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Investigation on effects of cutting condition on surface roughness in dry hard milling of AISI D2 tool steel

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Abstract
The paper aims to study the impacts of cutting speed, feed rate and depth of cut on the values of surface roughness R_a in dry hard milling of AISI D2 steel (60 ÷ 62 HRC) using coated carbide inserts. The Box-Behnken experimental design was applied to study the influences of input machining variables. The obtained results revealed that the feed rate has the strongest effect on surface roughness, followed by the cutting speed. Meanwhile, the depth of cut has insignificant influence. The interaction effects between cutting speed and depth of cut as well as between feed rate and depth of cut have the significant influences on the surface roughness R_a. Moreover, The cutting speed v=120 m/min, feed rate f=0.1mm/tooth, and cutting depth d= 0.1mm should be recommended for reaching the smaller surface roughness R_a values, which will be the helpful technical guides for further studies and machining practice on the hard milling process.
Keywords: *Hard milling; cutting parameter; cutting speed; feed rate; depth of cut; surface roughness;*

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I. Introduction

Up to now, milling is a cutting process and is commonly used for flat surfaces by using the cutting tools with multiple cutting edges, thereby achieving the high material removal rate [1]. Milling process has been playing an important role in the mold industry to form the mold cavity [2]. Along with the advances in the development of CNC machine tools, the milling process nowadays is widely used and automated. It promotes the productivity and contributes to reduce the manufacturing costs while ensuring the technical requirements. Recently, the demand for milling the new alloy steels and hardened steels has been increasing and putting more pressure and new challenges in the milling technology [3].

AISI D2 steel is a high-carbon, high-chromium, and air-hardening tool steel. It is extremely wear and abrasive resistance. In the hardened state, AISI D2 steel exhibits low deformation. Due to its high chromium content, hardened AISI D2 steel has a modest ability to resist corrosion. AISI D2 tool steel has good corrosion resistance when polished and hardens in air, so it is frequently used for tools that operate in harsh wear-and-tear environments or as an alternative to oil-hardening tool steel grades when lengthy runs are necessary [4]. However, AISI D2 tool steel is grouped among the difficult-to-cut materials so that the cutting tools and cutting modes are carefully selected. The coated carbide tools exhibit the high hardness, high abrasion resistance, low cost, especially good impact resistance [5], so they are commonly used in the hard milling process [6].

The application of hard milling technology has brought out an alternative solution to supplement or replace the grinding process [3,7].

Besides, the high dimensional accuracy and good surface quality can be achieved by this process. However, there has been a little information on the hard milling performance of AISI D2 tool steel [5,8]. Therefore, the author made a study on the influence of cutting speed, feed rate and depth of cut during hard milling of AISI D2 tool steel (60÷62HRC) on surface roughness R_a. The effect of each input factor and the interaction effects are investigated. Also, the technical guides are provided from the study results.

II. Methodology

The experiments were carried out on MCV-410 milling machine (Japan) under dry condition (Figure 1). AISI D2 tool steel samples were hardened to reach the hardness values ranging from 60 to 62HRC and used for the hard milling experiments. The chemical composition and mechanical Properties of AISI D2 tool steel are given in Tables 1, 2. The surface roughness R_a was measured three times after each cut and the average value was taken. The Box-Behnken experimental design was used to study the effects of input machining parameters (cutting speed, feed rate, and depth of cut) on surface roughness R_a. The input variables with their levels are given in Table 3.

Table 1. Chemical composition of AISI D2 tool steel (ASTM A681 standard specification)

Element	C		Mn		P	S	Si		Cr		V		Mo	
Weight (%)	1.4	1.6	0.1	0.6	0.03	0.03	0.1	0.6	11	13	0.5	1.1	0.7	1.2

Table 2. Mechanical Properties of AISI D2 tool steel

Mechanical Properties	Metric	Imperial
Hardness, Knoop (converted from Rockwell C hardness)	769	769
Hardness, Rockwell C	62	62
Hardness, Vickers	748	748
Izod impact unnotched	77.0 J	56.8 ft-lb
Poisson's ratio	0.27-0.30	0.27-0.30
Elastic modulus	190-210 GPa	27557-30457 ksi

Figure 1. MCV-410 milling machine used for experiments

Table 3. Input variables and their levels

Input variables	Low level	High level	Output variable
Cutting speed (m/min)	80	120	Surface roughness R_a (μm)
Feed rate (mm/tooth)	0.1	0.2	
Depth of cut (mm)	0.1	0.2	

