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The Effects of Cutting Parameters Used in Milling X153CrMoV12 Cold Work Tool Steel by End Mills on Surface Roughness and Hardness of The Workpiece

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Abstract

The goal of this project is to investigate the effect of the spindle speed and feed rate used in milling X153CrMoV12 cold work steel by X5070 blue coated solid carbide end mill on surface roughness and hardness of the workpiece. For this purpose, 0.2 mm material was removed in one pass without using refrigerant with the machining parameters of 2000, 2500, 2800, 3000 rpm spindle speed and 160, 180, 200, 240 mm/min feed rate. As a result of the tests, the topographic structure, surface roughness, surface hardness and microhardness of the machined surfaces were determined by Leica DMS300, Mitutoyo SJ 210, HRS-150 digital rockwell hardness tester and microhardness tester Future-Tech FM-700, respectively. As the feed rate increased at a constant 2800 rpm spindle speed, the surface roughness (SR) increased as the amount of metal removed per unit time increased. As the spindle speed increased at a constant feed rate of 180 mm/min, the amount of chips for the next cutting decreased, as the cutting blade removed more chips with each turn, and therefore the surface roughness decreased. The effects of spindle speed and feed rate machining parameters on the surface hardness were not much, and the hardness value before and after the process was measured between 60-62 HRC. However, it was determined that the microhardness value decreased due to the use of heat-hardened steel as well as the heat generated by the milling parameters in the regions 50-350 µm deep from the machined surface.

1. INTRODUCTION

The End Milling is a method of material removal by dipping a hard cutting tool into a material with a lower hardness than itself in circular motions. Many materials such as heat treated steel, plastic, casting, composite, alloy with different properties and shapes can be processed with very high productivity and accuracy by the end milling method containing flat and/or ball end mills [1]. It is widely used in aerospace, defense, military sectors due to it can achieve high surface quality in casting materials at low cost, as well as precision processing of many materials [2-3]. The parts used in the aviation industry and the molds used in the production of these parts must be processed precisely and with a good surface quality [4]. High quality machining of X153CrMoV12, which is the most common cold work tool steel used in these molds, is also important. The Cold work steel (X153CrMoV12) is widely used in the industry, particularly in sheet metal dies for cold forming, deep drawing die as well as in rolling machines such as roller, knife, comb [5-8]. It is preferred in cutting and crushing applications due to its features such as high wear resistance and high toughness. Additionally, its hardness up to 62 ± 2HRC makes it charming to use [9]. However, tool wear and cost are encountered in the processing of hard materials with traditional methods, and it is difficult to obtain good surface quality [10-12]. Lima et al. focused on the turning of hardened AISI 4340 high strength low alloy steel and AISI D2 cold work steels (58HRC) using a coated carbide insert and a polycrystalline cubic boron nitride insert cutting tools. They reported that when machining AISI 4340 steel selecting nominal feed rates and depths of cut, the forces were higher

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when machining the softer steel and that SR of the machined part was improved as cutting speed was elevated and deteriorated with feed rate. They also found that the surface roughness increased with the increase in the feed rate and decreased with the increase in the cutting speed [13]. Campos et al. used Response Surface Methodology to determine the optimal values of the machining parameters on the turning of AISI 52100 steel with Al2O3/TiC tool with wiper geometry through the development of a mathematical model of tool life, surface roughness and profile surface roughness parameters [14]. Vardhan et. al. used Artificial Neural Networks (ANN) to estimate material removal rate (MRR) and SR in CNC milling of P20. In the experiments, they used the Taguchi's L50 orthogonal array to design the experiments by selecting cutting speed, feed, axial depth of cut, radial depth of cut and nose radius as the input parameters MRR and SR as the output parameters. They reported that the effect of cutting speed (mm/min) on MRR and SR was minimal, on the other hand, the effect of feed rate (mm/tooth) was significant [15]. Shokrani et al. investigated the effects of cryogenic coolingusing liquid nitrogen (LN2) as a coolant on the surface integrityof Ti–6Al–4V titanium alloy in end milling operations using solidcarbide tools. They reported that cryogenic cooling significantly improved surface integrity when milling Ti–6Al–4V, reducing surface roughness by 39% and 31%, respectively, compared to dry and flood cooling. They notified that the microhardness of surfaces treated using cryogenic processing increased more than the dry and flood cooling method; nevertheless, in cryogenic and dry machining, the depth of the heat-affected zone is lower than in flood cooling [16]. Xu et al., emphasized that minimal lubrication is beneficial in machining metallic materials. They also studied the effects of thrust force and delamination in the drilling of CFRP/Ti6Al4V composite materials with dry or minimal lubrication. They reported that dry machining without the use of oil benefits the reduction of thrust force and delamination [17]. Various cutting fluids are commonly used in this manufacturing process in order that decrease friction and minimize the heat generated between the workpiece and the cutting tool, and to enhance the workpiece surface and cutting quality [18]. Also Kulkarni et al. have expressed that the metal cutting operation unrealizable exactly in the absence of coolants/cutting fluids [19]. But use of the dry cutting method has gained importance due to its negative effects such as the high expenditure of using cutting fluids and harm to the health of the machine operators [20].

