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RESEARCH ARTICLE **OPEN ACCESS**

CUTTING PARAMETERS EFFECT ON TiN COATED CBN CUTTING TOOLS IN HARD TURNING OF AISI 4140 STEEL

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ABSTRACT

Grinding method has a restricted use in the production of machine parts due to its long-processing time, high cost, and environmentally pollutant coolant liquid. The production of hardened materials via turning is an alternative to grinding operation. The generation by turning with little or no use of coolant liquid of surface properties similar to those obtained by grinding process decreases production time and cost. The present work aims at the determination of flank wear of cutting tool in turning of AISI 4140 hardened (53±1 HRC) steel materials with coated titanium nitride (TiN) cubic boron nitride (CBN) cutting tools under different cutting speeds and feed rates. Wear of cutting tool was determined through real-time monitoring and metallographic analysis. The best wear performance in turning of hardened AISI 4140 materials belonged to the cutting variables of 280 m/min, 0.04 mm/rpm coated cubic boron nitride.

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INTRODUCTION

Reducing the production cost in metal cutting, improving the productivity and the quality are directly related to the cutting tool materials' features. Industry gives priority to use tools with low friction coefficient, high wearing resistance and tools that can work in high cutting speeds. Production of new cutting tools that have high wearing resistance such as ceramic and cubic boron nitride (CBN) and that have high working temperatures and rigidity shots enable the processing of hardened steel by metal removing. Cutting tools like ceramic and CBN and steel tool with high hardness values such as 45-70 HRC can be processed by means of metal removing and parts with surface quality which can be reached in grinding can be produced (König *et al.,* 1993). In grinding process, length of processing time, having limited geometry and having the obligation to use contaminative coolant gave way to fast proliferation of processing hardened parts by metal removing. Production of tools that are in defined dimensional values and in surface quality by turning at high cutting speeds enables a decrease in costs and a high increase in production capacity (Çakan, 2011). Besides even easily processing parts with complicated shapes, not using coolant or using only a little makes this method superior to other conventional methods including grinding (Chou and Evans, 1999; Luo *et al.,* 1999). High temperature in the cutting zone and accordingly rapid wearing in the cutting tool are the disadvantages of the process. Using cutting tools in appropriate cutting conditions such as ceramic and CBN that can protect their mechanical features in high service temperatures eliminate the disadvantages at a great extent (Klocke *et al.,* 2005; Yang and Tarng, 1998). Determination of cutting tool wear in the defined cutting conditions has great importance in tool-life. Wearing of cutting tools in the production system affect the surfaces of parts processed negatively and the process generally results in tool damage (Derakhshan and Akbari, 2009; Cakan and Evrendilek, 2017). For this reason, developing systems that can define the wearing in the tools are the main aims of the metal cutting industry. For this purpose, measuring techniques were developed to define wear on the tools directly or indirectly. In direct measuring techniques, wearing on the insert is generally tried to be determined by stopping the cutting process at intervals and by measuring the areas with microscope (Marinescu and Axinte, 2011; Kara and Öztürk, 2019). Indirect measuring techniques aim to determine the state of tool wear by monitoring parameters such as cutting forces (Cakan *et al.,* 2008; Xuewei *et al.,* 2016), changes in the size of working part (Oteyaka *et al.,* 2014; Çakan, 2016), power, acoustic emission, current the engine draws and torque (Dimla and Dimla, Snr., 2000). Due to its ability to collect data at short intervals, works have been increasingly done on instant monitoring system use in determining wear on the cutting tool. The system used in instant monitoring of cutting tool wear is composed of mathematical processes and decision-analysis (Choudhury *et al.,* 1999; Cakan *et al.,* 2015). Defining system consists of signals attached to parameters about the tool status. Here, real condition of process performance is measured considering surface quality, and wearing levels of wearing in cutting edge and flank. These values can be calculated according to input data in mathematical processes. In decision-analysis section, however, instant monitoring information is compared with the desired information. In this study, wearing experiments at different cutting conditions were performed on CBN cutting tool specimens covered with TİN by using CNC turning lathe and AISI 4140 steel specimens. During the turning process, wear on the cutting tool while processing hardened steel material was determined with the instant monitoring system.

EXPERİMENTALWORK

Workpiece materials: For the present study, AISI 4140 (DIN 42CrMo4) medium carbon low alloy high strength steel (i.e. bars of 60mm diameter and 300 mm length) is selected as a workpiece, which is heat-treated to a hardness of 53 ± 1 HRC. AISI 4140 steel is typically used in the manufacturing of automobile and other application by virtue of its good hardenability. The chemical composition of AISI 4140 workpiece in weight % is as follows: 0.41C, 0.29Si, 0.78Mn, 0.034P, 0.98 Cr, 0.19Mo.