III. Results and discussion

The hard milling experiments were carried out by following the Box-Behnken experimental design. ANOVA results showing the effects of cutting parameters on surface roughness R_a are given in Table 4. The regression model of surface roughness R_a is given in Equation 1. The Pareto chart in Figure 2 presents the influences of each parameter and the interactive effects of the input variables on R_a. In Figure 2, it can be observed that the feed rate causes the strongest impact on surface roughness R_a, followed by the cutting speed. At the same time, the depth of cut and other interactive effects have little influence.

$$R_a\ (\mu m) = 0.317 - 0.00544*v + 2.18*f - 0.34*d + 0.000019*v*v - 7.15*f*f + 0.95*d*d + 0.00575*v*f + 0.00050*v*d + 0.60*f*d \quad (1)$$

Table 4. ANOVA results of effects of cutting parameters on surface roughness R_a

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.013057	0.001451	6.78	0.024
Linear	3	0.011398	0.003799	17.77	0.004
v (m/min)	1	0.001540	0.001540	7.20	0.044
f (mm/tooth)	1	0.009730	0.009730	45.50	0.001
d (mm)	1	0.000128	0.000128	0.60	0.474
Square	3	0.001517	0.000506	2.36	0.188

Source	DF	Adj SS	Adj MS	F-Value	P-Value
v (m/min)*v (m/min)	1	0.000215	0.000215	1.00	0.362
f (mm/tooth)*f (mm/tooth)	1	0.001180	0.001180	5.52	0.066
d (mm)*d (mm)	1	0.000021	0.000021	0.10	0.768
2-Way Interaction	3	0.000142	0.000047	0.22	0.878
v (m/min)*f (mm/tooth)	1	0.000132	0.000132	0.62	0.467
v (m/min)*d (mm)	1	0.000001	0.000001	0.00	0.948
f (mm/tooth)*d (mm)	1	0.000009	0.000009	0.04	0.846
Error	5	0.001069	0.000214		
Lack-of-Fit	3	0.001037	0.000346	21.61	0.045
Pure Error	2	0.000032	0.000016		
Total	14	0.014126			

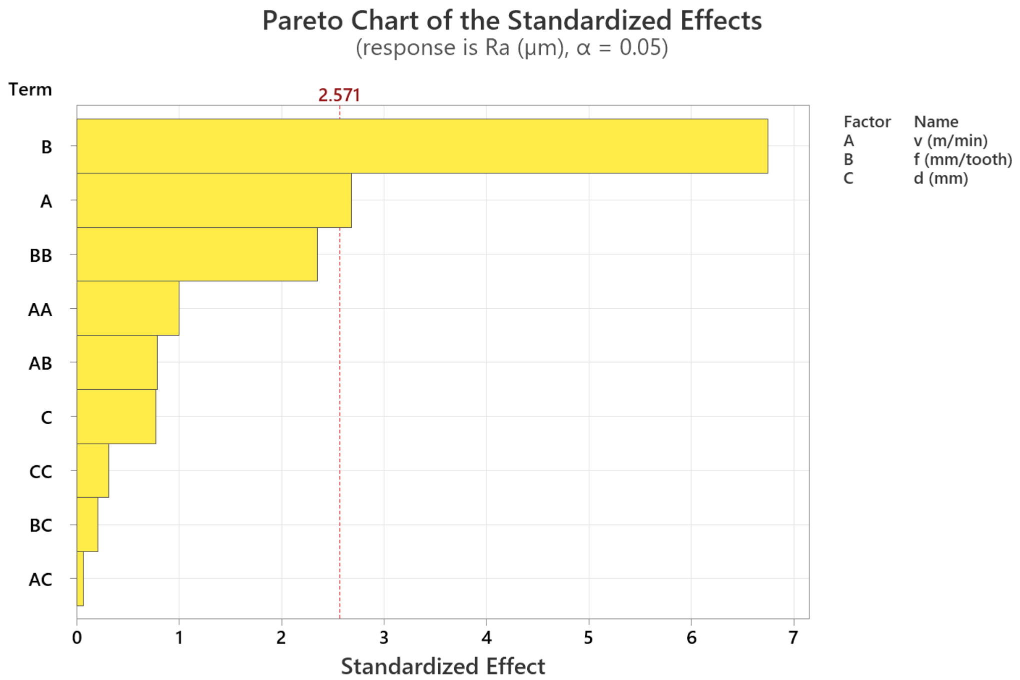

Figure 2. Pareto chart of the effects of input variables on surface roughness R_a

In Figure 3, it was noticeable that the feed rate has the greatest influence on surface roughness R_a due to the increase of the cutting layer area [2]. R_a values go up quickly when the feed rate rises from 0.1 mm/tooth to 0.2 mm/tooth. At the same time, the smaller growing rate is observed when the depth of cut increases from 0.1mm to 0.2mm. In contrast, the growth of cutting speed from 80m/min to 120 m/min contributes to reduce the surface roughness R_a, which can be explained by the reduction of cutting forces and cutting heat [3].