In this study, experiments were carried out without using any coolant in order to eliminate the negative environmental effects of fluids such as cutting oil used in cutting and chip removal processes, their harm to operators and usage costs. There is not enough work in the literature on the milling of hard materials with high surface quality without using coolants/cutting fluids. Hence, in this study, high hardness cold work tool steel X153CrMoV12 was processed using the end milling method and different machining parameters without the use of refrigerant thereby surface roughness, macro hardness as well as micro hardness of the processed steel surfaces were analyzed.

2.MATERIALS AND METHODS

2.1. Selected Test Materials

In this work, 1.2379 (X153CrMoV12) steel used in cold work applications, a ledeburitic steel containing 12% chromium, hardened up to 60-62 HRC hardness with a dimensions of 118 x 20 x 20 mm was used as the workpiece. This steel is preferred for analysis since it has high wear resistance and high toughness and is also widely used in cold forming molds. The workpiece was supplied with heat treatment from the Sağlam Metal company. The chemical composition as well as mechanical and physical characteristics of X153CrMoV12 are given in Table 1 and 2, respectively.

Table 1. *Chemical Composition of X153CrMoV12*

Carbon (C)	***Chrome (Cr)***	***Molybdenum (Mo)***	***Vanadium (V)***
1.55	12	0.8	0.9

Table 2. *Mechanical and physical properties of X153CrMoV12*

Usage Hardness (HRC)	*Thermal expansion coefficient* $(^{\circ}K)^{-1}x(10)^{-6}$	*Heat conductivity (W/mK)*	*Density g/cm³*	*Yield strength (MPa≥)*
60 - 62	10.5 - 13.00	16.7	7.85	420

YG X5070 (4 Flute 30° Helix Stub End mill) was used for milling hardened 1.2379 cold work steel. The X5070 blue – coated solid carbide end mills are preferred to machining high hardened mold & die steels with high speed cutting & dry cutting. The dimensions and shapes of G8A02080 X5070 were taken from YG catalogs; (D1:8) x (D2:8) x (L1:8) x (L3:20) x (L2:65) mm with 4 flute as well as h5 shank diameter tolerance as shown in figure 1.

