Sigma J Eng & Nat Sci 36 (4), 2018, 1165-1174

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

INVESTIGATION OF MACHINABILITY OF COOLED MICROALLOY STELL IN OIL AFTER THE HOT FORGING WITH COATED AND UNCOATED CBN CUTTING TOOLS

Barış ÖZLÜ*[1], Halil DEMİR[2], Mustafa TÜRKMEN[3], Süleyman GÜNDÜZ[4]

[1]*Aksaray University, Dept. of Mechanical and Metal Technology, AKSARAY;* ORCID: 0000-0002-8594-1234
[2]*Karabük University, Dept. of Manufacturing Engineering, KARABÜK;* ORCID: 0000-0002-9802-083X
[3]*Kocaeli University, Department of Metallurgy, Hereke-KOCAELI;* ORCID: 0000-0002-9402-2459
[4]*Karabük University, Department of Manufacturing Engineering, KARABÜK;* ORCID: 0000-0003-4285-5114

Received: 06.07.2018 Accepted: 01.11.2018

ABSTRACT

The aim of this study was to investigate the cutting forces and surface roughness of 38MnVS6 microalloyed steel quenched in oil following hot forging. The machinability tests were carried out by turning under dry cutting conditions using coated and uncoated cubic boron nitride (CBN) cutting tools at five different cutting speeds (120, 150, 180, 210 and 240 m / min), a constant feed rate (0.04 mm / rev) and a constant chip depth (0.6 mm). The microalloyed steel used in the experimental study was optically examined and a hardness test was applied. Scanning electron microscopy (SEM) was used to evaluate the wear on the cutting tools. The findings for the 38MnVS6 steel which was oil quenched after forging showed that due to the high cooling rate, a martensite structure had been formed and the hardness value was high. The lowest surface roughness values of 0.367 μm and 0.164 μm were obtained at a cutting speed of 180 m / min with the coated and the uncoated CBN cutting tools, respectively. In the turning experiments, the surface roughness values measured using the coated CBN cutting tool were about 103% higher than those measured using the uncoated CBN cutting tool and the highest cutting forces were obtained at a cutting speed of 120 m / min.
Keywords: Hot forging, microalloyed steel, machinability, CBN cutter.

1. INTRODUCTION

Over the last 40 years, the automotive industry has begun to use medium carbon microalloyed steels with ferrite-pearlite microstructure for the forging of automobile parts such as crankshafts and connecting rods [1]. With the development of technology, the heat treatments applied to steels have become increasingly important in order to increase their applications, as well as to improve their mechanical and metallographic properties. The high cooling rates cause the ferrite grain size to shrink and due to the deformation of the atomic pattern, high strength and hardness occur with the thin phases [4].

The turning of materials hardened at high cooling rates after hot forging and heat treatment is performed using cutting tools with high wear resistance and hardness. The machining of workpieces with these cutters is a process carried out to obtain a surface with a polished quality.

* Corresponding Author: e-mail: barisozlu@aksaray.edu.tr, tel: (382) 288 20 17

This technology, which is less costly than a polishing process, is widely used in the production of bearings, motion transmitting mills, axles, mold materials and various engine parts [5].

Very few studies have been done on using CBN cutting tools to process high hardness microalloyed steels obtained at high cooling rates after hot forging and heat treatment. However, although the turning of hard metals is still a new subject, there are many studies in the literature dealing with a number of different materials. These studies generally involve the turning of H13-H11, AISI 52100, 4130, 4140 and 4340 steels with coated and uncoated cubic boron nitride (CBN) cutting tools [6-11].

In the present study, samples of 38MnVS6 microalloyed steel which had been oil quenched following heat treatment and having a martensite structure were processed with carbide cutting tools at different cutting speeds. The martensite structure was seen to be more resistant to abrasion, causing significant amounts of wear on the carbide cutting tools used in the turning experiments. The cutting tools lost the ability to fully cut and the cutting forces and surface roughness values were increased to unacceptable levels [12]. During turning, the cutting forces and surface roughness depend on the hardness of the test specimens, the machinability parameters, the tool geometry and the cutting conditions [13-14]. Cutting forces and surface roughness are the most important criteria for machinability during chip removal [15].

