orthongonic array of the Taguchi method. Minitab V19 software is used to analyze the recess for the data obtained.

Table 6. The second experimental planning table using Taguchi method

No.	Speed (rpm)	Cutting feed (mm/min)	Drill bit diameter (mm)	Burr height (mm)
1	1500	70	8	0.154
2	1500	70	10	0.155
3	1500	70	12	0.186
4	1500	90	8	0.412
5	1500	90	10	0.226
6	1500	90	12	0.491
7	1500	110	8	0.425
8	1500	110	10	0.777
9	1500	110	12	0.704
10	2000	70	8	0.257
11	2000	70	10	0.623
12	2000	70	12	0.412
13	2000	90	8	0.459
14	2000	90	10	0.418
15	2000	90	12	0.404
16	2000	110	8	0.313
17	2000	110	10	0.425
18	2000	110	12	0.972
19	2500	70	8	0.661
20	2500	70	10	0.283
21	2500	70	12	0.296
22	2500	90	8	0.748
23	2500	90	10	0.196
24	2500	90	12	0.196
25	2500	110	8	0.353
26	2500	110	10	0.571
27	2500	110	12	0.411

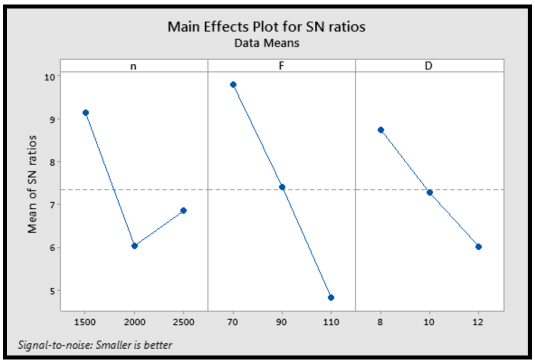


Figure 15. Analysis of factors affecting burr height

In raw drilling, burr height is an important criterion. The formation of burr when drilling mainly depends on the shape of the cutting tool, cutting parameters and workpiece material. When the material is flexible, the material tends to stretch throughout the burr formation process, resulting in a large volume and burr height. Many factors affect the quality of the machined surface, the machined parameters such as cutting speed, feed rate, cutting depth and workpiece characteristics have significant effects on hole drilling on CNC machine tools and workpiece setup.

A series of test steps to assess the effect of drilling parameters on burr height when drilling aluminum. Experimental results of a burr height for drilling with different parameters such as spindle speed (rpm), feed rate (mm/rev), and drill bit diameter (mm) result in S/N ratio of burr height. The S/N ratio for each experiment of the Taguchi L27 orthogonal array is calculated by applying the rule of "Lower is the best". The results are presented in Figures 15 and 16. Figure 16 showed that the optimal values of process parameters.

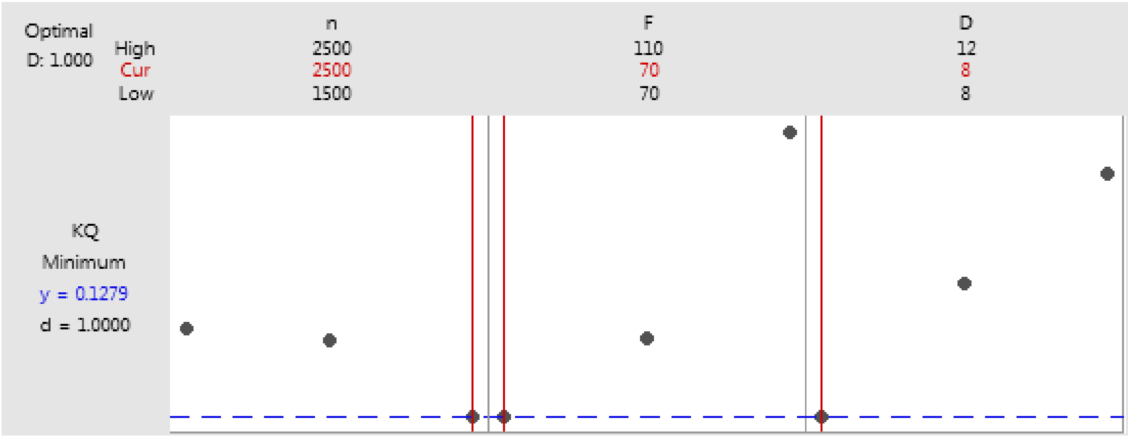


Figure 16. Value of optimal parameters when drilling to reach the smallest burr height