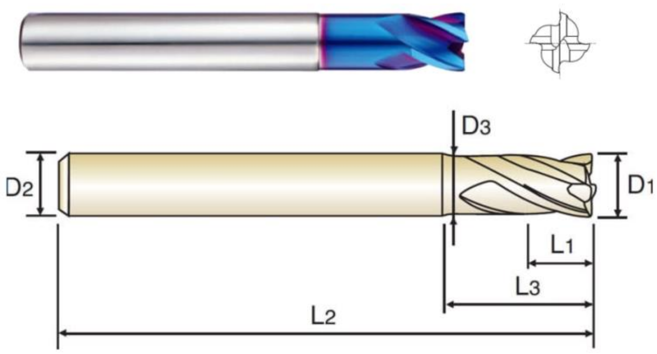
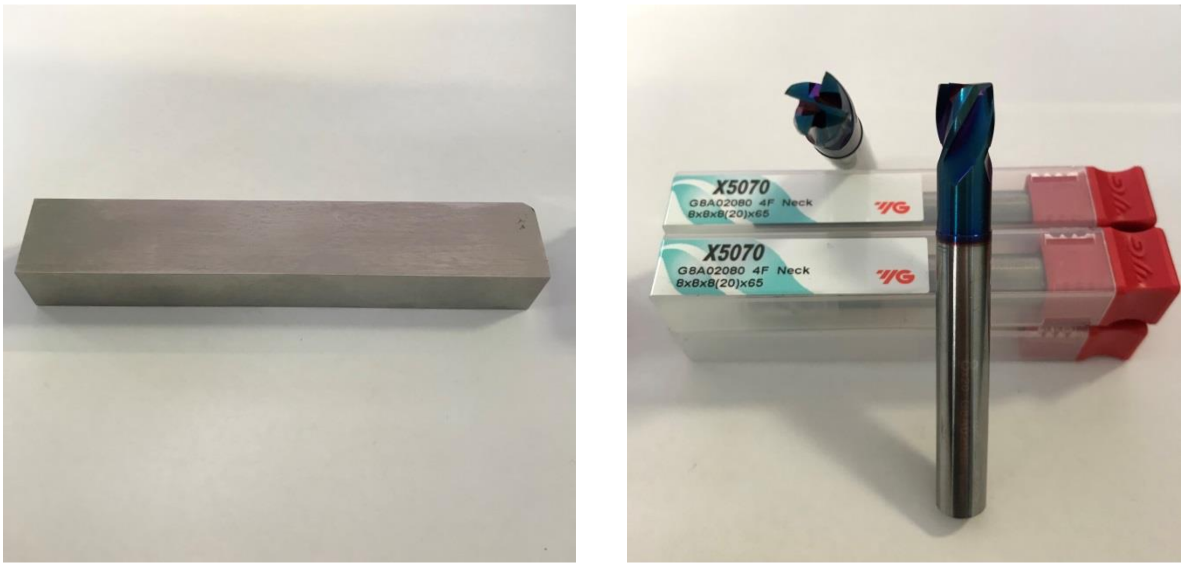


Figure 1. *The G8A02080 X5070 End mill technical drawing* [21].

X153CrMoV12 Cold work steel and X5070 blue – coated solid carbide end mills that used in milling operations are shown in figure 2. All surfaces of the cold work tool steel were ground.



(a) (b)

Figure 2. *Materials:* ***(a)*** *The X153CrMoV12) Cold work steel,* ***(b)*** *G8A02080 X5070 End mills*

2.2. Machining Methods

The acquisition time was changed to test whether the total counts obtained from both MCAs were compatible with each other. So, it was adjusted to 50, 100, 200 and 300 s. Each measurement was repeated three times to sensitively determine the number of counts for each time value. The counts from both MCAs were accumulated, and their averages were compared with each other.

In this study, vertical machining was performed using Makino S33 CNC machine with different machining parameters as shown in figure 3. In this figure, the milling process is shown in figure (a), while the dashboard where process parameters are controlled shown in figure (b). The cold work tool steel was carefully fixed to the vise and then the milling cutter was attached to the spindle and zeroing was made for each milling cutter. In each test process, only air was used as the coolant and milling operations were carried out by removing 0.2 mm of chips in one pass. Before each experiment, the workpiece was cleaned using compressed fresh air and a new milling cutter was used for each slot.

(a) (b)

Figure 3. *Machining centers MAKİNO S33 CNC : **(a)** Vertical milling **(b)** Dashboard*

2.3. Analysis Methods of Milled Parts

After the completion of the surface milling studies, surface examination with macro analysis, then surface roughness and hardness measurements were made, respectively. Surface controls were performed under high light and resolution using the digital microscope system Leica DMS300 as shown in figure 4: (a). After taking microscopic images, the surface roughness of each milled slot was determined using Mitutoyo SJ 210 as shown in figure 4 (b). Finally, surface hardness of all milled surfaces were measured using HRS-150 digital rockwell hardness tester as shown in figure 4 (c). The arithmetic mean of all measurements made was calculated and reported.

(a) (b) (c)

Figure 4. *Measurement analysis: **(a)** microscopical examination, **(b)** surface roughness, **(c)** hardness measurement*

All measurements after face milling were made in laboratories of Truva Makina Kalıp and Tel Erozyon San. Tic. ltd. Şti.

3.RESULTS

3.1. Milling Parameters and Experimental Findings

The machining parameters used in the surface milling of steels and the numerical values of the effects of these parameters are given in Table 3. The machining parameters used in the experiments were chosen by considering the safe working parameters of the CNC machine, the cutting regimes of the cutting tool and industrial applications. The results of the cutting operations using these parameters were recorded and the average values of the results obtained were reported. These values reflect the average values of 3 different tests for each procedure. The X5070 dry cutting high performance blue coated nanograin carbide end mills were used as the cutting tool in each experiment. Some features of this milling cutter; made of high hardness raw carbide material, high endurance and power. Its nano blue coating enables it to cut materials up to 65 HRC hardness at high speed.

