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A study on cutting parameters on dry hard milling of AISI D2 tool steel

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Abstract
The work presents an experimental study on the effects of cutting parameters on hard milling of AISI D2 tool steel using carbide tools. Box-Behnken experimental planning design for response surface methodology was used to analyze the influence of cutting speed, feed rate, and depth of cut on the surface roughness R_a. The obtained results showed that feed rate has the strongest impact on the surface roughness of machined surface, followed by cutting speed and depth of cut. The increase of R_a goes with the increase of the amount of feed and cutting depth. When the cutting speed grows, R_a values decrease. Also, the technological guides will be provided for further studies and machining practice. The use of cutting speed of 110 m/min, feed rate of 0.1 mm/r, and depth of cut of 0.2 mm should be recommended to achieve the better machined surface quality.
Keywords: *Hard milling, hard machining, cutting parameter, dry cutting, difficult-to-cut material*

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I. Introduction

In the field of industrial production, the increasing demand for productivity and product quality is putting new challenges to supporting industries, especially the mold manufacturing industry. In recent years, the mold industry is developing rapidly to meet the needs of the market [1]. Mold materials usually require high hardness, strength, and durability, as well as good wear resistance, so the commonly used materials to manufacture molds are tool steels, alloy steels, and so on [2]. AISI D2 tool steel is a commonly used steel for mold making because it can be heat treated to achieve high hardness of up to 60-62HRC to reach high strength and good wear resistance. Therefore, there have been some experimental studies on machining this type of steel. The finishing process of the mold cavity made of heat-treated steels plays a very important role, because it not only determines the dimensional accuracy but also the geometry of the machined parts [3]. Therefore, the solution for efficient machining of the mold cavity is always an urgent issue to research and develop. The traditional solution is grinding process and electrical discharge machine (EDM), but in recent years, hard milling is being applied more and more widely and attracting great attention from manufacturers and researchers. This technology shows outstanding machining productivity, while maintaining high accuracy. The use of cutting oil under flood condition for hard milling faces many difficulties due to the discontinuous cutting process, which easily causes thermal shock causing breakage of the cutting tool [4]. Another problem is that the cutting force and heat generated from the cutting zone are very high, so the selection of the cutting parameters as well as the cutting tool material plays a crucial role in the success of the hard milling process [5]. The most commonly used cutting tool materials in hard milling are coated carbide, ceramics, Cubic Boron Nitride (CBN), and so on. Q. An et al. [6] studied the hard milling performance of 30Cr3SiNiMoVA (30Cr3) using PVD-AlTiN coated cemented carbide tool. The obtained results indicated that the increase of cutting speed contributed to reduce the cutting forces and improve surface quality. The growth of feed rate and depth of cut causes negative effects on machined surface finish. Also, the high temperature from the cutting zone accelerated the tool wear and caused the oxidation on chip surfaces. M.C. Kang et al. [7] investigated high speed end milling of AISI D2 cold-worked die steel (62HRC) using coated carbide inserts under MQL environment. The authors stated that the better tool life was recorded by using MQL technique when compared to dry cutting. Also, the work deeply investigated the element content in the coated layer of carbide tool and showed the appropriate element content. H. Çalışkan et al. [8] made a study on the wear behavior and cutting performance of hard milling of AISI O2 cold work tool steel (58HRC) using carbide tools. The abrasive and oxidation wear are the main mechanism to cause tool failures. The AlTiN/TiN nanolayer coating gives the best wear resistance and brings out the longest tool life. In this study, the authors concluded that hard milling under dry condition exhibits the environmentally friendly characteristics and can be used to replace or support grinding process. However, the studies on hard milling process were still limited, so the author made a study on the effects of cutting parameters on hard milling of AISI D2 (52HRC) using carbide tools.

II. Material and Method

The AISI D2 tool steel with the hardness of 52HRC was used in the experiments and the chemical composition is shown in Table 1. The hard milling experiments were conducted on Muraki KV-700 vertical milling machine (Figure 1) by following Box–Behnken experimental designs for response surface methodology with three input variables with the help of Minitab 19 software. The input cutting variables and their levels are given by Table 2. The depth of cut is fixed at 0.12 mm. The carbide inserts with the designation of APMT 1604 PDTR LT3000 were used. The surface roughness was measured three times after each cutting trials and taken by the average values.