Table 8. Feedback table for noise signal ratio

Lower is The **Best Level**	**N**	**F**	**D**			
1	9.147	9.797	8.748			
2	6.031	7.413	7.265			
3	6.847	4.815	6.011			
Delta	3.115	4.982	2.737			
Tier	2	1	3			
Parameters						
Response	**Goal**	**Lower**	**Target**	**Upper**	**Weight**	**Importance**
Kq	Minimum		0.154	0.777	1	1
Solution	**N**	**F**	**D**	**KQFit**	**CompositeDesirability**	
1	2500	70	8	0.127919	1	

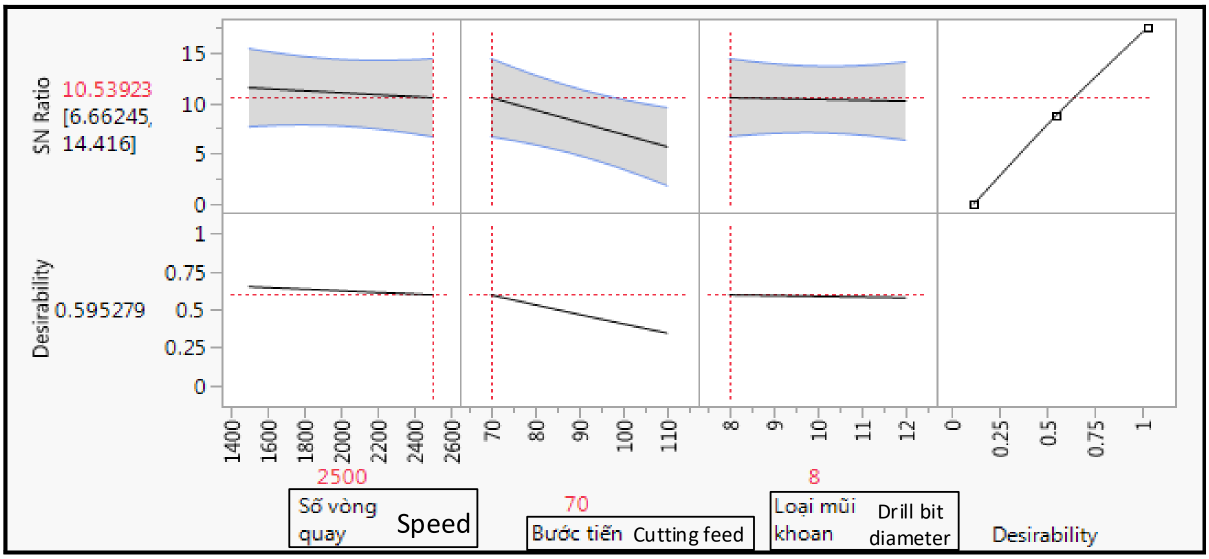


Figure 17. Optimal value for extreme burr

Based on the Figure 16, the two most important factors affecting the burr are the speed of the spindle and the feed rate. It is easy to see that an 8 mm drillbit diameter, a CNC spindle speed of 2500 rpm, and feed rate of 70 mm/rev, which will result in the smallest output in terms of the height of the obtained burr is 0.12792 mm. Analyzing the effect of each work outing on the average burr height is given in Table 8.

Figure 17 shows the optimal value for a burr minimum height corresponding to spindle speed of 1500 rpm, cutting feed rate of 70 mm/min, and a drill bit with a diameter of 10 mm. Because some parameters have a p-value value of > 0.05, the ANOVA model does not represent well statistically to build a regression equation.

4.2 ANN model

This study also builds a burr height prediction model by artificial neural network (ANN) without the use of a regression equation. In order to implement the ANN model, we need data as large as possible because of the high probability results. The second 27 experiments of the Taguchi method were combined with 52 preliminary experiments of the 1st experiments to form a dataset with 79 experiments for the construction of the ANN model as shown in Figure 18. The ANN model's response surface for burr height is shown in Figures 19 and 20 for discrete and continuous data, respectively. These figures show that the best value for burr height with the collected data set as the CNC spindle speed of 2500 rpm, cutting feed of 70 mm/min and 8 mm diameter drill bit, then the average burr height is 0.385 mm (in case of 27 samples). For the case of 79 samples, the predicted value for the burr height is 0.9 mm – this value is consistent with the results of drilling simulation from DEFORM3D (Scientific Forming Technologies Corporation, Ohio, USA; www.deform.com). Because 52 preliminary samples were for screening experiments, the results were misleading and inaccurate. The ANN model for the 27 Taguchi experiments gives a higher reliability result and helps us to forest the burr height value according to three input parameters such as CNC spindle speed, cutting feed, and drill bit type diameter.