Table 3. *Experimental set-up and milling parameters*

Test No	*Spindle Speed (rpm)*	*Feed Rate (mm/min)*	*Depth of Cut (mm)*	*Surface Roughness (Ra)*	*Surface Hardness (HRC)*
1	2800	240	0.2	0.772	59.60
2	2800	200	0.2	0.497	60.50
3	2800	160	0.2	0.480	60.40
4	3000	180	0.2	0.489	60.80
5	2500	180	0.2	0.686	60.40
6	2000	180	0.2	0.692	61.00

According to the results of the analysis, it was obtained that the spindle speed and feed rate cutting parameters had a remarkable effect on the roughness of the machined surfaces. On the other hand, the surface hardness of the machined surfaces was measured in the range of 60-62 HRC values, which was the steel hardness before machining. The topographic structure of the steels processed with different processing parameters was examined with a digital microscope system Leica DMS300 and shown in figure 5. Here, the cutting tool marks, which also affect the surface roughness, are clearly visible.

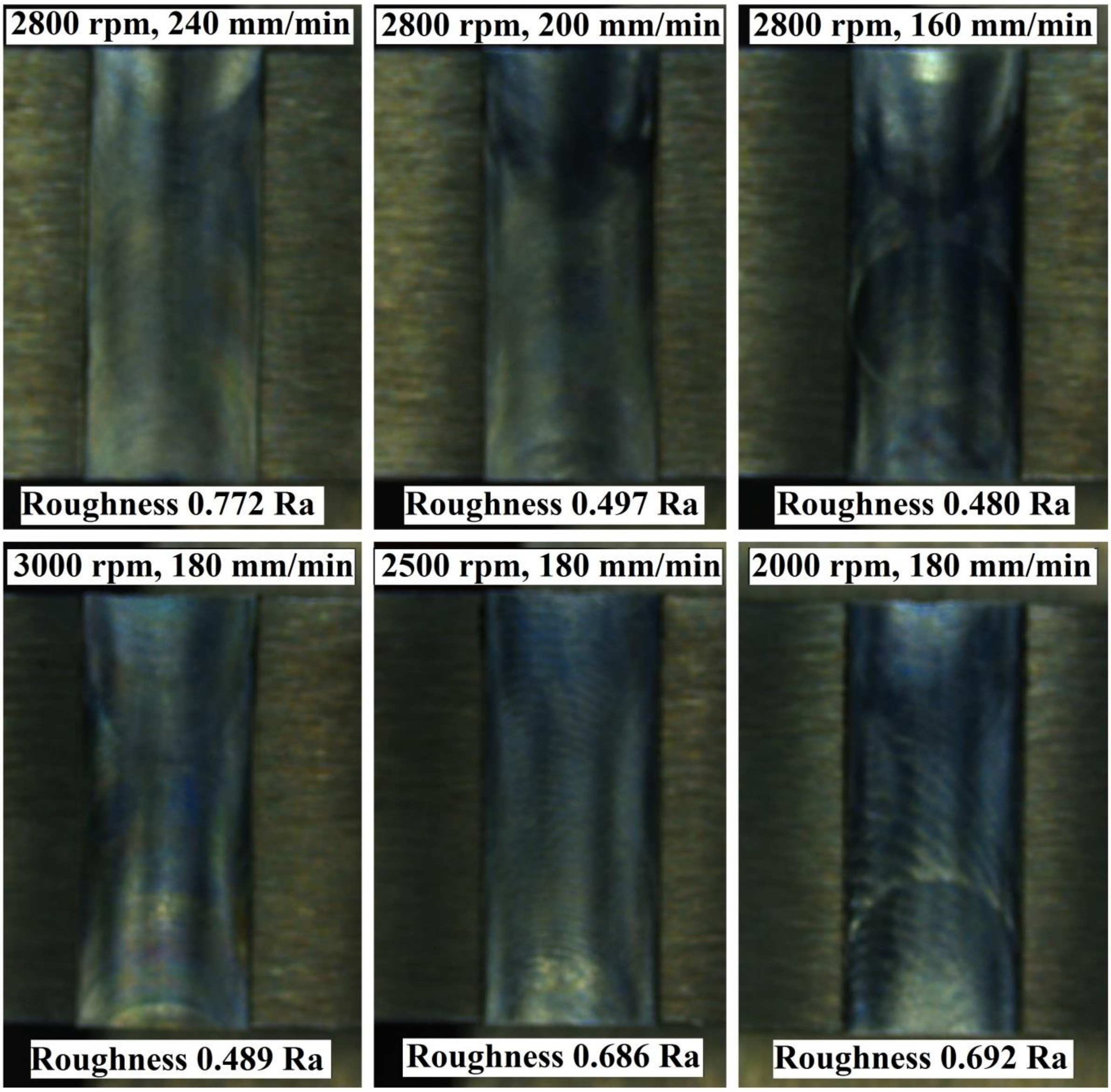


Figure 5. *Optical microscope images of test samples*

Surface roughness is an important parameter that affects the mechanical performance and machining cost of a machined part [22]. The most considered Ra surface roughness measurement parameter is mostly used to characterize or assign a finishing grade (ISO 1302) to a machined surface or a surface about to be machined [23]. In operations with a lower depth of cut, the surface roughness is generally lower [24]. For this reason, in this study, the cutting depth was chosen as 0.2 mm and the chip was removed. As a result, as the feed rate increased at a constant 2800 rpm spindle speed, the surface roughness increased as the amount of chip removed per unit time increased as shown in figure 6. Similarly, Brezocnik et al. reported that the SR was commonly affected by the feed rate in their study on the estimation of surface roughness by genetic programming [25]. As the spindle speed increased at a constant feed rate of 180 mm/min, the amount of chips for the next cutting decreased, as the cutting blade removed more chips with each turn, and therefore the surface roughness decreased as shown in figure 6. Kalidass and Palanisamy made a study on a regression and artificial neural network model to estimate SR in terms of helix angle, spindle speed, feed rate and depth of cut. They reported that enhancement in feed rate, depth of cut and spindle speed increases the SR. Additionally, increasing the helix angle decreases the SR [26].