The aim of this study was to determine the degree of impact generated on the surface roughness and cutting forces by the use of coated and uncoated CBN cutting tools at different cutting speeds during the turning of 38MnVS6 steel quenched in oil after hot forging.

2. EXPERIMENTAL PROCEDURE

2.1. Hot forging and microstructure

The chemical composition of the Ø60 × 6000 mm sections of 38MnVS6 microalloyed steel (Çelik Makine San. ve Tic. A.Ş) used in the experiments is given in Table 1. Before forging, the materials had been turned to the size of Ø46.7 × 240 mm.

Table 1. Chemical composition of 38MnVS6 steel used in this study

C	*Si*	*Mn*	*P*	*S*	*Cr*	*Mo*	*Ni*	*Al*	*Cu*	*Sn*	*V*
0.418	*0.52*	*1.37*	*0.008*	*0.058*	*0.144*	*0.025*	*0.068*	*0.016*	*0.175*	*0.017*	*0.099*

The samples were heated to 1200 °C in the induction annealing system. After the samples were annealed, the diameter was reduced to 35 mm by hot forging in a 1600-ton eccentric press closed mold. The final temperature of the samples after forging was measured by an infrared laser thermometer as 1150 ± 20 °C. After forging, the samples were quenched in oil. At the end of the forging process, metallographic examinations and machinability tests were carried out. In order to remove the oxides and decarburization areas formed on the surfaces of the samples, the surfaces were turned and a 1-mm chip removed to ensure that the tests were accurately performed. The samples for the microstructure studies were prepared via conventional metallographic methods by etching with 2% Nital solution. Surfaces of the treated samples were cleaned with alcohol and examined under an optical microscope. The Vickers hardness method was used to measure the hardness values of the samples. The hardness measurements were carried out by applying a load of HV1 (1000 g). The average of 10 hardness measurements taken for each sample was determined as the hardness value. The experimental steps for forging and machinability testing are schematically shown in Figure 1.