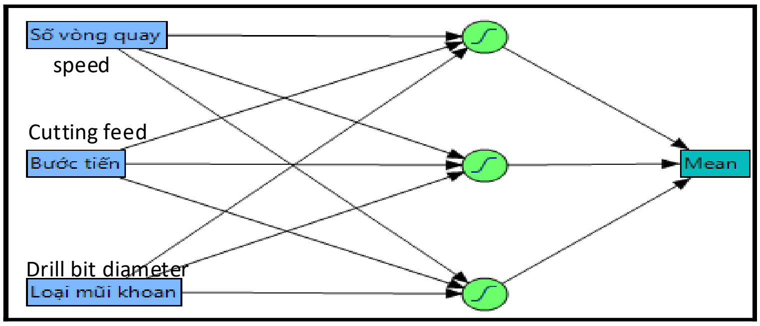
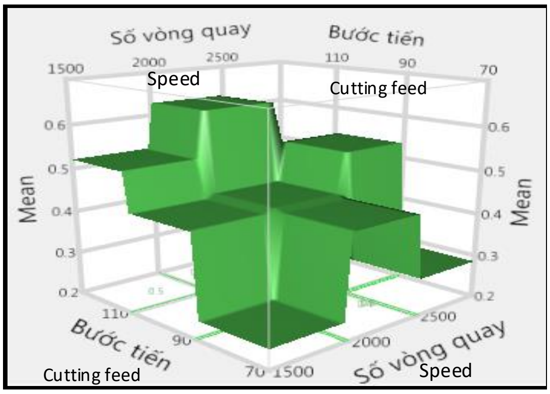
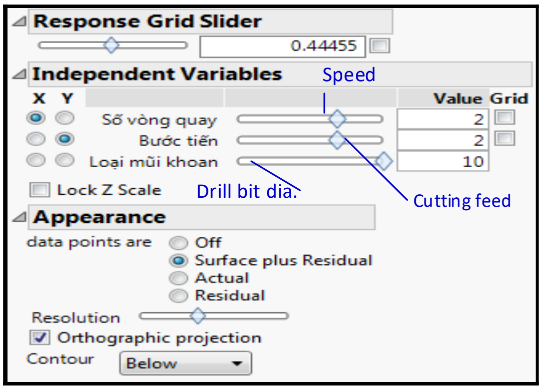


Figure 18. ANN model to predict the burr height in drilling operation





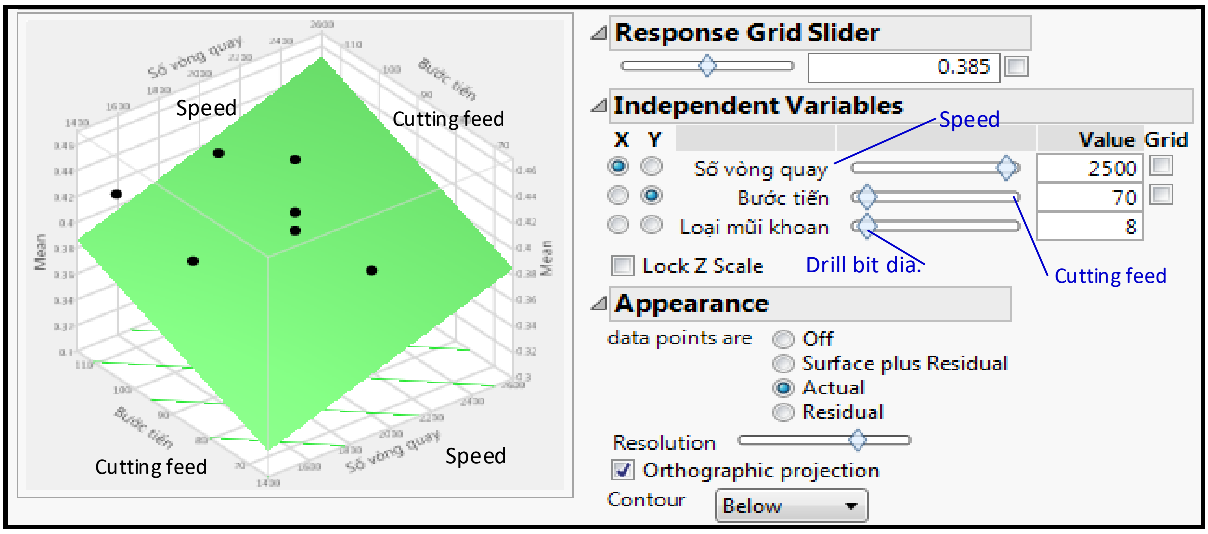


Figure 19. ANN responsive surface for 27 experimental samples according to Taguchi