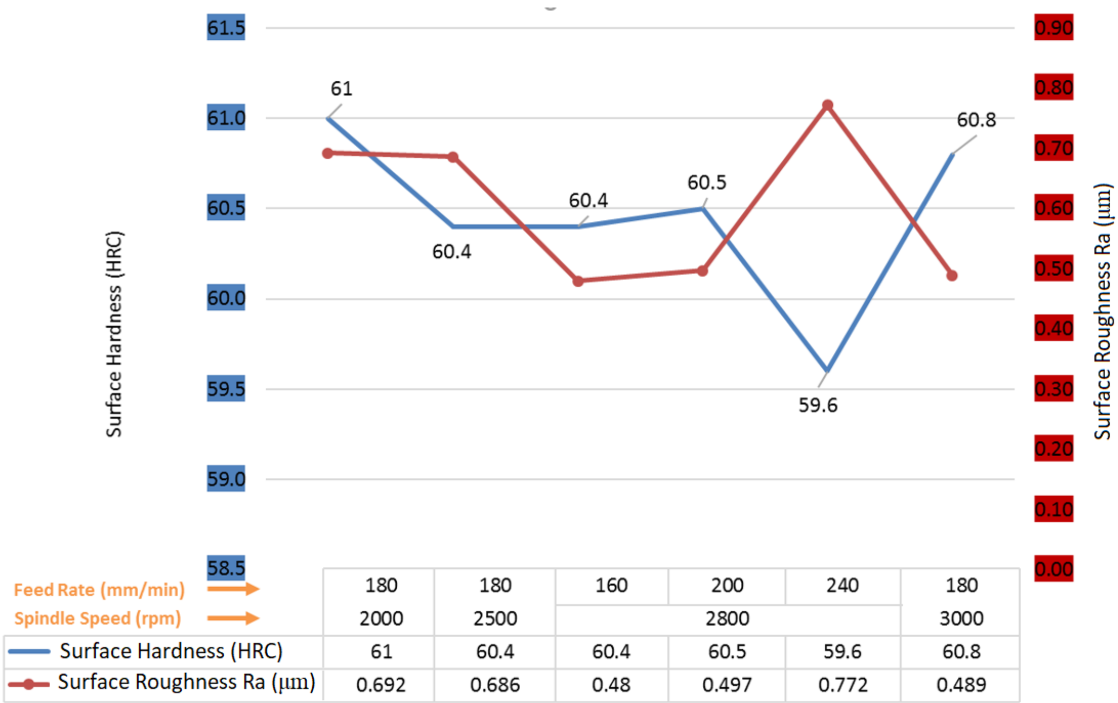


Figure. 6. *Graphical display of test results*

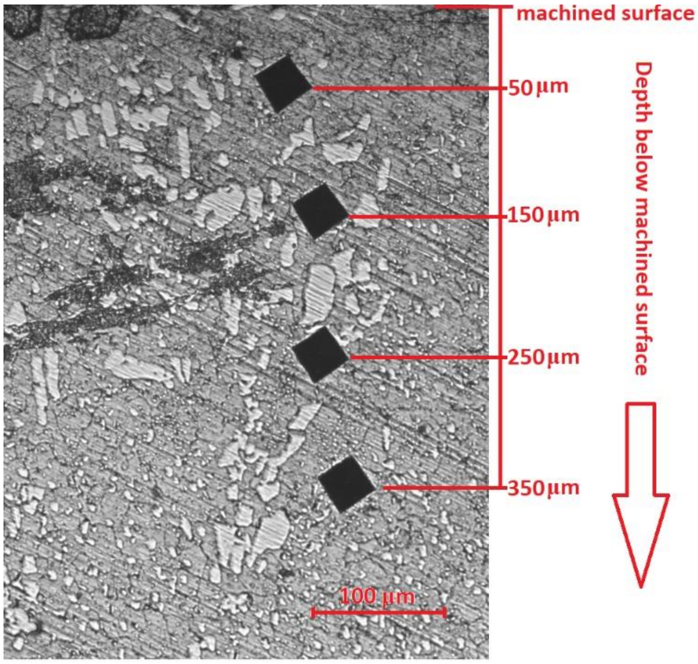


Figure 7. *Microhardness measuring points*

Microhardness values were taken from the cross-section of each treated sample by using microhardness tester Future-Tech FM-700. Values were measured from 4 different regions starting from the machined surface, approximately 50 μm, 150 μm, 250 μm and 350 μm as shown in figure 7. It was observed that the microhardness values in these regions were different from each other. There are findings in the literature that the microhardness of machined surfaces of