EFFECT OF PARAMETER CONDITION ON SURFACE ROUGHNESS FOR MACHINING AISI D2 HARDENED TOOL STEEL

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ABSTRACT: Hardened steel such as AISI D2 is often used in mould and die industry. Some of the application required to have good surface quality profile and sophisticated free-form shape simultaneously. In current industry practice, manual polishing and grinding is often performed to achieve the required machining tolerance which tends to lower the productivity and difficulty in ensuring the component accuracy. Machining surface roughness is directly affected by the milling parameter and should be methodically analyzed. Thus, this paper aims to study the effect of milling parameter on surface roughness of AISI D2 tool steel. Response Surface Methodology (RSM) technique was used to evaluate the influence of milling parameter namely cutting speed, feed rate and depth of cut on machined surface. From the conducted study, based on the statistical analysis result it is found that feed rate is the main factor that influence the surface roughness followed by milling speed and depth of cut. In addition, the machined surface roughness observed was between 1.5 to 4.5 μm Ra.

KEYWORDS: *Machining, AISI D2 Tool Steels, Surface Roughness.*

1.0 INTRODUCTION

End milling process is one of the most commonly used methods for mould and die manufacturing [1]. The requirements to have good surface quality on complex free-form shape poses a great challenge for mould and die manufacturer. The problem is worsened when the material is hardened steel such as AISI D2 tool steel. In current industry practice, the required workpiece surface roughness is achieved with manual polishing and grinding. Distinctly the existing techniques on achieving the desired surface finish for mould and die component have a tendency to lower productivity and difficulty in ensuring the component accuracy. The requirement for a fine surface roughness poses a major concern in machining of hardened materials due to its properties such as high wear resistance, high compressive strength, and high stability in hardening.

Machining performance such as surface roughness is directly affected by the milling parameter (cutting speed, feed rate and depth of cut) and should be methodically analyzed [2]. Thus, this paper aims to study the effect of milling parameter on surface roughness of AISI D2 hardened tool steel under flooded machining condition. Response Surface Methodology (RSM) technique was used to evaluate the influence of milling parameter namely cutting speed, feed rate and depth of cut on machined surface.

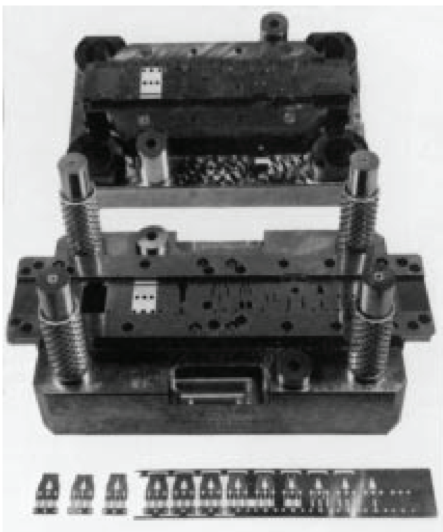


Figure 1: Progressive die made of AISI D2 tool steel

They were few reported work on machining AISI D2 tool steel found in the literature. Zhou et al. [3] studied the effect of tool angle on tool life and cutting forces when machining hardened AISI-52100 steel of hardness 60–62 HRC. The machining parameters used in their experiment were cutting speed of 160 m/min, feed rate of 0.05 mm/rev and depth of cut 0.05 mm. Konig et al. [4] pointed out that PCBN tools (with metal carbide binders) could economically be used not only for turning hardened steels but also for milling and drilling of these materials. Their turning test results showed that PCBN gave much longer tool life values compared to ceramic tools. Li et al. [5] investigated the rough machining cycle of free form surfaces to identify the optimum cutter path pattern for each cutting layer in contour map machining.

The study focused on free form surfaces with a single island and no significantly concave profiles. Cutter path planning/generation were automated and machining time was considerably reduced. The surface integrity formation of AISI D2 steel was studied by Kishawy and Elbestawi [6]. They concluded that, at cutting speeds above 350 m/min, the surface roughness increased with increase in tool wear and this was attributed to material side flow. In the literatures, it can be observed that most of the research in machining AISI D2 steel only focuses on few areas such as turning process and cutting tool material. Little attention is given on the effects of milling process parameter due to its complexity [7]. Proper selection of machining condition is extremely importance because the quality of surface finish has a major effect on the integrity and the adequate functioning of the mould and die component. The applications require high quality machined surfaces, including dimensional accuracy and surface integrity. Thus, there exists a strong need to study on the effect of milling parameter on the surface roughness formation for effectively machining AISI D2 tool steel.