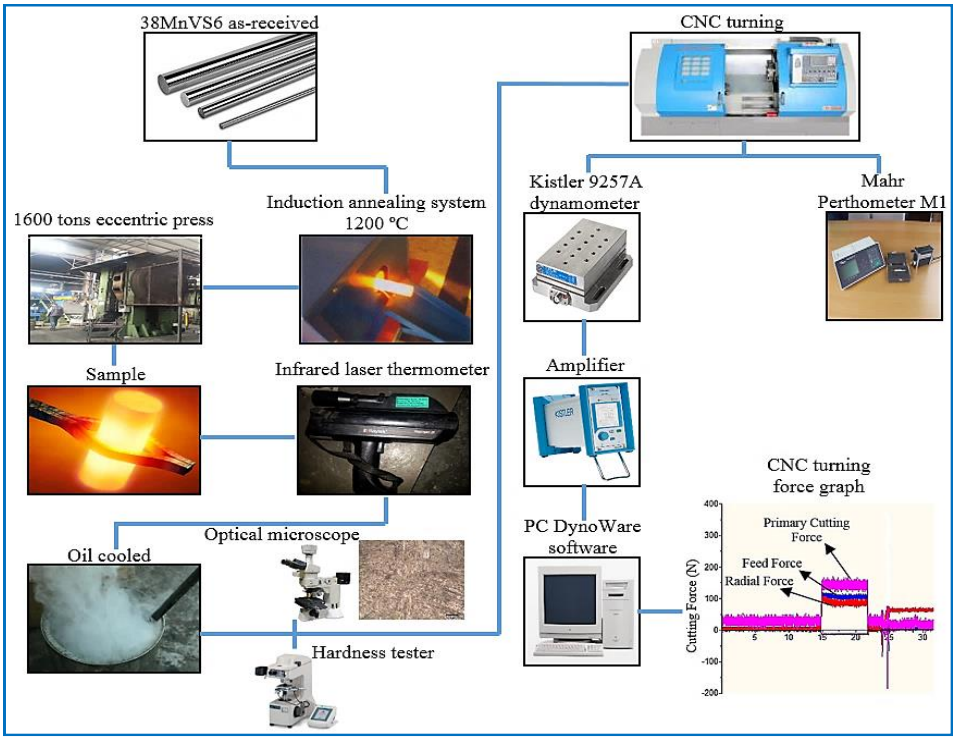


Figure 1. Schematic view of the test setup

2.2. Experimental measurement system and procedures

Turning experiments were carried out on a Johnford TC-35 industrial CNC lathe under dry cutting conditions without the use of cooling fluid. The cutting parameters used for the turning experiments are given in Table 2. The turning experiments used polycrystalline cubic boron nitride (PCBN) cutting tools. These included the quality grade inserts KB5610, coated with TiAlN via the Kennametal PVD method, and KB1610 (uncoated), both having CNGA120404S01025FWMT geometry (Kennametal). In Figure 2, descriptions of the cutting tools and tool holder used in the turning experiments are given in detail. These cutting tools are used in the machining of hardened steels and cast iron. The PCNNR 2525M12 Kenlever external turning tool holder (Kennametal) was chosen to firmly attach the cutting inserts. Turning tests were carried out on the 38MnVS6 steel samples, which had acquired martensite morphology as a result of the oil quenching after its subjection to hot forging. Cutting force measurements were performed during the turning experiments using a Kistler 9257A dynamometer and the cutting force factors were recorded. During turning experiments, the maximum cutting force is usually Fz (Fc) at the basic cutting force, followed by the feed force Fx (Ff) and the radial force Fy (Fp).

Table 2. Experimental processing parameters

Steel	Feed Rate (mm/rev)	Cutting Speeds (m/min)	Depth of Cut (mm)
38MnVS6	0.04	120	0.6
		150	
		180	
		210	

Figure 2. Cutting tools and tool holder used in the turning experiments

Measurements of surface roughness values were made during the processing of the 30 × 35 mm samples. In the turning experiments, the Mahr Perthometer M1 instrument was used to measure the roughness of the machined surfaces. These measurements were made parallel to the sample axis without removing the machined samples from the CNC lathe to prevent damage being caused to the machined surfaces during their removal. Surface roughness values were determined by taking the average of four measurements made on each sample.

3. RESULTS AND DISCUSSION

3.1. Microstructure and hardness

The formation of the martensite can be seen in the microstructure images taken of the 38MnVS6 steel samples obtained by oil quenching after hot forging (Fig. 3). This structure resulted from the fact that the cooling rate of the oil quenched 38MnVS6 steel was higher than the critical cooling rate. The alloying elements are effective on the critical cooling rate in steels. Alloying elements reduce the critical cooling rate by shifting the continuous cooling diagrams over a long time and thus facilitate the formation of the martensite structure [16-17]. The martensite transformation takes place via cooling above the critical cooling rate. Otherwise, bainite, residual austenite and ferrite are formed instead of the martensite phase, resulting in the loss of strength [18]. The hardness value of the hot forged oil quenched 38MnVS6 sample was measured as 587 HV1. The higher hardness value resulted from the fact that the microstructure of the sample oil quenched after hot forging exhibited martensite morphology. The most important reason for the high hardness value of the martensite formation was that the cage structure was excessively distorted. The distortion of the cage structure also caused a significant increase in the hardness and strength of the steel cooled at high cooling rates, making dislocation movement difficult or disrupting it [16].