Cutting tools: Turning experiments were performed under dry cutting conditions using CBN cutting tool inserts (ISO code CNGA 120408T01030A 7015) manufactured by Sandvik^{TM} Coromant with a thin coating of TiCN layer (1 µm) on the CBN substrate, deposited by the physical vapor deposition (PVD) method. CBN 7015 insert was rigidly mounted on a tool holder with an ISO designation of DCLNR 2525M12 from Sandvik^{TM} Coromant. The combination of the insert and the tool holder resulted in the following geometry: a negative rake angle ($\gamma = -6^{\circ}$), a clearance angle ($\alpha = 6^{\circ}$), a negative cutting edge inclination angle ($\lambda = -6^{\circ}$) including angle 80°, and a cutting edge angle ($\chi_r = 95^{\circ}$) (Fig. 1). These removable inserts are of a square form with four cutting edges whose characteristics are shown in Table 1. For each machining test, a new tool was used.

Table 1. Characteristics of inserts used in this study

Cutting materials	Designation	Chemical composition	Hardness (HV)	Thermal conductivity ($Wm^{-1}K^{-1}$)
Cubic boron nitride CBN7015	CNGA120408T01030A	CBN (50%) + ceramic binder	~ 2800	~ 740

Experimental design: Hard turning is a lathe machining process of steel workpieces with hardness higher than 50 HRC where cutting tool media are essentially CBN. Turning tests were performed in dry cutting environment without any cutting fluid on a Ler. Tc. 150B CNC turning lathe. Cutting tools have been tested in terms of cutting parameters consisting of two different cutting speeds which are 200 m/min. (1062 rpm) and 280 m/min. (1486 rpm), three different feed rates which are 0.04, 0.08 and 0.12 mm/rev and a constant depth of cut 0.2 mm. Based on the parameters used in tests, wearing in cutting tool during the turning process was tired to be determined indirectly by using instant monitoring system. After the workpiece was turned with a fresh cutting tool for about 1.5 cm in length as an initial reference, the process was stopped, and the initial gap between the sensor and the workpiece was adjusted to 2.5 mm. Then, the turning operation was continued for the rest of the workpiece. During turning, the sensor voltage output was continuously recorded. Change in the output voltage relative to the initial reference was measured after turning operation. Three replicates of each turning test were performed. The turning conditions were selected according to the recommendations provided by manufacturers of cutting tools.

Real-time monitoring system: This indirect measuring method includes sending the light produced by laser diode to working part via fiber optic cable and storing the voltage values on computer via A/D convertor, acquired from diode output resulting from sending the light reflected from working part to photo diode using another fiber optic cable(Çakan,2006). Fiber optic, detector-amplifier photo diode and analog to digital convertor constitute the main elements of optic detection system. These two fibers' views make up the working principle of the system. In case of the contact of fiber optic with the working part, all the light(laser) coming along with the fiber hits the surface of working part and is reflected back to the same fiber. With the higher spaces between fiber optic ends and working part, the amount of light reflected on fiber optic increases. Signs acquired from diode output is stored on computer (PC) by using analog-digital convertor (ADC). Schematic view of optic detection system is shown in Figure 1.

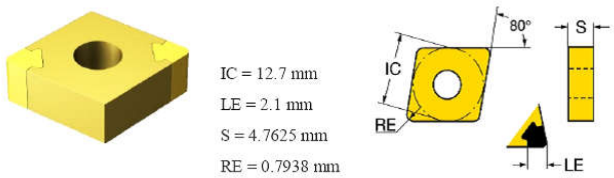

Fig. 1.Cutting tool of CBN 7015 used in this study (S: insert thickness; RE: nose radius; IC: inscribed circle; LE: effective length of cutting edge)

Turning tests: In the process of turning test specimens produced with hardened AISI 4140 steel, wearing performances of CBN cutting edges covered with TiN were tried to be determined. Each experiment was repeated three times and 18 turning tests were performed in total. Specimens having 60 mm in diameter and 180 mm in length were prepared from AISI 4140 (42CrMo4) steel.