2.0 EXPERIMENTAL WORK

The objective of this experimental work is to evaluate the effect of machining parameter on machined surface roughness during the end milling process. The workpiece used in the experiment was AISI D2 tool steel. The test specimen is a square block (200 mm by 200 mm) with thickness of 50 mm. The physical properties of AISI D2 tool steel materials are described in Table 1. A two flutes carbide flat end mill with a diameter of 10 mm and total length of 70 mm were used for slot cutting test. Slot milling cutting tests were conducted using a 5-axis Deckel Maho milling machine to investigate the machining surface roughness with respect to the changes in speed, feed rate and depth of cut. After the machining process, the surface roughness value and burr formation were measured using a Mitutoyo SJ-301 portable surface roughness tester and optical microscope respectively.

Table 1: Physical properties of AISI D2 tool steel materials

Typical analysis	C 1.55	Si 0.3	Mn 0.4	Cr 11.8	Mo 0.8	V 0.8
Standard specification	AISI D2, W.-Nr. 1.2379					
Delivery condition	Soft annealed to approx.. 210 HB					
Color code	Yellow/white					

Response Surface Methodology (RSM) technique was used to evaluate the effect of machining parameter. Central-Composite-Design (CCD) with six central points and α value of 1.68179 was employed as the design of experiment matrix. The three significant independent variables considered in this study were cutting speed (A), feed rate (B) and depth of cut (C), which are presented in Table 2. Each independent variable were varied over three levels between −1 and +1 at the determined ranges based on the recommendations of the cutting tool's manufacturer and the knowledge gathered through contemporary literature on machining AISI D2 tool steel material. A total of 17 numbers of experiments were generated for the analysis.

Table 2: Levels of independent parameters

	Low (-1)	Centre (0)	High (+1)
Cutting speed (m/min)	15	20	25
Feed rate (mm/tmin)	100	150	200
Depth of cut (mm)	0.2	0.4	0.6

Table 3: Central-Composite Response Surface design

Run	Cutting speed	Feed rate	Depth of cut
1	20	150	0.4
2	20	200	0.6
3	15	200	0.4
4	20	100	0.2
5	15	100	0.4
6	25	150	0.6
7	20	150	0.4
8	20	150	0.4
9	25	150	0.2
10	20	100	0.6
11	20	150	0.4
12	15	150	0.2
13	25	100	0.4
14	15	150	0.6
15	20	150	0.4
16	25	200	0.4
17	20	200	0.2

3.0 RESULT AND DISCUSSION

Based on the experimental runs, the observed surface roughness values varied between 1.5 and 4.5 μm. Table 4 shows analysis of variance (ANOVA) of the predicted response surface model on the influence of cutting speed, feed rate and depth of cut for a confidence level of 95%.

Based on the ANOVA, the quadratic model is found to be significant with a P-value of less than 0.05 and F-value of 29.00171. The cutting parameters with P-values of less than 0.05 indicate that these model terms significantly affect the response in the design space. In this model, based on the P-value and F-value the significant factors in chronological order from the highest F-value are B, C, BC, C2, B2 and A2. It can be observed that, feed exerts the strongest effect on the roughness value, whilst depth of cut has a secondary influence followed by cutting speed. Although by controlling the feed rate to a minimum value could control the surface roughness, however the machining productivity is low. Thus, the optimal combination between parameters is necessary to ensure the machining performance can be achieved. In addition, the interaction between these two factors (feed rate and depth of cut) also indicated a strong contribution to the model. Factors that value exceeding 0.1000 indicate that model terms are insignificant. Factor A, AB and AC are insignificant but not excluded from the mathematical model development so as to minimize the deviation between predicted and experimental values.