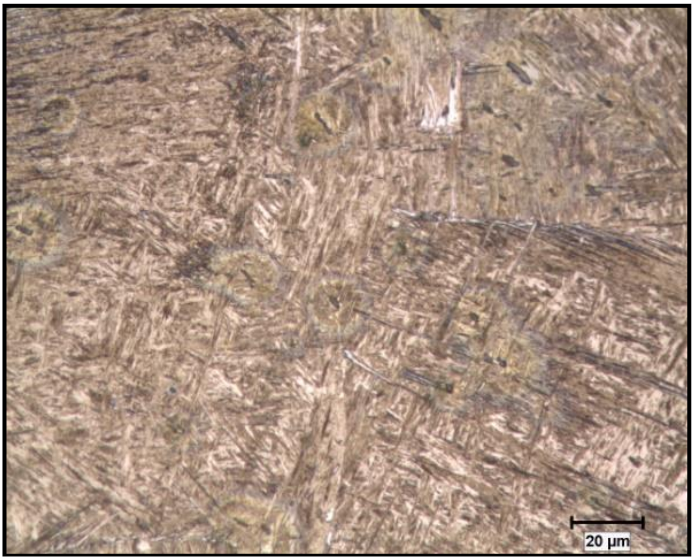


Figure 3. Microstructure view of 38MnVS6 steel samples quenched in oil after forging

3.2. Cutting forces

The effects of cutting forces generated during the cutting of the hot forged oil quenched 38MnVS6 steel using coated and uncoated CBN cutting tools at different cutting rates (120, 150, 180, 210 and 240 m / min) are given in Figure 4. The cutting forces measured for the coated CBN cutting tool averaged 8.4% higher than those measured for the uncoated CBN cutting tool. Because coated cutting tools have a low coefficient of friction, lower cutting temperatures occur during machining. For this reason, it was expected that the cutting force levels for the coated cutting tools would be lower. However, in this study, the cutting force values measured on the coated CBN cutting tool were higher than the values of those measured on the uncoated CBN cutting tool. The high build-up of cutting forces in the machining with the coated CBN cutting tool can be explained by the larger cutting edge radius due to the coating [19].

The highest cutting forces were obtained in turning experiments at a cutting speed of 120 m / min. The cutting forces were measured at 163.5 N and 150.75 N in the coated and uncoated CBN cutting tools, respectively (Fig. 4). The high cutting forces at low cutting speeds can be attributed to the fact that less heat was generated around the slip area, and therefore the hardness of the workpiece did not decrease, resulting in higher cutting forces [20].

In the tests performed with increasing cutting speeds (150, 180, 210 and 240 m / min), the cutting forces measured with the coated and uncoated CBN cutting tools decreased regularly. With a cutting speed increase from 120 to 240 m / min, there were cutting force reductions of 9.6% (149.2 N) and 8% (139.49 N) with the coated and uncoated CBN cutting tools, respectively. This reduction in cutting forces with the increase in cutting speed caused a decrease in the length of the cutting tool-chip contact area and due to the rising temperature with increasing cutting speed, reduced sliding resistance of the material in the slip area of the tool-chip surface resulted in a reduction in cutting strength [21]. As the length of the cutting tool-chip contact area decreased, the temperature increased with the increasing cutting speed.

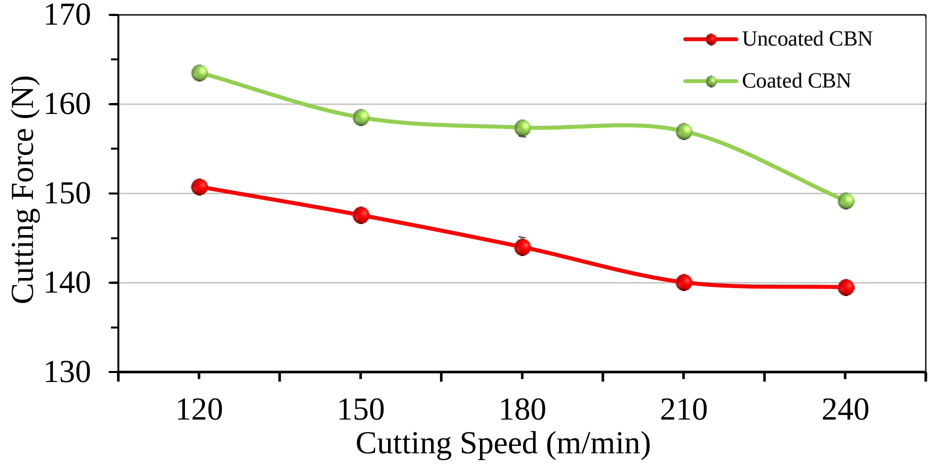


Figure 4. Effect of cutting speed on cutting force of 38MnVS6 specimens with coated and uncoated CBN cutting tools

3.3. Surface roughness

The effects of cutting speed (120, 150, 180, 210 and 240 m / min) on the average surface roughness values (Ra) using the coated and uncoated CBN cutting tools in the turning of the 38 MnVS6 steel samples obtained after forging are given in Figure 5.