The graph of interaction effects of input machining variables shown in Figure 4 indicates that the interaction effects between cutting speed and depth of cut as well as between feed rate and depth of cut have the significant influences on surface roughness R_a. On the other hand, the interaction effect between cutting speed and feed rate has insignificant influence. Hence, the reasonable set of cutting parameters is chosen as the cutting speed of 120 m/min, feed rate of 0.1mm/tooth, and cutting depth of 0.1mm for achieving the smaller surface roughness R_a values.

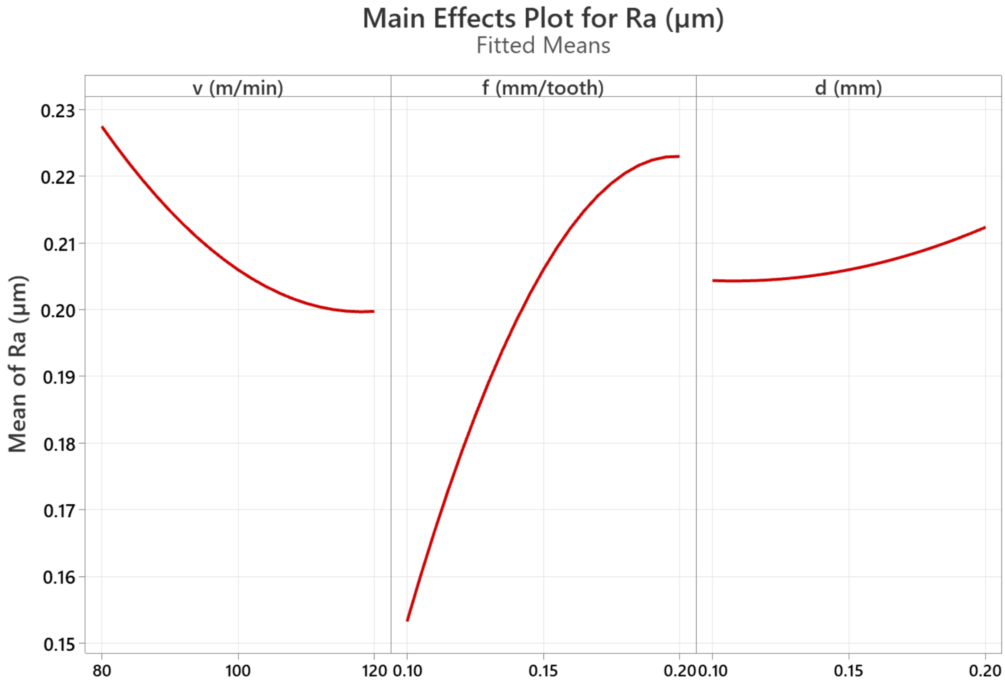

Figure 3. Main effects of input variables on surface roughness R_a

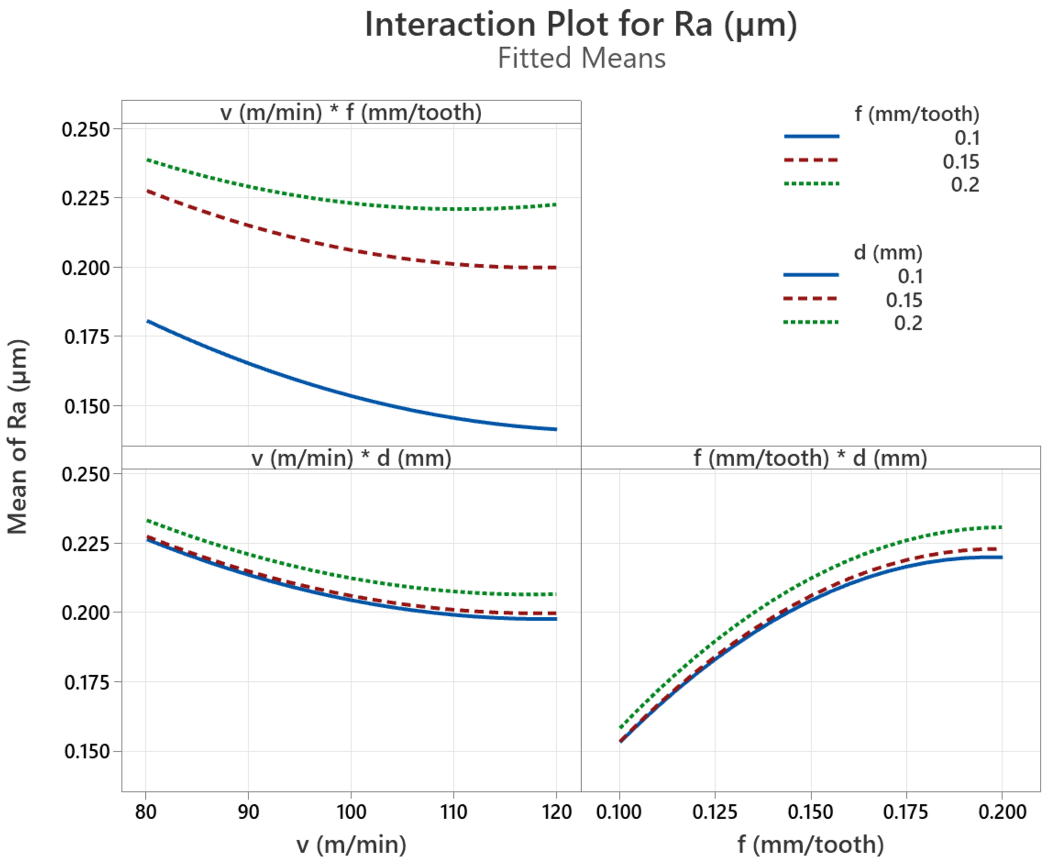

Figure 4. Interaction effects of input variables on surface roughness R_a

IV. Conclusion

In this article, the influences of the input machining variables on the values of surface roughness R_a in hard milling of AISI D2 steel (60÷62HRC) using coated carbide inserts under dry environment were experimentally studied. The Box-Behnken experimental design was used to evaluate the influence of cutting speed, feed rate and depth of cut. The obtained results clearly show the influence trends and interaction effects on surface roughness R_a. Among the surveyed factors, the feed rate has the strongest impact on surface roughness R_a, followed by the cutting speed, while the depth of cut exhibits the little impact. On the other hand, the interaction effects between cutting speed and depth of cut as well as between feed rate and depth of cut have the significant influences on surface roughness R_a. Moreover, the technical guide is provided for further investigations and machining practice. The cutting speed v=120 m/min, feed rate f=0.1mm/tooth, and cutting depth d= 0.1mm should be suggested for achieving the smaller surface roughness R_a values.

