OPTIMIZATION OF PROCESS PARAMETERS IN DRILLING OF AISI 1015 STEEL FOR EXIT BURR USING RSM AND TAGUCHI

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ABSTRACT

This paper concentrates on the analysis and optimization of input parameters for minimum burr size using Response surface methodology and Taguchi method. Speed, feed, drill diameter and point angle were taken as input machining parameters while two response variables namely burr height and burr thickness were chosen for the given study. Central composite design (CCD) was used for the experimental design. Optimum machining parameters were determined using S/N ratio obtained from Taguchi optimization method for multi response characteristics i.e. burr height and burr thickness. With this technique minimum burr height were obtained at cutting speed 28 m/min, feed rate 0.1 mm/rev, drill diameter 20 mm and point angle 135° and minimum burr thickness were obtained at cutting speed 16 m/min, feed rate 0.05 mm/rev, drill diameter 4 mm and point angle 142°.

Keywords: Burr height, Burr thickness, Grey relational analysis, Drilling, AISI 1015.

1. INTRODUCTION

Drilling is one of the important manufacturing operations that can be carried out on number of parts for assembly work. Drilling operation is essential for manufacturing industries like automobile industry, aerospace industry, medical and electrical related industries etc.

Formation of exit burr after drilling operation is one of the important problems that have to be minimized or control in order to avoid its adverse effect during manufacturing stage or assembly work. Burr is defined as the projection of material at the end of the hole due to plastic deformation of the material. Burr has two types’ viz. entrance burr and exit burr. The exit burr is important because these are larger in size than entrance burr. Exit burr creates several problems like decreasing quality
of the products, improper seating between mating parts during assembly, jamming and misalignment of parts etc. Burrs are injurious to workers during machining operations. Especially in precision industries, burrs are quiet undesirable. Due to all these problems deburring operation should be carried out on the work piece to remove the burr formed during drilling operation. This will result in waste of time and money. Almost 30% of the total manufacturing cost will be spending on deburring and edge finishing of components.


As drilling burr formation is a very complicated phenomenon affected by many parameters such as drill geometry, material property and process conditions. Therefore it is imperative to develop a reliable model that predicts the burr size to reduce deburring cost as burrs cannot be completely eliminated. “However, no generally accepted analytical model is available in drilling up to now”. This investigation work differs from other studies carried out on burr formation as it attempts to develop a prediction model, which determines whether a drill bit consisting of important process parameters yields a minimum burr or not. The important process parameters are determined based on the literature review of previous studies carried out on burr formation. An response surface methodology (RSM) model is developed that predicts burr height and thickness. RSM is selected because of its capability to learn and simplify from examples and adjust to changing conditions. In addition they can be applied in manufacturing area as they are an effective tool to model non linear systems.

2. RESPONSE SURFACE METHODOLOGY

RSM consists of the experimental strategy for exploring the space of the process or input factors, empirical statistical modeling to develop an appropriate approximating relationship between the output and the process variables, and optimization methods for finding the levels or values of the process variables that produce desirable values of the response outputs. Response surface method designs also help in quantifying the relationships between one or more measured responses and the vital input factors (MINITAB SOFTWARE version 14).

Process modeling by response surface methodology (RSM) using statistical design of experiment based on central composite design is proved to be an efficient modeling tool. The methodology reduces cost of experimentation and provides the information about the main and interaction effects.

The first step of RSM is to define the limits of the experimental domain to be explored. These limits are made as wide as possible to obtain a clear response from the model. The cutting speed, feed rate, drill diameter and point angle are the drilling variables selected for present investigation. The different levels retained for this study are depicted in Table 1.

In the next step is the planning to accomplish the experiments by means of RSM using a Central Composite Design. In many engineering fields, there is a relationship between an output
variable of interest (y) and a set of controllable variables \((x_1, x_2, \ldots, x_n)\). The relationship between the drilling control parameters and the responses is given as:

\[ y = f(x_1, x_2, \ldots, x_n) + \varepsilon \]  

(1)

where \(\varepsilon\) represents the noise or error observed in the response (y). If we denote the expected response to be \(F(y) = f(x_1, x_2, \ldots, x_n) = \eta\), then the surface represented by

\[ \eta = f(x_1, x_2, \ldots, x_n) \]  