In the turning experiments, the surface roughness values measured with the coated CBN cutting tool were about 103% higher than those measured using the uncoated CBN cutting tool. The high surface roughness values in the experiments with the coated CBN cutting tool can be explained by the increase of the cutting edge radius due to the coating on the cutting tool.

For the turning experiments at a cutting speed of 120 m / min, surface roughness values were measured as 0.907 µm for the coated CBN cutting tool and 0.341 µm for the uncoated CBN cutting tool. The surface roughness values were about 250% higher in the experiments with the coated CBN cutting tool than in those with the uncoated CBN cutting tool. However, this difference decreased in the experiments in which the cutting speed was increased. The minimum surface roughness values were obtained in the experiments where the cutting speed was increased to 180 m / min. At the cutting speed of 180 m / min, surface roughness values of 0.367 µm were obtained for the coated CBN cutting tools and 0.164 µm for the uncoated CBN cutting tools. Consequently, the surface roughness values had been reduced by about 60% with the coated CBN cutting tools and by about 50% with the uncoated CBN cutting tools.

The reduction in surface roughness with increasing cutting speed was due to the thermal softening property of the test samples at high cutting speeds. Increased cutting speed resulted in easy chip removal and reduced surface roughness values [22-23]. The reduced tool-chip contact area due to the temperature at the high cutting speed of 180 m / min led to reduction of friction in the tool-chip contact area. This in turn led to the reduced surface roughness values of the machined surface [24].

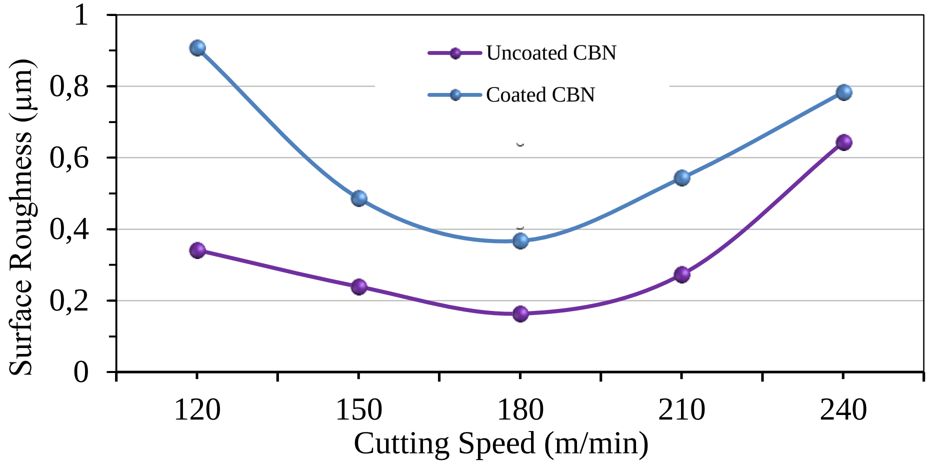
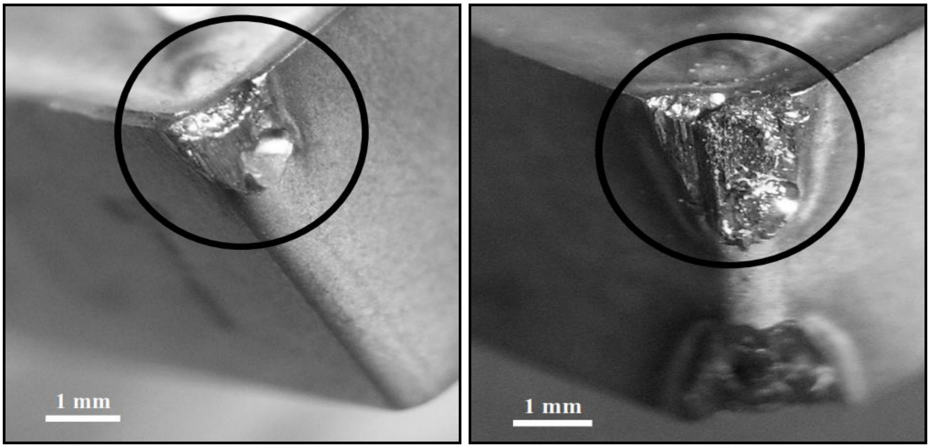


