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Effect of Cutting Parameters on Machinability of Hardened AISI 52100 Bearing Steel

[1]Mohammad Rafighi
*[1]Faculty of Engineering, Department of Mechanical Engineering University of Turkish Aeronautical Association, Ankara, Turkey

Abstract

In this study, the effects of machining parameters, namely feed rate, cutting speed and depth of cut on the surface roughness was investigated experimentally in hard turning of AISI 52100 bearing steel using cubic boron nitride insert under dry cutting condition. Taguchi method was utilized to reduce the number of trials to 9 for saving the time and manufacturing cost. The significant factor on the surface roughness was determined using analysis of variance. Furthermore, the optimum cutting parameter for reducing the surface roughness was obtained. The findings showed that the feed rate has the highest impact on surface roughness among any other cutting parameters, with 88.32% contribution.

Key words: AISI 52100 bearing steel, Surface roughness, CBN insert, Response surface methodology

1. Introduction

Over the last few years, there is a significant increase in research and development studies regarding the quality of the machining process on a global scale. Now there are some new norms formed on defining the parameters that affect the performance in metal cutting. These main parameters can be listed as cutting speed, depth of cut, feed rate and type of cutting tools. However, there are additionally two key factors in defining the outcome of the quality of metal products. These two elements are the type of the raw material and hardness of the materials with the combination of listed parameters mentioned earlier.

The structure of the base material plays a crucial role in the quality of the process, ease of machining, and precision of the final product. The hardness of the material may not be suitable enough or even may not be adequate for the applications in the metal machining industry. In these cases, it is required to utilize the heat treatment process. These refinements are widely used in particular applications. For instance: the production of bearing steel, heat treatment is exceptionally crucial. Once the hardness of the workpiece has been increased to the desired level, suitable cutting tools should be selected. Selecting the appropriate cutting tools based on the hardness of a material is of great importance in the manufacturing sector to have a reliable machining process.

The hard turning is performed on the materials that have a hardness of 45 HRC or greater. Hard turning is performed using specially produced cutting tool materials such as cubic boron nitride (CBN) and ceramics [1, 2]. Besides, with the increasing reliability of ceramic and CBN tools, hard

*Mohammad Rafighi: Address: Faculty of Engineering, Department of Mechanical Engineering, University of Turkish Aeronautical Association, 06790, Ankara, TURKEY. E-mail address: mrafighi@thk.edu.tr, Phone: +903125896107

turning has an important place in manufacturing. The following studies show the effect of different cutting tools during machining of hardened AISI 52100 bearing steel.

Bouacha et al. [3] performed a hard turning process on the AISI 52100 bearing steel (64 HRC) with CBN inserts. The relevance between output variables (cutting forces, surface roughness) and cutting parameters (feed rate, cutting speed and depth of cut) is determined using response surface methodology (RSM). The effects of cutting parameters on the output variables are examined using variance analysis (ANOVA). The quadratic RSM model has been used to achieve optimum cutting parameters (cutting force and surface roughness values). Based on the results, surface roughness mainly affected by feed rate and cutting speed. However, the depth of cut has a major effect on the cutting force. The values that provide the optimum surface roughness machining parameters are 246 m/min cutting speed, 0.08 mm/rev feed rate and 0.15 mm depth of cut.

Khamel et al. [4] evaluated the effect of cutting parameters on tool life, surface roughness and cutting forces. The material used in the turning machine is AISI 52100 bearing steel machined with CBN insert. According to the results, feed rate contribution on surface roughness is 64.09% and cutting speed contribution is 23.99%. The effect of cutting depth is negligible. Optimum cutting parameters for AISI 52100 bearing steel using CBN tool was found as: ap = 0.22 mm, f = 0.08 mm/rev and Vc = 168 m/min.

Meddour et al. [5] investigated the machinability of AISI 52100 steel (59 HRC) using a ceramic cutting tool. The results showed that cutting depth had an important effect on cutting forces. Furthermore, the effect of feed rate on the surface roughness was dominant. The better surface quality was obtained using a large nose radius cutting tool.

