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# An investigation of cutting condition on hard milling of SKD 11 tool steel

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***Abstract***
*Hard machining technology is playing an increasingly important role in the field of metal cutting, including hard milling. Outstanding productivity, machining precision and high surface quality are notable advantages that have made this method attractive to researchers and manufacturers. In the paper content, the influence of input parameters on machined surface roughness is experimentally studied. Box-Behnken experimental planning design was used to evaluate the influence of cutting speed, feed rate, and hardness on surface roughness $R_a$ in hard milling of SKD 11 tool steel. The obtained results indicated that surface roughness was most influenced by feed rate. Moreover, the proper values of these input variables were determined and recommended to achieve the better machined surface quality.*
***Keyword:** Hard milling; MQCL; cutting fluid, hardness, cutting speed, feed rate, surface roughness*

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## I. INTRODUCTION

The field of metalworking and cutting plays a very important role in industrial production in the world. This is a group of methods that can machine most materials and surface types from simple to complex shapes [1]. Besides, the cutting processes can achieve very high accuracy and surface quality. Along with the development of supporting industries such as materials technology and machine tools, the productivity and quality of cutting processes are increasingly improved to better meet the growing needs [2]. The use of cutting oil for lubrication and cooling in the cutting zone plays a very important role, but the discharge of used cutting oil is one of the main causes of environmental pollution [3]. Meanwhile, more and more strict environmental regulations such as ISO 14000 and Green Round are setting new limits and requirements [4]. Therefore, the trend to reduce the use of cutting oils and use vegetable-based, biodegradable cutting oils has been recognized in research and applications in industrial production. Machining in dry condition is the first solution proposed and applied [5]. The complete elimination of cutting oil contributes to reduce the usage costs and especially the expensive cost of disposing of used cutting oil, thereby ensuring the environmental friendliness [6]. However, when machining hard or difficult-to-cut materials in dry condition, the cutting heat and cutting forces are very high. Therefore, rapid tool wear and low tool life are still the huge problems, especially in hard machining [7]. Since then, in hard machining technology, it is often required to use high-quality cutting tools such as CBN, ceramics, coated carbide tools. Besides, the selection of cutting tool material as well as the cutting parameters plays a crucial role, determining the efficiency of the cutting process [8]. In last 4 decades, there have been many studies on hard turning technology, but the research on hard milling is still limited [9]. In order to further improve the efficiency of the hard milling process, a technological solution for creating the lubricating and cooling effects in the cutting zone is required because the cutting force and heat generated in the cutting zone are very large. Therefore, Minimum Quantity Cooling Lubrication (MQCL) has been proposed and developed in recent years [9,10]. The introduction of a low-temperature cutting oil in the form of a high-pressure mist directly into the cutting zone results in a significant improvement. Therefore, the author is motivated to make a study on the effects of cutting speed, feed rate, and hardness of workpiece material on surface roughness $R_a$ in hard milling of SKD 11 tool steel.

## II. MATERIAL AND METHOD

### 2.1 Experimental design

Box-Behnken experimental design with the help of Minitab 19.0 software is utilized for three input parameters including cutting speed, feed rate and hardness with two levels given by Table 1.

***Table 1. Factorial design with two input variables and their levels***

| Input variables | Low level | High level | Response variables |
|---|---|---|---|
| Cutting speed, $V$ (*m/min*) | 90 | 110 | Surface roughness $R_a$ |
| Feed rate, $f$ (*mm/tooth*) | 0.012 | 0.016 | |
| Hardness (HRC) | 52 | 60 | |

## 2.2 Experimental devices

The cutting trails were conducted on Mazak vertical center smart 530C and the setup of experimental devices is shown in Figure 1. The chemical composition of SKD 11 tool steel samples is shown in Table 1. The APMT 1604 PDTR LT30 carbide inserts was used (Figure 2). The water-based emulsion 5% was used as the cutting fluid for MQCL system. The depth of cut was fixed at 0.12 mm. SJ-210 Mitutoyo (Japan) was used for measuring surface roughness, and the values of surface roughness were measured 3 times and taken by the average value. Each experiment trial was repeated 3 times and taken by the average values.