Figure 5. Effect of cutting speed on surface roughness in machining of 38MnVS6 samples with coated and uncoated CBN cutting tools

However, when the cutting speed was increased from 180 to 240 m / min, the surface roughness values showed a significant tendency to rise. The reduction of surface roughness values with increasing cutting speed has been observed in a number of studies [25]. Conversely, with a further increase of cutting speed (from 180 to 240 m / min), the surface roughness values for the coated and uncoated CBN cutting tools increased by approximately 110% and 290%, respectively. The maximum surface roughness for the coated CBN cutting tool was seen at 120 m / min cutting speed, whereas the maximum surface roughness for the uncoated CBN cutting tool was found at 240 m / min.

The increase of the surface roughness values at the cutting speeds of 210 and 240 m / min can be explained by the wear mechanisms on the cutting tools during the experiments. In the study, samples of 38MnVS6 microalloyed steel oil quenched after heat treatment and having a martensite structure were processed with carbide cutting tool at different cutting speeds. The martensite structure, being resistant to abrasion, was found to be more durable, leading to significant wear in the carbide cutting tools used in the turning experiments [12] (Fig. 6). In these cases of processing high hardness materials, CBN cutting tools are recommended.

The wear mechanisms in the coated and uncoated CBN cutting tools are visible in the scanning electron microscopy (SEM) images in Figure 7a, b, c and d. In this case, it can be said that the results from the processing of high hardness materials showed the resistance against wear to be better with the coated and uncoated CBN cutting tools than with the carbide cutting tools. However, at high cutting speeds, minor wear, chip adhesion and coating deposits occurred on the cutting edges of the CBN cutters, although this was not so great as the wear on the carbide cutters.



(a) (b)

Figure 6. Cutting tool wear with water-quenched material processed at different cutting speeds; (a) 150m / min and (b)180 m / min. [12]