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References

[1]. D.A Stephenson, J.S Agapiou. Metal Cutting Theory and Practice. CRC Press 2016.
[2]. An Qinglong, Wang Chang ying, Xu Jinyang, Liu Pulin, Chen Ming. Experimental investigation on hard milling of high strength steel using PVD-AlTiN coated cemented carbide tool, International Journal of Refractory Metals and Hard Materials (2013), doi: 10.1016/j.ijrmhm.2013.11.007 IRP 37 (1), pp 89-92.
[3]. J. Paulo Davim. Machining of Hard Materials. Springer-Verlag London Limited 2011.
[4]. M.C. Kang, K.H. Kim, S.H. Shin, S.H. Jang, J.H. Park, C. Kim. Effect of the minimum quantity lubrication in high-speed end-milling of AISI D2 cold-worked die steel (62 HRC) by coated carbide tools. Surface & Coatings Technology 202 (2008) 5621–5624.
[5]. Klocke F, Brinksmeier E, Weinert K. Capability profile of hard cutting and grinding processes. CIRP Annals-Manufacturing Technology (2005) 54:22-45
[6]. Halil Calıskan, Cahit Kurbanoglu, Peter Panjan, Miha Cekada, Davorin Kramar. Wear behavior and cutting performance of nanostructured hard coatings on cemented carbide cutting tools in hard milling. Tribology International 62 (2013) 215–222.
[7]. Saketi, S.; Sveen, S.; Gunnarsson, S.; M'Saoubi, R.; Olsson, M. (2015). Wear of a high cBN content PCBN cutting tool during hard milling of powder metallurgy cold work tool steels. Wear, 332-333, 752–761. doi:10.1016/j.wear.2015.01.073
[8]. Sharma, A., Kalsia, M., Uppal, A. S., Babbar, A., & Dhawan, V. (2021). Machining of hard and brittle materials: A comprehensive review. Materials Today: Proceedings. doi:10.1016/j.matpr.2021.07.452.