hard steels is affected by machining parameters such as cutting speed, feed rate, axial depth of cut and radial depth of cut [27]. It is known that cutting speed and feed rate are the parameters that affect the microhardness the most [27-28]. Pereira et al. reported that increase cutting speed and feed per tooth lead to higher microhardness values near the surface of AISI 4340 steel; the former probably due to the presence of untempered martensite and the latter owing to work hardening [29].

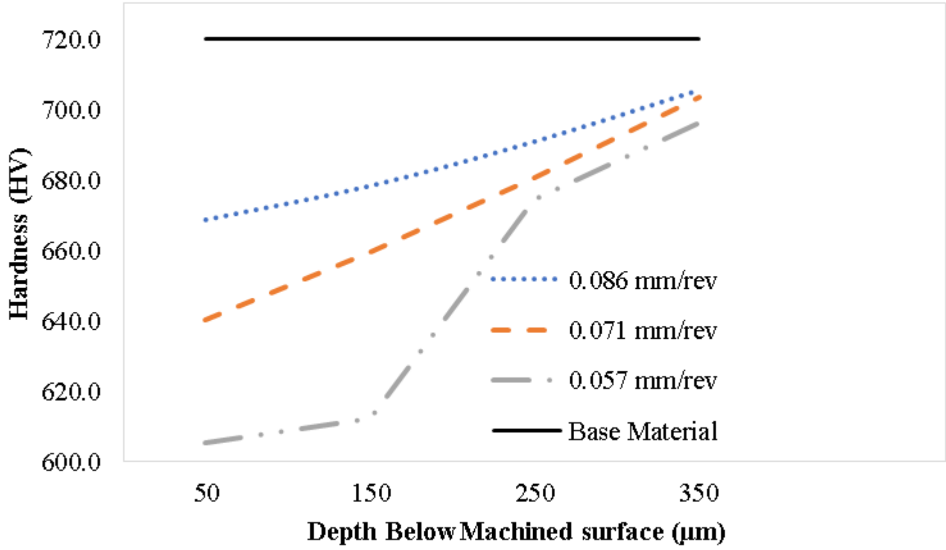


Figure 8. *Change of microhardness with increasing spindle speed at constant feed rate value*