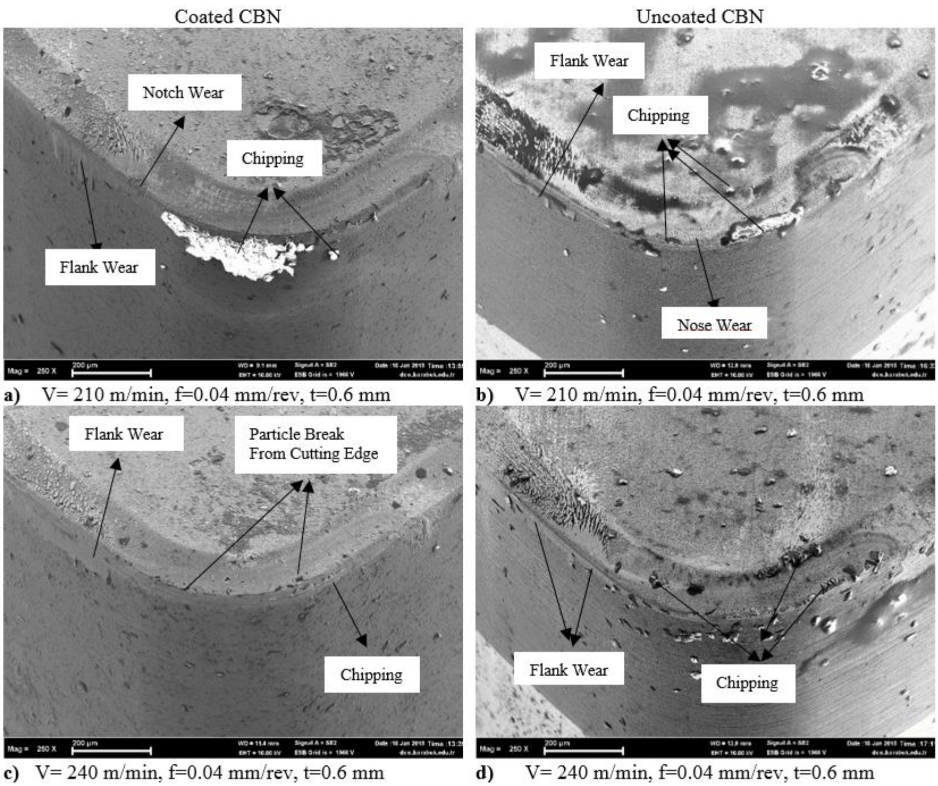


Figure 7. SEM images of wear mechanisms of coated and uncoated CBN cutting tools

4. CONCLUSIONS

This study investigated the microstructure and hardness values of 38MnVS6 steel quenched in oil after hot forging and turning tests were carried out on the samples using coated and uncoated CBN cutting tools. The results obtained in this study are given below.

- It was determined that the samples quenched in oil after forging had a martensite structure. This is a result of quenching the samples at higher cooling rates than the required critical cooling rate. In addition, the high cooling rates caused the network structure of the material to deform, making the dislocation motion difficult and resulting in the high hardness values of the samples.
- The coated CBN cutting tools were expected to display lower cutting force and surface roughness values than the uncoated CBN cutting tools; however, in experiments with the coated CBN cutting tools, cutting force and surface roughness values were higher than with the uncoated CBN cutter inserts.
- The lowest surface roughness values were obtained at a cutting speed of 180 m / min as 0.367 µm for the coated CBN cutting tools and 0.164 for the uncoated CBN cutting tools.
- In the turning experiments the highest cutting forces were obtained at a cutting speed of 120 m / min.
- In the turning experiments the surface roughness values measured with the coated CBN cutting tool were about 103% higher than those measured with the uncoated CBN cutting tool.
- Although the surface roughness values were expected to decrease when the cutting speed increased, the surface roughness values increased in both the coated and uncoated CBN cutting tools with cutting speeds of 180 to 240 m / min. In the experiments with the coated and uncoated CBN cutting tools, this can be explained by the wear mechanisms that occurred with the increase of the cutting speed.
- Compared to carbide cutting tools, CBN cutting tools performed better in terms of wear, cutting force and surface roughness.

Acknowledgements

This work was supported by the Karabük University Scientific Research Projects Coordination Unit (Project Number: KBÜ-BAP-16/1-DR-169).

REFERENCES

[1] Chen S.L., Hui W.J., Wang L.H., Dai G.W., Dong H., (2014) Research and development of energy-saving high performance microalloyed forging steels, Iron and Steel, 49 (6), 1-7.

[2] Salleh, T. S., Nishida, S-i., Hattori N., (2004) Influence of microalloyed elements and ion nitriding on fatigue properties of ultra-low carbon steel sheets, Strength, Fracture and Complexity, 2 (2), 69-80.

[3] Ghosh A., Das S., Chatterjee S., Ramachandra R.P, (2006) Effect of cooling rate on structure and properties of an ultra-low carbon HSLA-100 grade steel, Materials Characterization, 56, 59-65.

[4] Ghosh A., Mishra B., Das S., Chatterjee S., (2005) Microstructure, properties and age hardening behaviour of a thermo-mechanically processed ultra low carbon Cu bearing high strength steel, Metallurgical and Materials Transaction, 36, 703-713.

[5] Al-Zkeri, İ.A., (2007) Finite element modeling of hard turning, Doctoral Thesis, The Ohio State University.