**Table 1.** Chemical composition of SKD 11 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 | ≤0.25 | ≤0.25 | ≤0.03 | ≤0.03 |

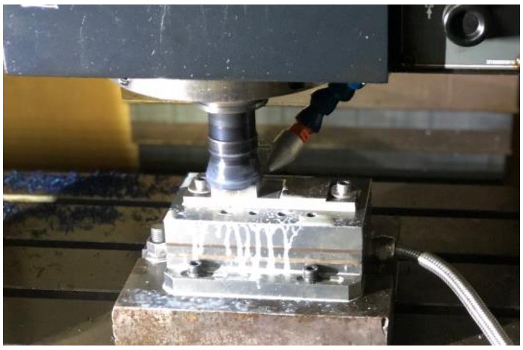

*Figure 1. Experimental set up*


*Figure 2. Milling head and carbide inserts used in the experiment*

## III. RESULTS AND DISCUSSION

The cutting trials were carried out by following the experimental run order, and the surface roughness values were measured after each trial. The Pareto chart of the input parameters exhibits the effects of the input variables and their interaction effects on the surface roughness (Figure 3). It can be seen that feed rate causes the strongest impact on the objective functions, followed by hardness of workpiece and then the cutting speed. The quadratic interaction effect of feed rate also has the large influence.

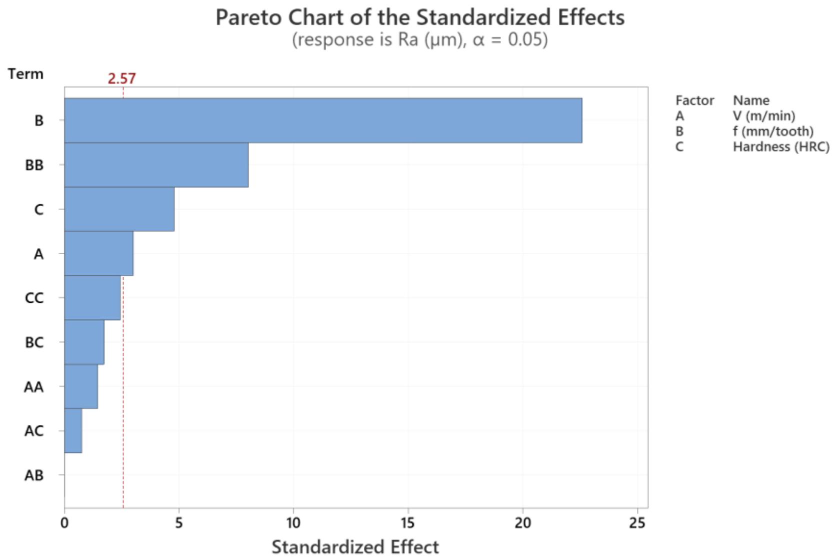


*Figure 3. Pareto chart of the input parameters on surface roughness $R_a$*

From Figure 4, it can be seen that when increasing the cutting speed from 90 to 110 m/min, the surface roughness tends to slightly decrease, but it decreases significantly with the increase of feed rate. When increasing the hardness of SKD 11 tool steel from 52 to 60 HRC, it contributes to increase the values of surface roughness. For figure 5, the interaction effects between the feed rate and hardness as well as between the cutting speed and hardness were significant. The interaction influence of cutting speed and feed rate is little.