It is seen in figure 8 that the microhardness reduction as the spindle speed increases. It was determined that the microhardness value, especially in the areas close to the machined surface, was lower than the machined surface. Lu et al. reported that the microhardness of micromilled Inconel 718 decreased with increasing spindle speed and increased with increasing axial depth of cut. The effect of size has a extraordinary impact on micro-hardness when the feed per tooth increases, which at first increases micro-hardness but then decreases it after the feed per tooth reaches the minimal cutting thickness [30]. The increase in plastic deformation rate with increasing cutting speed causes this situation, resulting in a narrower initial deformation zone. In addition, the yield strength increases as the plasticity of the workpiece material decreases. These conditions produce a reduced degree of plastic deformation. Moreover, as the cutting speed increases, the contact time between the cutting tool and the workpiece decreases, which leads to a decrease in the thermal time. All these cases affect the reduction of surface microhardness with increasing spindle speed [30]. Shokrani et al. determined that the depth of the affected area is lower in dry machining and cryogenic machining than in flood cooling [16]. In this study, microhardness change was determined in the region between 50-350 µm by dry machining. In addition, as the feed rate per revolution of the milling cutter decreased at a constant cutting speed of 2800 rpm, the microhardness value decreased. This decrease was greater near the treated surface as shown in figure 9.

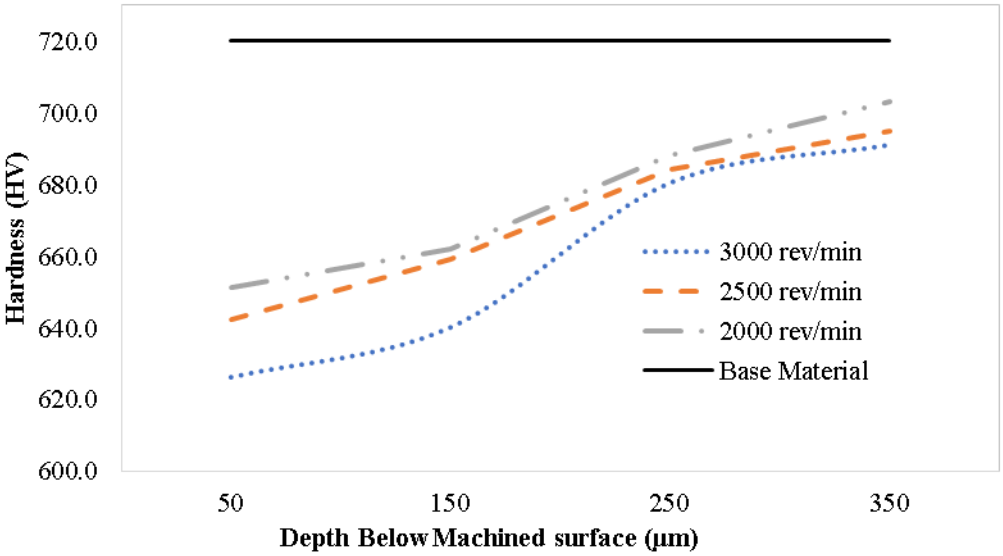


Figure 9. *Microhardness at different feed rates at constant cutting speed*

A well milled surface significantly improves fatigue strength and corrosion resistance [25, 31]. In this work, successful results were obtained by reaching a surface roughness of 0.480 Ra by processing X153CrMoV12 Cold Work Tool Steel with 60-62 HRC hardness using 2800 rpm Spindle Speed and 160 mm/min Feed Rate processing parameters without the need for refrigerant fluid.

4.CONCLUSIONS

In this work, the following results were obtained about the effects of machining parameters on the surface roughness and hardness by processing high hardness cold work tool steel without using coolant;

· As the spindle speed increased at a constant feed rate of 180 mm/min, the amount of chips for the next cutting decreased, as the cutting blade removed more chips with each turn, and therefore the surface roughness decreased.

· As the feed rate increased at a constant 2800 rpm spindle speed, the surface roughness increased as the amount of chip removed per unit time increased.

· The increase in spindle speed caused a decrease in microhardness. It was determined that the microhardness value, especially in the areas close to the machined surface, was lower than the machined surface.

· As the feed rate per revolution of the milling cutter decreased at a constant cutting speed of 2800 rpm, the microhardness value decreased. This decrease was greater near the treated surface.

DECLARATION OF CONFLICTING INTERESTS

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