Table 1 – Chemical composition in % of AISI D2 tool steel

Chemical composition (%)										
C	Si	Mn	Ni	Cr	Mo	W	V	Cu	P	S
1.4 - 1.6	0.4	0.6	0.5	11.0 -13.0	0.8 -1.2	0.2 - 0.5	$\leq$ 0.25	$\leq$ 0.25	$\leq$ 0.03	$\leq$ 0.03

Table 2. The input cutting variables and their levels

Input machining parameters	**Low**	**High**
Cutting speed, V (m/min)	70	110
Feed rate, f (mm/r)	0.10	0.14
Depth of cut (mm)	0.2	0.6

Figure 1. Muraki KV-700 vertical milling machine

III. Results and Discussion

The experiments were carried out by following the standard order of the Box-Behnken experimental design and the surface roughness values were measured after each cutting trial. The Pareto chart shows the influence of the survey parameters on the objective function (Figure 2). It can be seen that the amount of feed has the greatest influence on the surface roughness, followed by the cutting speed and depth of cut. The second order interaction effect of the feed rate is also significant.

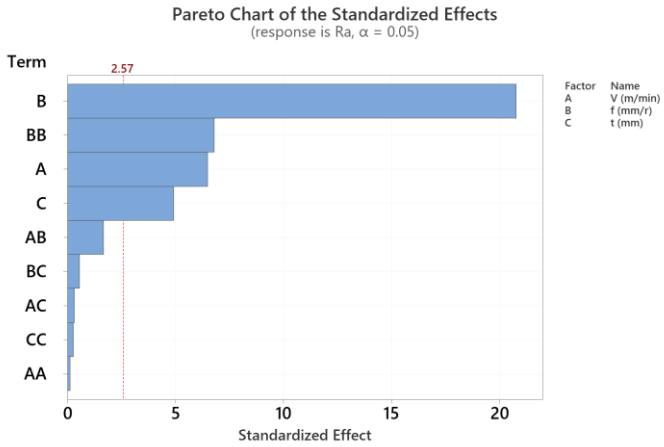

Figure 2. Pareto chart of the standardized effects of input variables on surface roughness

Figure 3 shows the independent influence of each survey parameter on the objective function. Through the results shown, increasing the cutting speed will contribute to the reduction of surface roughness. Meanwhile, as the feed rate and depth of cut increase, the surface roughness value goes up, especially with the feed rate. From the surface plot, the influence trend can be seen and the reasonable range of values can be determined to achieve the desired objective function. When the depth of cut is fixed at t=0.4mm, a high cutting speed should be selected in combination with a low feed rate for good surface quality (Figure 4).