Ranjan Das and Kumar [6] evaluated the effect of machining parameters on the surface roughness and cutting force during finish hard turning of AISI 52100 steel using the CBN tool under dry cutting conditions. The design of the experiment was performed using Taguchi L_9, and ANOVA was utilized to determine the significant parameters. The results revealed the major effect of feed and cutting speed on the surface roughness with 68.12% and 25.11% contribution effect, respectively. However, cutting force mainly influenced by the depth of cut with 64.39% contribution.

Zhao et al. [7] investigated the effect of cutting parameters and nose radius on surface roughness and tool wear during hard turning of AISI 52100 using CBN inserts. They used three different nose radius (0.2, 0.3 and 0.4 mm). According to the result, nose radius has an important effect on the surface roughness and tool wear. The best surface quality was obtained using a 0.3 mm nose radius.

In this study, the effect of machining parameters (cutting speed, feed rate and depth of cut) was investigated on surface roughness during machining of hardened AISI 52100 bearing steel using cubic boron nitride insert under dry cutting condition.

2. Materials and Method

2.1. Workpiece preparation

AISI 52100 bearing steels have a high level of wear resistance. Also, AISI 52100 is high tensile, pressure and vibration resistant steels. It is generally used in the manufacture of different bearings. The purpose of the research conducted in the experiment is to measure the surface roughness of AISI 52100 bearing steel using CBN inserts. The workpiece has a length of 200 mm and a diameter of 50 mm.

Heat treatment of this material was performed as follows:
1. AISI 52100 exposed to 800-830°C for 4 hours.
2. The material was cooled at 70°C in oil.
3. It was tempered between 120-140°C.
4. The hardness was measured as 56 HRC.

The chemical composition of AISI 52100 bearing steel is presented in Table 1.

Table 1. Chemical composition of AISI 52100 bearing steel

Mo	Ni	Si	Cu	Mn	C	Cr
0.10	0.25	0.25	0.30	0.35	1.05	1.45

2.2. Lathe Machine and Cutting tools

The trials were conducted on the HARDINGE CONQUEST T42 CNC lathe machine. The maximum power of this machine is 13.2 kW, and the maximum spindle speed is 6000 RPM.

Cutting tool selection is very important in the turning process. Incorrect cutting tool selection may cause the operation not to be completed successfully. CBN (Cubic Boron Nitride) and the ceramic cutting tool can be used for machining hardened steel. They have high wear and abrasion resistance. In this study, Taegutec VBGW 160404 LS TB650 CBN cutting inserts with 0.4 mm nose radius was used.

2.3. A surface roughness measuring device

The material processing process started first with a surface cleaning of 1 mm. The MITUTOYO SJ-210 portable device was used to measure surface roughness. Then, for each combination of cutting parameters, three measurements were performed on three different places of the workpiece with 120° intervals, and the mean value of these three measurements was considered as final arithmetic surface roughness. The experimental setup for machining of AISI 52100 bearing steel is presented in Figure 1.

2.4. Cutting parameters and their levels

Machining of the material was performed by selecting cutting parameters, namely depth of cut (a), cutting speed (V), and feed rate (f) and depth of cut based on previous studies and cutting tool manufacturer catalog. In this study, depth of cut is (0.10 mm, 0.20 mm, 0.30 mm), cutting speed is (130 $m \cdot min^{-1}$, 190 $m \cdot min^{-1}$, 250 $m \cdot min^{-1}$), and feed rate is (0.06 $mm \cdot rev^{-1}$, 0.12 $mm \cdot rev^{-1}$, 0.18 $mm \cdot rev^{-1}$).

Figure 1. Experimental setup for machining of AISI 52100 bearing steel

3. Results and Discussion

The effect of cutting parameters on the surface roughness during hard turning of AISI 52100 is presented here. The design of the experiment was performed based on Taguchi L_9 orthogonal array. The full factorial design needs 27 trials, however using the Taguchi L_9 orthogonal array, the number of trials reduced to 9. The response surface methodology was applied to obtain the relationship between input and output parameters. The analysis of variance was performed to obtain the most significant factor that affects surface roughness, and the main effect plots showed the effect of each level of cutting parameters on the response. The experimental results for the surface roughness using are presented in Table 2. The surface roughness ranges 0.54-1.39 (μm) for CBN insert.