(2)

is called a response surface. The variables \(x_1, x_2, \ldots, x_n\) in Eq. 2 are called natural variables because they are expressed in natural units of measurement. In most RSM problems, the form of the relationship between the independent variables and the response is unknown; it is approximated. Thus, the first step in RSM is to find an appropriate approximation for the true functional relationship between response and the set of independent variables. Usually, a low-order polynomial in some region of the independent variables is employed. If the response is well modeled by a linear function of the independent variables, then the approximating function is the first order model:

\[ y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon \]  

(3)

If there is curvature in the system, then a polynomial of higher degree must be used, such as the second-order model:

\[ y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \sum_{j=1}^{k} \beta_{ij} x_j x_j + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} x_i x_j + \varepsilon \]  

(4)

Where \(i = 1, 2, \ldots, k - 1\) and \(j = 1, 2, \ldots, k\) also \(i < j\)

3. EXPERIMENTAL WORK

AISI 1015 steel plates with 10 mm thickness were used as a work piece material for the given study. AISI 1015 steel is widely used in the applications like Rivets, Screws, panels, ship plates, boiler plates, fan blades, gear, valves, cam shafts, crank shafts, connecting rods, railway axles, tubes of bicycles and automobiles, small forgings etc. The composition of AISI Steel is 0.178% C, 0.60% Mn, 0.04% Cr, 0.03% Ni, 0.002% Mo, 0.019% S, 0.020% P and 0.19% Si. The Hardness is 170 BHN. Experimental studies were performed on CNC Machining centre HASS VF2SS with Maximum speed, 12000 r.p.m.

In the present study four process parameters (speed, feed, drill diameter and point angle) were considered. A five level central composite design was used to study linear, quadratic and two factor interaction effect between the four process variable and responses (Table 1). The upper limit of a factor was coded as +2 and the lower limit as -2; coded values for intermediate levels were calculated from the following relationship:

\[ X = \frac{2[X - (X_{\text{max}} + X_{\text{min}})]}{X_{\text{max}} - X_{\text{min}}} \]  

(5)

Where \(X_i\) is the required coded values of a variable \(X\), \(X\) is any value of the variable from \(X_{\text{min}}\) to \(X_{\text{max}}\). X_{\text{min}} the lower level of the variable and \(X_{\text{max}}\) is the upper level of the variable.
Table 1 Factors and their levels

<table>
<thead>
<tr>
<th>Factors</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (V), m/min</td>
<td>-2 16 20 24 28</td>
</tr>
<tr>
<td>Feed (f), mm/rev</td>
<td>0.05 0.1 0.15 0.2 0.25</td>
</tr>
<tr>
<td>Drill dia. (D), mm</td>
<td>04 08 12 16 20</td>
</tr>
<tr>
<td>Point angle(PA), degree</td>
<td>110 118 126 134 142</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSION

4.1 Experimental results and Taguchi analysis

A series of drilling experiments were conducted to investigate the influence of process parameters on burr height and burr thickness in drilling AISI 1015 steel. Experimental results and S/N ratio for burr height and burr thickness for drilling AISI 1015 steel with various drilling parameters are shown in Table 1. The S/N ratios for each experiment were calculated by using equation:

\[
S/N = -10\log_{10}(\frac{y_i}{N})
\]

Where, \( y_i \) is the response value at the \( i^{th} \) run.

Now, by utilizing calculated values of S/N ratios (Table 1), average S/N response ratios were calculated for burr height and burr thickness. Table 2 shows S/N response table for burr height and Table 3 shows S/N response table for burr thickness. The S/N ratio response graphs for both responses are shown in Fig 1 and 2.

Table 2 S/N response table for burr height

<table>
<thead>
<tr>
<th>Levels</th>
<th>S/N ratio for Burr height</th>
</tr>
</thead>
<tbody>
<tr>
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<td>V</td>
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<td>10.43</td>
</tr>
<tr>
<td>2</td>
<td>9.85</td>
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<td>3</td>
<td>9.46</td>
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<tr>
<td>4</td>
<td>10.03</td>
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<tr>
<td>5</td>
<td>11.54</td>
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Table 3 S/N response table for burr thickness