[6] Ng E., Aspinwall D.K., (2002), The effect of workpiece hardness and cutting speed on the machinability of AISI H13 hot work die steel when using PCBN tooling, Trans. ASME J. Manuf. Sci. Eng., 124, 582-594.
[7] Aouici H., Yallese M.A., Chaui K., Mabrouki T., Rigal J.F., (2012), Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization, Measurement, 45, (3), 344-353.
[8] Huang Y., Liang S.Y., (2005), Modeling of cutting forces under hard turning conditions considering tool wear effect, Trans. ASME J. Manuf. Sci. Eng., 127, 262-270.
[9] Lima J.G., Avila R.F., Abrao A.M., Faustino M., Davim J.P., (2005), Hard turning: AISI 4340 high strength low alloy steel and AISI D2 cold work tool steel, J. Mater. Process. Technol., 169, 388-395.
[10] Arsecularatne J.A., Zhang L.C., Montross C., Mathew P., (2006), On machining of hardened AISI D2 steel with PCBN tools, J. Mater. Process. Technol., 171, 244-252.
[11] Elbah M., Yallese A.M., Aouici H., Mabrouki T., Rigal J.F., (2013), Comparative assessment of wiper and conventional ceramic tools on surface roughness in hard turning AISI 4140 steel, Measurement, 46, (9)3041-3056.
[12] Demir H., Özlü B., (2009), An investigation into the machinability of 30MnVS6 microalloyed steels based on cutting forces and surface roughness, Erciyes University Journal of Institute of Science and Technology, 25 (1-2), 262-271.
[13] Shihab K.S., Khan A.Z., Mohammad A., Siddiquee N.A., (2014), A review of turning of hard steels used in bearing and automotive applications, Production & Manufacturing Research, 2 (1), 24-49.
[14] Palanisamy D., Senthil P., (2018), A comparative study on machinability of cryo-treated and peak aged 15Cr5Ni precipitation hardened stainless steel, Measurement, 116, 162-169.
[15] Demir H., (2008), The effects of microalloyed steel pre-heat treatment on microstructure and machinability, Int. J. Adv. Manuf. Technol., 35, 1041-1046.
[16] Savaşkan, T.(1999) Material Information and Examination, KTÜ, Trabzon.
[17] Tekin A., (1984), Steel and Heat Treatment, İTÜ, İstanbul.
[18] Bergman G., (1999) Modeling and simultaneous forming and quenching, Doctoral Theses, Lulea University of Technology, Schweden.
[19] Zhoua J., Bushlyaa V., Avdovic P., Stahla J.E., (2012), Study of surface quality in high speed turning of Inconel 718 with uncoated and coated CBN tools, Int J Adv Manuf Technol, 58, 141-151.
[20] Basavarajappa S., Suresh R., Gaitonde V.N., Samuel G.L., (2014), Analysis of cutting forces and surface roughness in hard turning of AISI 4340 using multilayer coated carbide tool, Int. J. Machining and Machinability of Materials, 16 (2), 169-185.
[21] Çiçek A., Kara F., Kıvrak T., Ekici E., (2013), Evaluation of machinability of hardened and cryo-treated AISI H13 hot work tool steel with ceramic inserts, Int. J. Refractory Metals Hard Mater. 41, 461-469.
[22] Ranganathan S., Senthilvelan T., Sriram G., (2010), Evaluation of machining parameters of hot turning of stainless steel (Type 316) by applying ANN and RSM, Materials and Manufacturing Processes, 25, 1131-1141.
[23] Ferreira R., Carou D., Lauro C.H., Davim J.P., (2016), Surface roughness investigation in the hard turning of steel using ceramic tools, Mater Manuf Process, 31 (5), 648-665.
[24] Demir H., Gündüz S., (2009), The effects of aging on machinability of 6061 aluminium alloy, Materials and Design, 30, 1480-1483.
[25] Shaw M.C., (1984), Metal Cutting Principles, Oxford Series on Advanced Manufacturing Press, London.