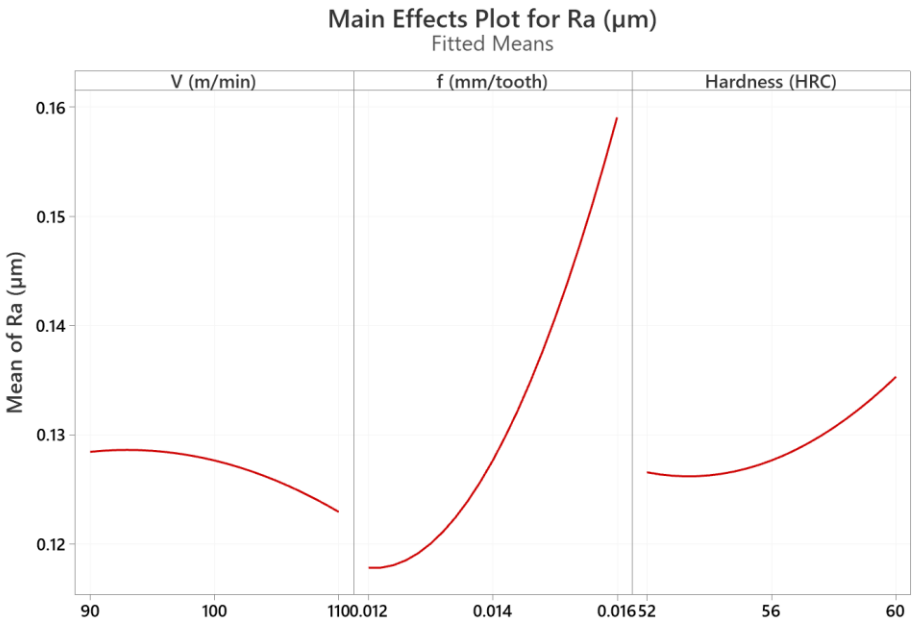


*Figure 4. Main effects of the input parameters on surface roughness $R_a$*

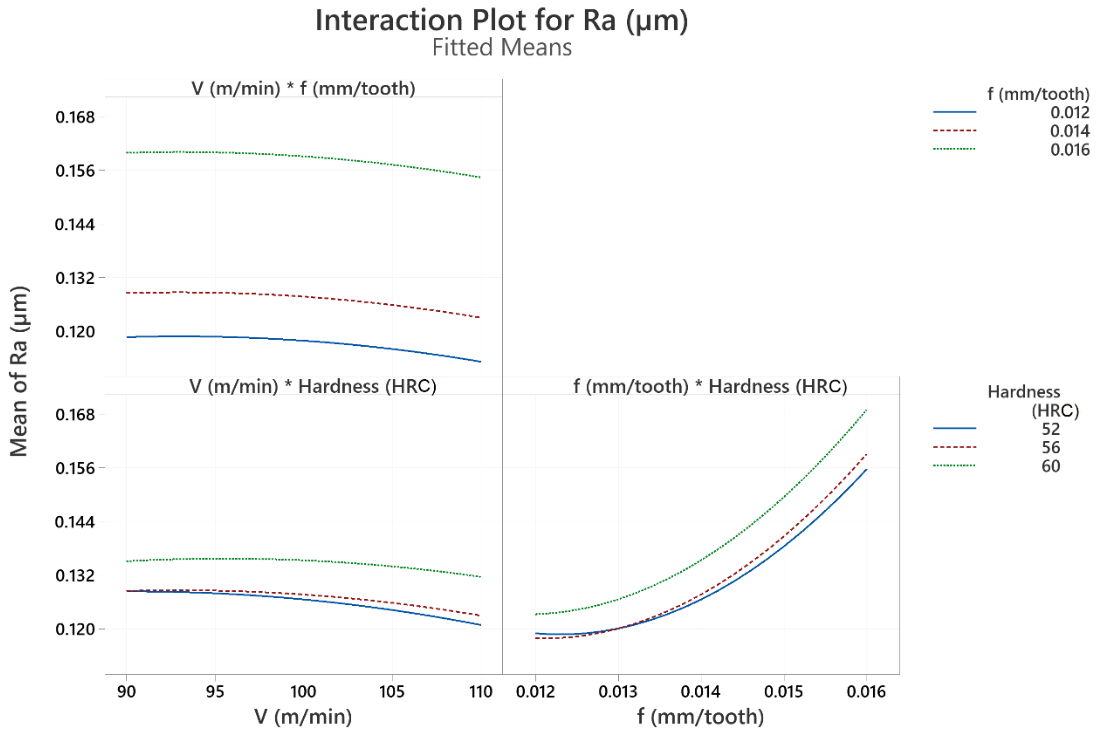


*Figure 5. Interaction effects of the input parameters on surface roughness $R_a$*

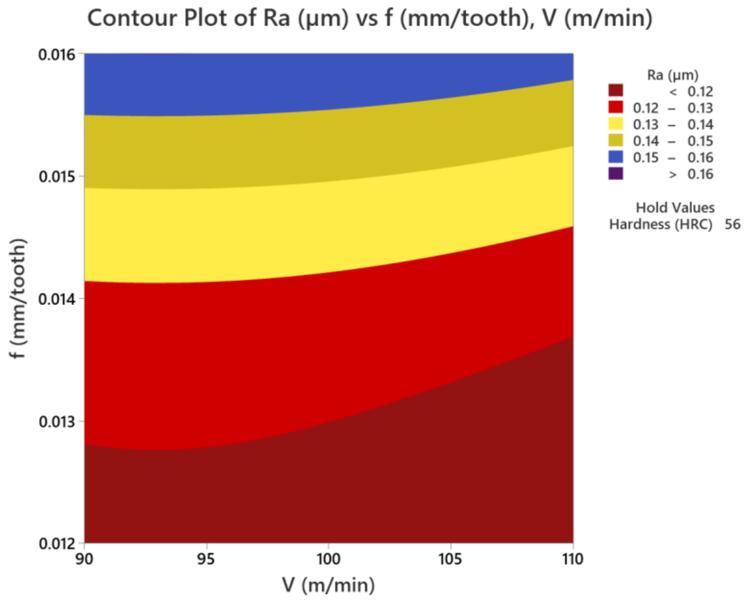


*Figure 6. Contour plot of feed rate and cutting speed on $R_a$*

From Figures 6, it can be seen that the combination of low levels of feed rate f=0.012-0.114 mm/tooth with the cutting speed levels V=90-110 m/min will achieve the lower surface roughness ($R_a$<0.12 µm) in the case of fixed hardness of 56 HRC. Meanwhile, for feed rate fixed at 0.014 mm/tooth, the combination of high cutting speed 105-110 m/min and the hardness of 52-56HRC can bring out $R_a$ <0.122 µm (Figure 7). For fixing V=100 m/min, using low feed rate f=0.012-0.013 mm/tooth and hardness of 52-58HRC will reach the lower $R_a$ values ($R_a$<0.12 µm) (Figure 8). Through the contour plots, the interaction effects between three input variable will be clearly presented, and it will help to provide the study direction and quickly choose the proper value domains to meet each specific criterion.