<table>
<thead>
<tr>
<th>Levels</th>
<th>S/N ratio for Burr thickness</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>V</td>
</tr>
<tr>
<td>1</td>
<td>20.45</td>
</tr>
<tr>
<td>2</td>
<td>21.44</td>
</tr>
<tr>
<td>3</td>
<td>20.07</td>
</tr>
<tr>
<td>4</td>
<td>20.19</td>
</tr>
<tr>
<td>5</td>
<td>20.26</td>
</tr>
</tbody>
</table>

Regardless of quality characteristics, a greater S/N ratio corresponds to a better performance. The level of factor with the highest signal-to-noise ratio is the optimum level.
Optimal parameter combination for Burr height:

The optimal parameter combination level for the present research work in the drilling process is speed at level 5, feed rate at level 2, drill diameter at level 5 and point angle at level 4 for burr height. That means, the optimal cutting parameters for burr height (Bh) were obtained at 28 m/min cutting speed (level 5), 0.1 mm/rev feed rate (level 2), 20 mm drill diameter (level 5), and 134° point angle (level 4).

Optimal parameter combination for Burr thickness:

The optimal parameter combination level for the present work in the drilling process is speed at level 2, feed rate at level 1, drill diameter at level 1 and point angle at level 5 for burr thickness. That means, the optimal cutting parameters for burr thickness (Bt) were obtained at 16 m/min cutting speed (level 2), 0.05 mm/rev feed rate (level 1), 4 mm drill diameter (level 1), and 142° point angle (level 5).

Fig. 1 The effect of drilling parameters on burr height

Fig. 2 The effect of drilling parameters on burr thickness
<table>
<thead>
<tr>
<th>Run</th>
<th>Levels of factors</th>
<th>Expt. results</th>
<th>S/N ratio</th>
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<td>1</td>
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<td>1</td>
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<td>-1</td>
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<td>-1</td>
<td>-1</td>
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<td>29</td>
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<tr>
<td>30</td>
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<td>-1</td>
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<td>31</td>
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<td>-1</td>
<td>1</td>
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</table>
Table 5 Regression table for burr height

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.341857</td>
<td>0.008979</td>
<td>38.073</td>
<td>0.000</td>
</tr>
<tr>
<td>V</td>
<td>-0.007500</td>
<td>0.004849</td>
<td>-1.547</td>
<td>0.141</td>
</tr>
<tr>
<td>f</td>
<td>0.035500</td>
<td>0.004849</td>
<td>7.321</td>
<td>0.000</td>
</tr>
<tr>
<td>D</td>
<td>-0.004667</td>
<td>0.004849</td>
<td>-0.962</td>
<td>0.350</td>
</tr>
<tr>
<td>PA</td>
<td>0.001000</td>
<td>0.004849</td>
<td>0.206</td>
<td>0.839</td>
</tr>
<tr>
<td>V*V</td>
<td>-0.014089</td>
<td>0.004442</td>
<td>-3.171</td>
<td>0.006</td>
</tr>
<tr>
<td>f*f</td>
<td>0.009161</td>
<td>0.004442</td>
<td>2.062</td>
<td>0.056</td>
</tr>
<tr>
<td>D*D</td>
<td>-0.013089</td>
<td>0.004442</td>
<td>-2.946</td>
<td>0.009</td>
</tr>
<tr>
<td>PA*PA</td>
<td>0.000286</td>
<td>0.004442</td>
<td>0.064</td>
<td>0.950</td>
</tr>
<tr>
<td>V*f</td>
<td>-0.016125</td>
<td>0.005939</td>
<td>-2.715</td>
<td>0.015</td>
</tr>
<tr>
<td>V*D</td>
<td>0.037625</td>
<td>0.005939</td>
<td>6.335</td>
<td>0.000</td>
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<tr>
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<td>0.005939</td>
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<tr>
<td>f*PA</td>
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<td>D*PA</td>
<td>0.028000</td>
<td>0.005939</td>
<td>4.715</td>
<td>0.000</td>
</tr>
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</table>