Table 2. Experimental results

Trial	a (mm)	V ($m \cdot min^{-1}$)	f ($mm \cdot rev^{-1}$)	Ra (μm)
1	0.10	130	0.06	0.62
2	0.10	190	0.12	0.88
3	0.10	250	0.18	1.11
4	0.20	130	0.12	1.05
5	0.20	190	0.18	1.26
6	0.20	250	0.06	0.42
7	0.30	130	0.18	1.39
8	0.30	190	0.06	0.54
9	0.30	250	0.12	0.75

3.1. ANOVA results for surface roughness

The analysis of variance was employed to analyze the contribution of input parameters on the surface roughness. Table 3 shows ANOVA results for surface roughness using CBN radius. The results revealed that the feed rate is the most significant parameter on the surface roughness with 88.32% contribution. Cutting speed is the next effective parameter, with an 11.31% contribution. Based on the results, the depth of cut does not affect the surface roughness. Most of the studies reported the same result, in which feed rate is the dominant factor in surface roughness [4-6].

Table 3. ANOVA results for surface roughness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
a	2	0.002422	0.27%	0.002422	0.001211	2.53	0.283
V	2	0.101422	11.31%	0.101422	0.050711	106.14	0.009
f	2	0.792089	88.32%	0.792089	0.396044	828.93	0.001
Error	2	0.000956	0.11%	0.000956	0.000478		
Total	8	0.896889	100.00%				

3.2. Main effects plot

The main effects plot for surface roughness, is illustrated in Figure 2. According to this figure, the surface roughness increased sharply by increasing the feed rate. However, increasing the cutting speed decreased the surface roughness. The depth of the cut does not affect the response. Minimum surface roughness value considering mean corresponds to (a: 0.1 mm, V: 25 $m \cdot min^{-1}$, f: 0.06 $mm \cdot rev^{-1}$).

Increasing the feed value increases the temperature in the machining zone due to removing a large number of chips. Therefore, surface quality adversely affected by increasing the feed rate.

However, increasing the cutting speed decreases the cutting forces during the machining, and it causes much better surface quality. Thus, it is of great importance to use a combination of low feed rate with high cutting speed to obtain the best surface quality.

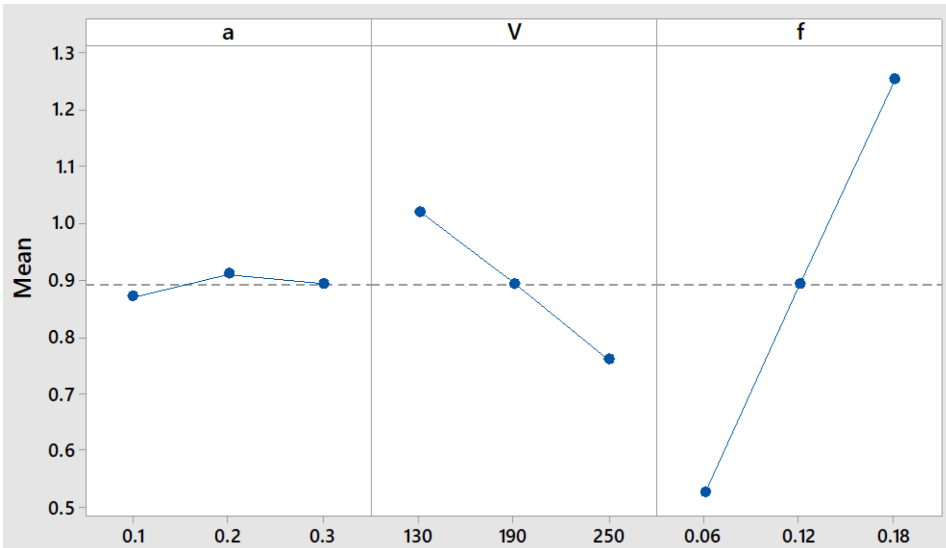

Figure 2. Main effects plot for surface roughness

3.3. Wireframe surface plots

The 3D wireframe surface plots show the combined effect of cutting parameters with surface roughness. The surface plots are given in Figure 3. According to the V-f plot, high cutting speed and low feed rate results in minimum surface roughness. The a-f plot shows the dominant effect of feed rate on the surface roughness. These plots confirm the result of the main effects plots.