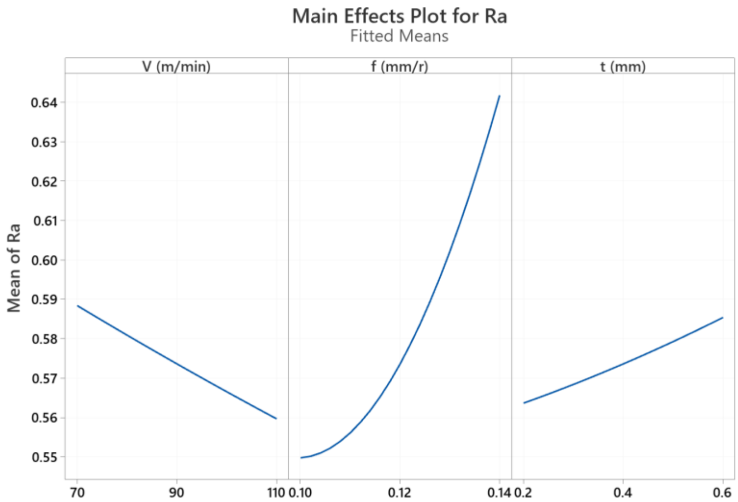

Figure 3. Main effects of input machining variables on surface roughness

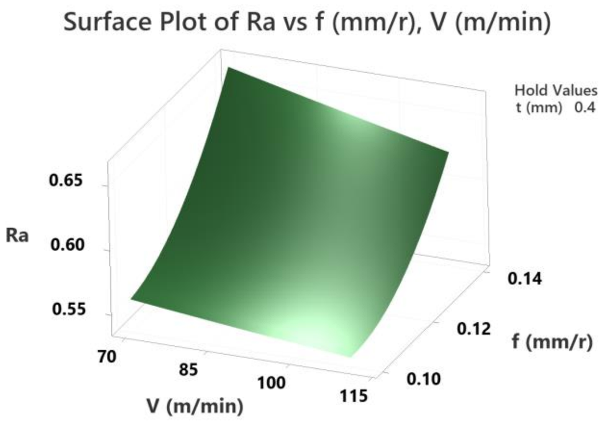

Figure 4. Surface plot of effects of cutting speed and feed rate on surface roughness

In Figure 5, when the feed rate is fixed at f=0.12mm/r, a high level of cutting speed combined with a low depth of cut should be chosen for good surface quality. In figure 6, the low levels of both feed rate and depth of cut should be used to achieve a smaller surface roughness values with a fixed cutting speed at 90 m/min.

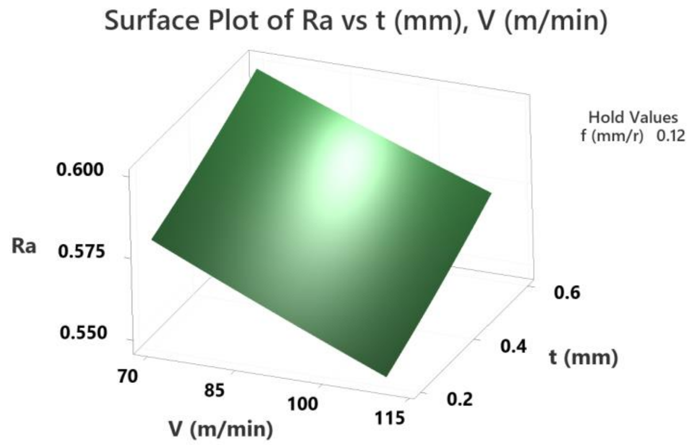

Figure 5. Surface plot of effects of cutting speed and depth of cut on surface roughness

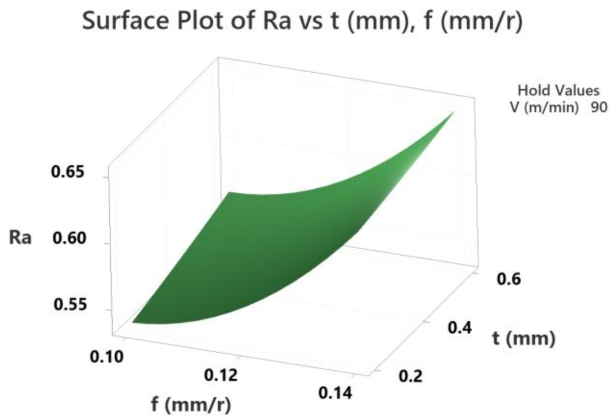

Figure 6. Surface plot of effects of feed rate and depth of cut on surface roughness

IV. Conclusion

In the work content, the hard milling process of AISI D2 (52 HRC) steel has been successfully carried out under dry condition using carbide inserts. The Box-Behnken experiment design with the support of Minitab 19 software was used to study the effects of cutting speed, feed rate and depth of cut on surface roughness R_a. The research results evaluated the influence level and trend of the input survey parameters on the objective function. In addition, the proper value domains will be the important technological instructions for application to the hard milling process in production practice. From empirical research, it is recommended to use the cutting speed of 110 m/min, feed rate of 0.1 mm/r, and depth of cut of 0.2 mm parameters to achieve the smaller surface roughness R_a. This study also plays an important role in the development of environmentally friendly machining solutions. In the further study, more investigation on the influence of cutting force is needed and the optimal set of parameters should be determined.

Acknowledgments

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