$S = 0.02376$  $R-Sq = 90.5\%$  $R-Sq(adj) = 82.1\%$

Table 6 Regression table for burr thickness

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.001502</td>
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<tr>
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<td>0.001502</td>
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<tr>
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<td>0.001502</td>
<td>-3.635</td>
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<tr>
<td>V*V</td>
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<td>0.001376</td>
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<tr>
<td>f*f</td>
<td>-0.001942</td>
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</tr>
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$S = 0.007357$  $R-Sq = 90.8\%$  $R-Sq(adj) = 82.8\%$
<table>
<thead>
<tr>
<th>Run Order</th>
<th>V</th>
<th>f</th>
<th>D</th>
<th>PA</th>
<th>Experimental values (mm)</th>
<th>Predicted values from RSM model (mm)</th>
<th>Error %</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Bh</td>
<td>Bt</td>
<td>Bh</td>
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4.2 Response surface analysis

For the burr height data, the regression table shows the following:

- **Linear effects:** The p-value of 0.141, 0.350 and 0.839 for speed, drill diameter and point angle is not less than 0.05. Therefore, there is no significant effect of these three factors on the model. The p-value of 0.000 for feed is less than 0.05. Therefore drill diameter has significant effect.

- **Squared effect:** The p-value of squared effect $V^2$ and $D^2$ is less than 0.05. Hence these two squared effects are significant.

- **Interaction effect:** The p-values of $Vf$, $Vd$ and $D\theta$ are less than 0.05. Therefore, their effect on the model is significant. That means the effect of speed on burr height depends on the drill diameter and feed rate. The effect of diameter on burr height depends on the point angle.

For the burr thickness data, the regression table shows the following:

- **Linear effects:** The p-value of 0.011, 0.000 and 0.002 for speed, feed and point angle is less than 0.05. Therefore, there is significant effect of these three factors on the model.

- **Squared effect:** The p-value of squared effect $V^2$, $D^2$ and $\theta^2$ is less than 0.05. Hence these three squared effects are significant.

- **Interaction effect:** The p-values of $V\theta$ and $D\theta$ are less than 0.05. Therefore, their effect on the model is significant. That means the effect of speed on burr height depends on the point angle and the effect of diameter on burr height depends on the point angle.

For each term in the model, there is a coefficient. Using these coefficients we have construct an equation representing the relationship between the response and the factors.

For the burr height data, regression equation is:

\[
\text{Burr height (Bh)} = 0.341857 - 0.007500(V) +0.035500(f) - 0.004667(D) + 0.001000(\theta) - 0.014089(V^2) + 0.009161(f^2) - 0.013089(D^2) + 0.000286(\theta^2) - 0.016125(Vf) + 0.037625(VD) + 0.000250(V\theta) - 0.005125(fd) + 0.003000(fd\theta) + 0.028000(D\theta)
\]  

(5)

For the burr thickness data, regression equation is:

\[
\text{Burr thickness (Bt)} = 0.108143 + 0.004292(V) + 0.012958(f) - 0.001708(D) - 0.005458(\theta) - 0.002942(V^2) - 0.001942(f^2) - 0.006067(D^2) - 0.004192(\theta^2) - 0.000812(Vf) + 0.001938(VD) + 0.005063(V\theta) - 0.003188(fd) + 0.000063(fd\theta) + 0.008438(D\theta)
\]  

(6)

The normal probability plots of the residuals versus the predicted response for burr height and burr thickness are shown in Figs. 3 and 4, respectively. Figures 3 and 4 revealed that the residuals generally fall on a straight line, implying that the errors are normally distributed. This implies that the models proposed are adequate, and there is no reason to suspect any violation of the independence or constant variance assumption.
5. CONCLUSION

This paper has used Taguchi method and response surface methodology for selecting the optimum combination values of process parameters affecting the burr height and burr thickness in dry drilling of AISI 1015 steel. The conclusions of this present study were drawn as follows:

- The optimal levels of the controllable factors were cutting speed 28 m/min, feed rate 0.1 mm/rev, drill diameter 20 mm and point angle 135° for burr height.
- The optimal levels of the controllable factors were cutting speed 16 m/min, feed rate 0.05 mm/rev, drill diameter 4 mm and point angle 142° for burr thickness.
- RSM has been used to determine the burr height and burr thickness attained by various drilling parameters. The quadratic modes developed using RSM were reasonably accurate and can be used for prediction within the limits of the factors investigated.
- From RSM model and experiment results, the predicted and measured values are quite close, which indicates that the developed model can be effectively used to predict the burr height and thickness. The given models can be utilized to select the level of drilling parameters.
REFERENCES