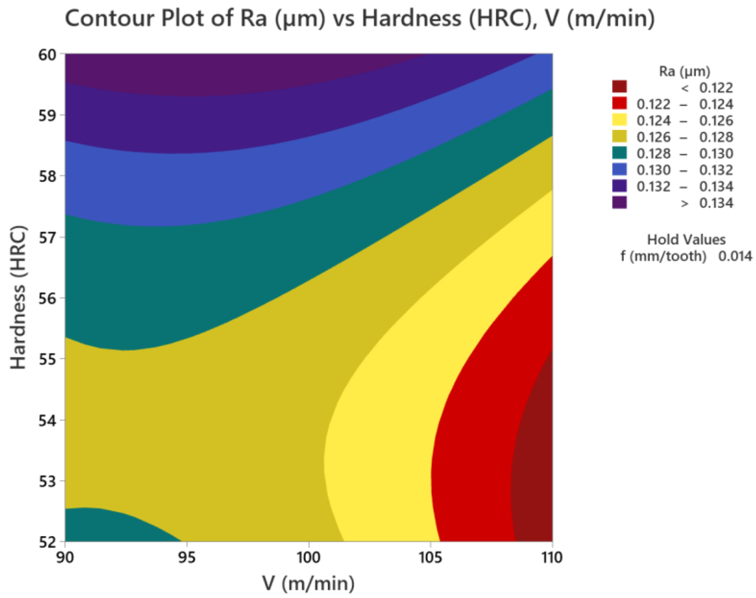


*Figure 7. Contour plot of hardness and cutting speed on $R_a$*

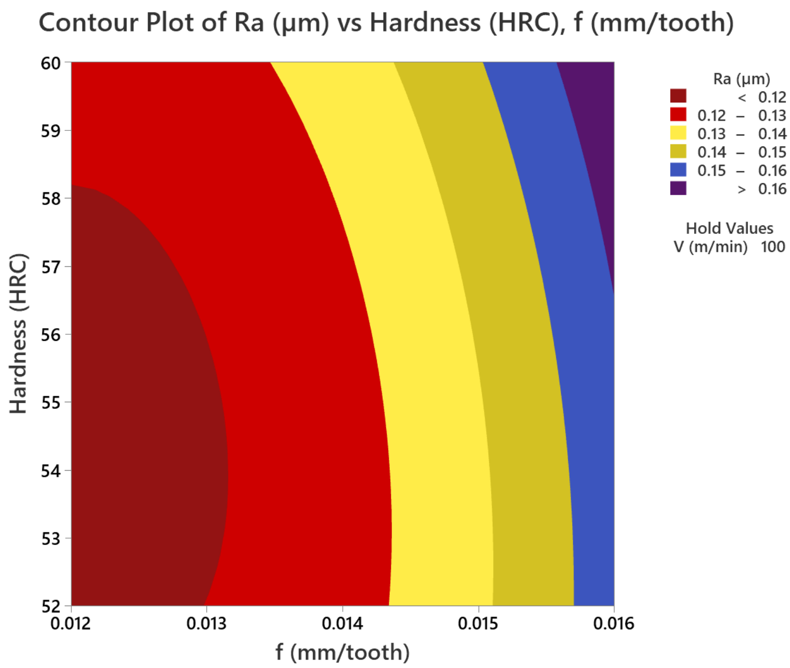


*Figure 8. Contour plot of hardness and feed rate on $R_a$*

## III. CONCLUSION

In this paper, the hard milling of SKD 11 tool steel under MQCL environment has been successfully conducted to study the influence of three input parameters including cutting speed, feed rate and hardness on surface roughness $R_a$. The obtained results show that MQCL technique has contributed to improve the hard milling performance and machinability of carbide tools due the significant enhancement of cooling lubrication in the cutting zone. Box-Behnken experimental planning design was used to study the effects and influence trend of the investigated variables. Among the three input variables, feed rate has the strongest impact on $R_a$, followed by hardness and cutting speed. From the contour graphs, technological guidelines are provided for the selection of input parameters to achieve the smaller surface roughness values. In further research, more investigations are needed to focus on optimizing cutting speed and feed rate.

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