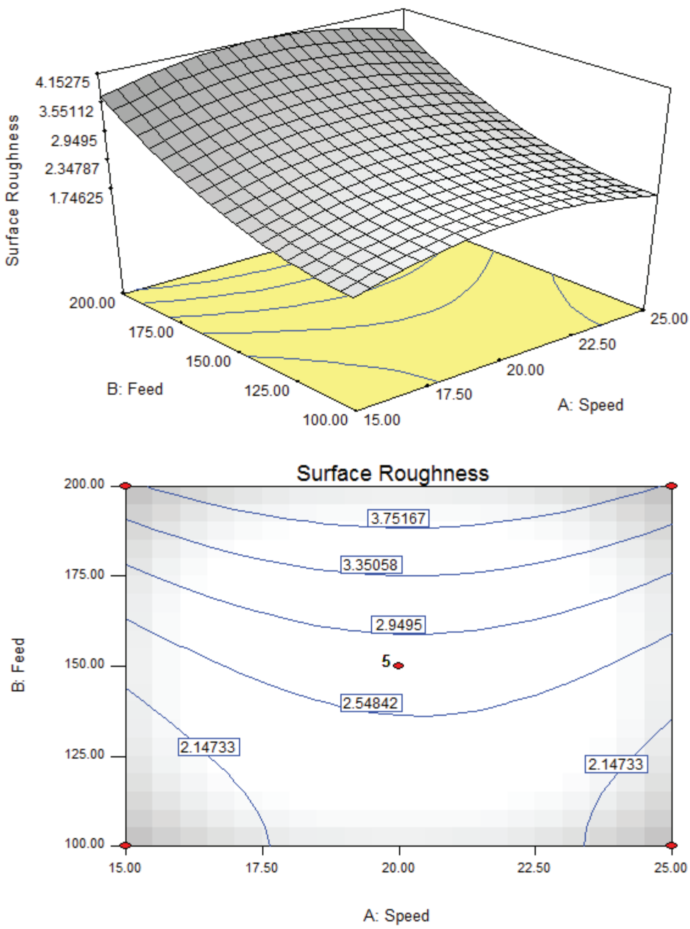
Table 4: ANOVA result

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	13.54688	9	1.505209	29.00171	< 0.0001	significant
A	0.023113	1	0.023113	0.445321	0.5259	
B	6.9192	1	6.9192	133.3161	< 0.0001	
C	2.844113	1	2.844113	54.7991	0.0001	
A2	0.863084	1	0.863084	16.62953	0.0047	
B2	0.870727	1	0.870727	16.77677	0.0046	
C2	0.959021	1	0.959021	18.478	0.0036	
AB	0.0064	1	0.0064	0.123312	0.7358	
AC	0.018225	1	0.018225	0.351151	0.5721	
BC	1.1236	1	1.1236	21.64903	0.0023	
Residual	0.363305	7	0.051901			

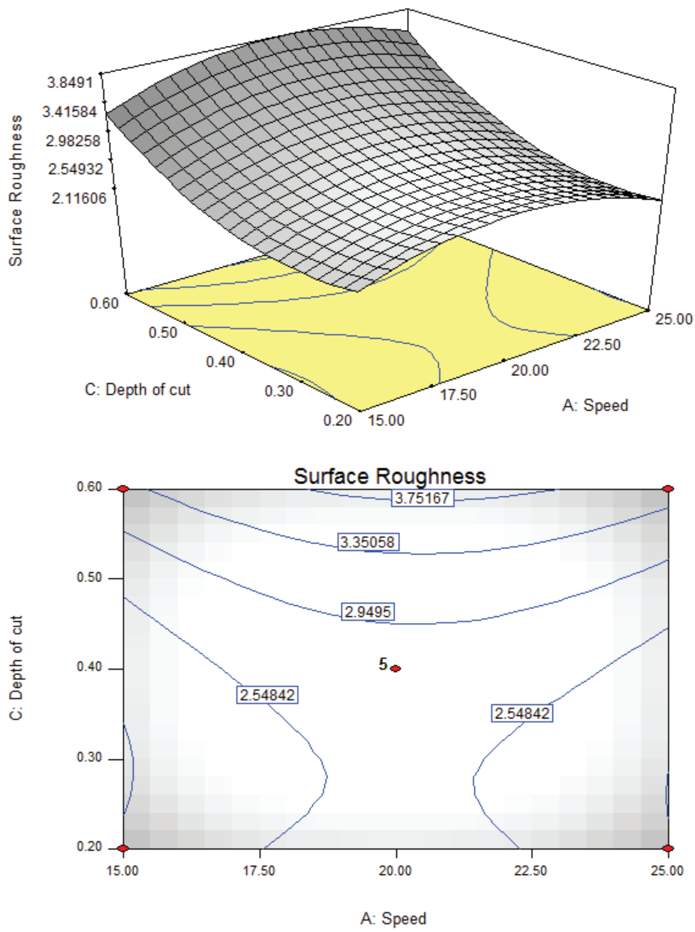
The predicted R2 of 0.974 is in reasonable agreement indicating that only 2.6% of the total dissimilarity might not be explained by the empirical model. For a good fit of a model, the correlation coefficient should be at a minimum of 0.80. High R2 value illustrates good agreement between the calculated and observed results within the range of experiment. Based on results, the response surface model constructed in this study for predicting surface roughness was considered reasonable [8]. The final regression model, in terms of their coded factors, is expressed by the following quadratic model (Equation 1).