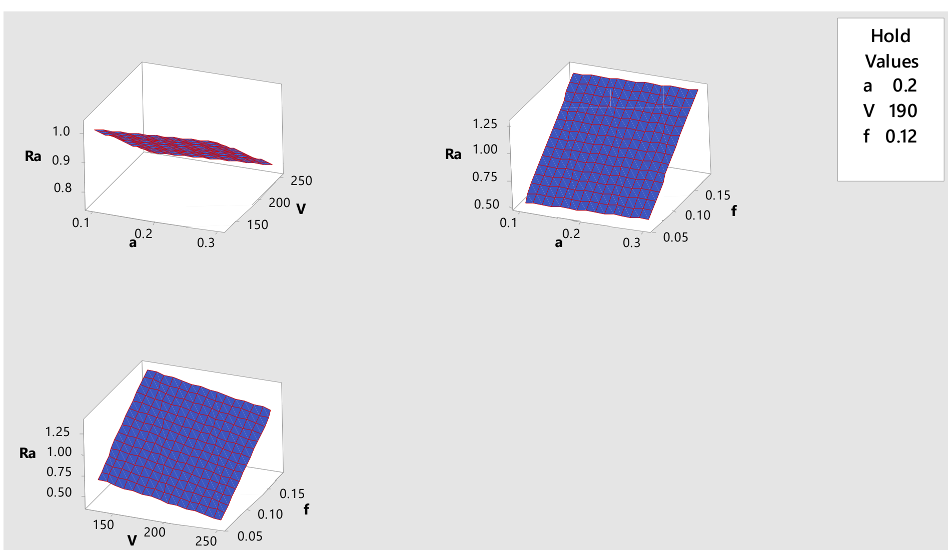

Figure 3. Wireframe surface plot for surface roughness

3.4. Mathematical models

The multiple linear regression models were used to develop the mathematical model for surface roughness. Equation (1) corresponds to surface roughness considering all machining parameters. According to the R^2, the developed model can predict surface roughness with very good accuracy.

The regression equation for surface roughness

$$Ra = 0.5528 + 0.1167\ a - 0.002167\ V + 6.056\ f \quad (1)$$

R-Sq = 99.89% R-Sq (adj) = 99.57% R-Sq (pred) = 97.84%

3.5. Optimum cutting parameters

The surface roughness mean value for CBN insert is given in Table 4. According to this table, the first level of feed rate, the third level of cutting speed and the first level of depth of cut should be selected to obtain the minimum surface roughness in hard turning of AISI 52100 bearing steel.

Table 4. Surface roughness mean value

Level	a	V	f
1	**0.8700**	1.0200	**0.5267**
2	0.9100	0.8933	0.8933
3	0.8933	**0.7600**	1.2533
Delta	0.0400	0.2600	0.7267

In addition, the mean surface roughness value for a CBN insert is 0.89 μm. According to the Equation (2) the surface roughness decreases by increasing the nose radius at low feed rate.

$$Ra = f^2/32r \quad (2)$$

Where, Ra is mean surface roughness in (μm), f is feed rate in (mm/rev), and r is nose radius in (mm).

Conclusions

In this study, hard turning was performed on AISI 52100 bearing steel using CBN inserts under dry cutting conditions. Three different depth of cut, cutting speed and feed rate were used as cutting parameters, and the number of trials decreased from 27 to 9 using Taguchi L_9 orthogonal array. The response surface methodology was utilized to obtain a relationship between input and output parameters. The most significant parameters were obtained using an analysis of variance. Optimum cutting parameters were selected based on minimum surface roughness.

The results show that the feed rate is the most significant parameter that affects surface roughness with 88.32% contribution. The next important parameter that influences surface roughness is cutting speed. According to the results, feed rate has a direct proportion with surface roughness, whereas cutting speed has indirect proportion. The main effects plot shows that as the feed rate increases, the surface roughness also increases. In contrast, as the cutting speed increases, the surface roughness decreases. Hence, the combination of high cutting speed with a low feed rate should be preferred to obtain the best surface quality.

Obtained mathematical equations show very good accuracy for predicting the surface roughness based on the cutting parameters. The surface roughness was modeled with 99.57% accuracy. The mean surface roughness value for a CBN insert was found to be 0.89 µm, which is acceptable for hard turning process.

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