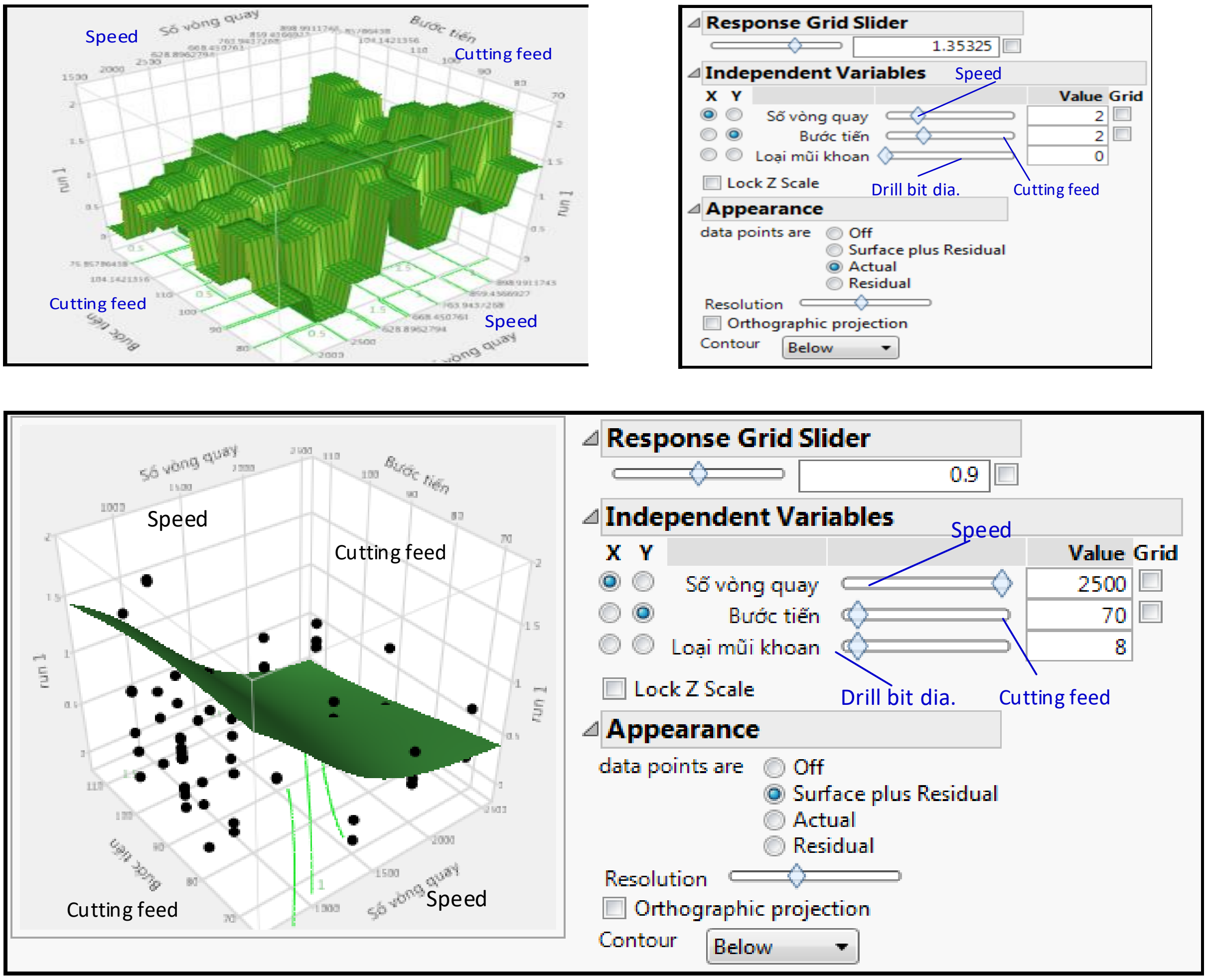


Figure 20. ANN responsive surface for 79 hole drilling experimental samples on aluminum workpiece 6061

Conclusion

This study conducted on 8mm aluminum alloy 6061 sheet using the drilling bits available on the Ho Chi Minh - Vietnam cutting tool market. The aim is to determine the optimal process parameters of CNC spindle speed, cutting feed, and drill bit diameter having the significant impact on the burr height to improve the productivity and quality of machining process. The 27-experiment runs based on Taguchi approach were used to evaluate the effects of each factors, and ANN model was applied to predict the burr height based on three above input factors. The results highlighted that the selected 3 factors had a significant influence on the burr height and ANN model is potential in practice. The optimum process parameters were an 8 mm drillbit diameter, a CNC spindle speed of 2500 rpm, and feed rate of 70 mm/rev, which will result in the smallest output in terms of the height of the obtained burr is 0.12792 mm. In the future, it is necessary to test on some other hard materials such as stainless steel, SKD61 and apply other intelligent techniques to predict the burr height more accurately in drilling operation.

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