$$Surface\ Roughness\ (\mu m) = 2.77 + 0.054A + 0.93B + 0.60C - 0.45A2 + 0.45B2 + 0.48C2 - 0.040AB + 0.067AC - 0.53BC \quad (1)$$

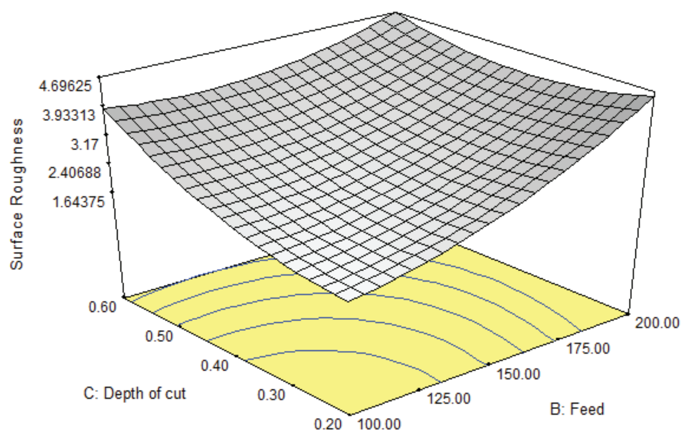
In Figure 2a, the 3D response surface and contour plots were introduced as a function of feed rate and spindle speed, while the depth of cut was kept constant. As can be seen in Figure 2a, it indicates that lower feed rate with higher cutting speed can reduce the surface roughness value. Figure 2b shows the 3D response surface and contour plots as a function of depth of cut and cutting speed, while feed rate was kept constant. At the maximal point of both parameters, minimum surface roughness can be seen in the graph. While the 3D response surface and contour plots as a function of depth of cut and feed rate are depicted in Figure 2c. It can be observed that by reducing the feed rate will greatly reduce the surface roughness values. On the other hand, increasing depth of cut slightly reduce the surface roughness values.

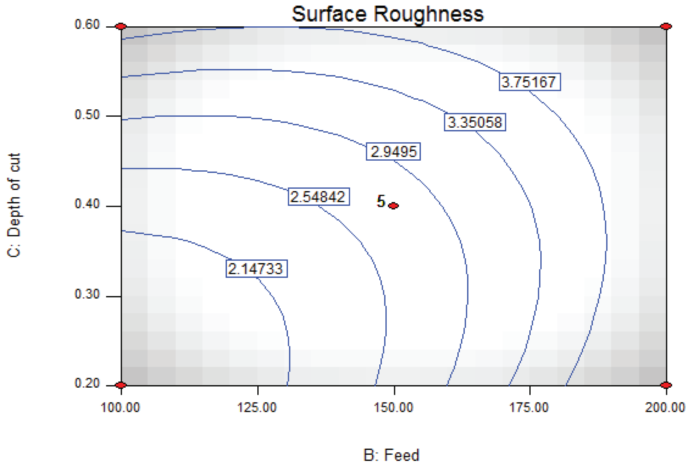


(a)


3.8491
3.41584
2.98258
2.54932
2.11606
Surface Roughness
0.60
0.50
0.40
0.30
0.20
C: Depth of cut
15.00
17.50
20.00
22.50
25.00
A: Speed
Surface Roughness
3.75167
3.35058
2.9495
2.54842
2.54842
5
C: Depth of cut
A: Speed

(b)

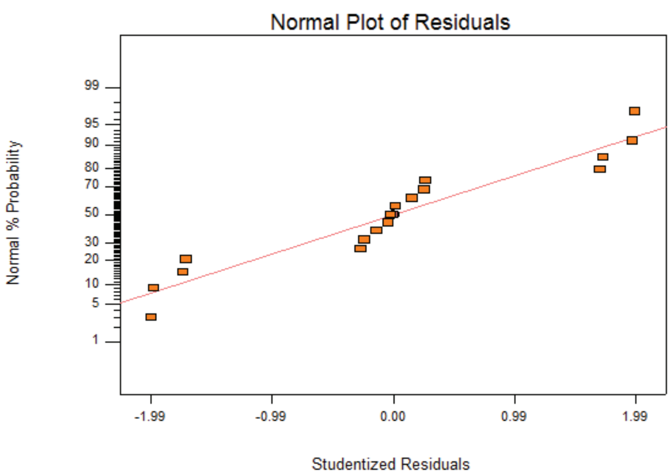

4.69625
3.93313
3.17
2.40688
1.64375
Surface Roughness
0.60
0.50
0.40
0.30
0.20
C: Depth of cut
100.00
125.00
150.00
175.00
200.00
B: Feed



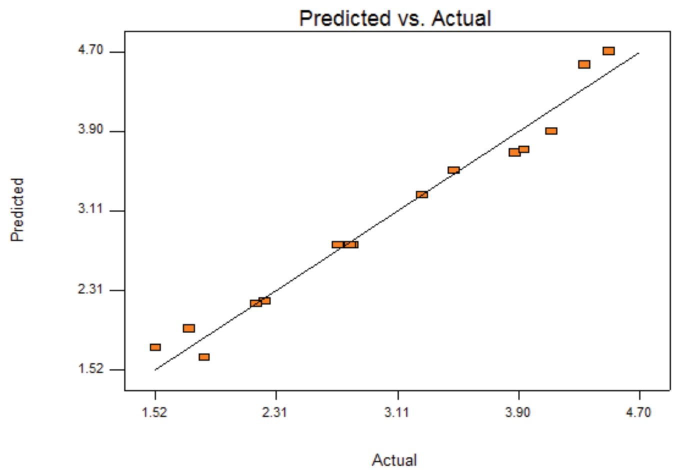
(c)

Figure 2: Response graph of factors interaction for surface roughness (a) feed-speed, (b) depth of cut-speed, and (c) depth of cut-feed

Normal probability plots of the studentized residuals and the predicted versus actual value plots were used to confirm the adequacy of the real system for approximation. It can be observed that the normal probability plots of the studentized residuals for the surface roughness value follow a normal distribution in a straight line. As shown in Fig. 3, the predicted values of surface roughness obtained from the model and the actual experimental data were in good agreement.



(a)



(b)
Figure 3: (a) Normal plot of residual, and (b) Predicted versus actual

4.0 CONCLUSION

Surface roughness play an important factor for mould and die material since the applications require high quality machined surfaces, including dimensional accuracy and surface integrity. Proper selection of machining condition is extremely importance because the quality of surface finish has a major effect on the integrity and the adequate functioning of the mould and die component. From the conducted investigations, it is evident that machining parameters are important criteria that affect the machined surface roughness characteristic. Based on the statistical analysis result it is found that feed rate is the main factor that influence the surface roughness followed by depth of cut and cutting speed. Although by controlling the feed rate to a minimum value could control the surface roughness, however the machining productivity is low. Thus, the optimal combination between parameters is necessary to ensure the machining performance can be achieved.

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