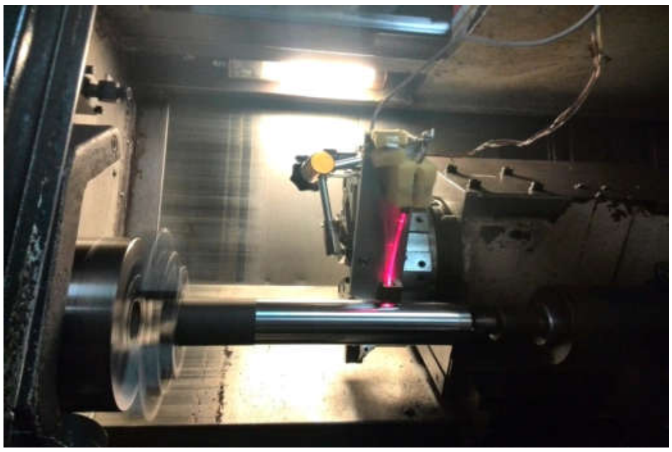

Fig. 2. Experimental setup

Prepared specimens were put on CNC turning lathe, on which the process is performed. Then, in order to monitor the wearing in edges during the process, instant monitoring system shown in Figure 2 was connected to CNC lathe and data was collected from the materials.

RESULTS AND DISCUSSIONS

After processing cutting depth of 0.2 mm and cutting length of 15 mm on working part put between center and plate on turning lathe, cutting process was stopped and initial space between processed surface and fiber optics was adjusted as 2.5 mm. CBN cutting tool covered with TİN was attached to tool holder and edge part was adjusted to be in contact with processed surface. Then the cutting process was started. Turning length of working part was taken as 150 mm. During the process, photo diode output was continuously recorded at 0.1s intervals. For determining wearing in cutting tools, instant monitoring system was used. For the processing of AISI 4140 (DIN 42CrMo4) hardened (52–54 HRC) steel materials with CBN cutting tools covered with TİN, in the turning tests which were performed within the parameters consisting of two different cutting speeds which are 200 m/min. and 280 m/min. and three different feed rates which are 0.04, 0.08 and 0.12 mm/rev, voltage values acquired from photo diode output are shown in Figure 3 (a) (b). SEM image of cutting edge wearing is shown in Figure 4.

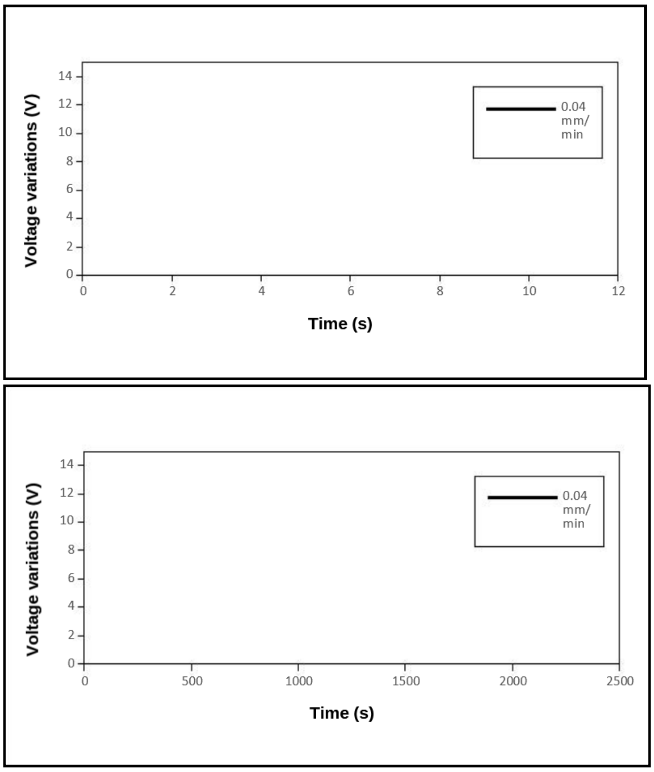

Figure 3. TiN coated CBN cutting tool, different progress in speed (a) 200 m/min. comparison of voltage change that occurs in a constant cutting speed, (b) 280 m/min constant comparison of voltage change that occurs in a cutting speed

As can be seen from Figure 3(a) (b), an increase in voltage values was observed from the beginning of cutting process. Because, there was wearing in cutting edges of the tool and the formation of a radius on the tool edge. This enables a better surface in the working part and thus increased reflection feature of the surface. The continuous increase in voltage values during the cutting process was caused by reduction of space between working part and fiber optic resulting from increasing wearing in cutting edges of cutting tool. In the light of turning experiment results acquired from CBN cutting tool specimens coated with TİN, an increase was observed in feed rate and working rate as expected. As can be seen in Figure 3, apparent breaks and tearing in the edges of CNB insert coated with TİN occurred and smearing tendency on cutting edge as material residue was observed. During cutting process, the materials plastered on cutting edge acted as an abrasive and created unwanted surface properties until it came out of the cutter.

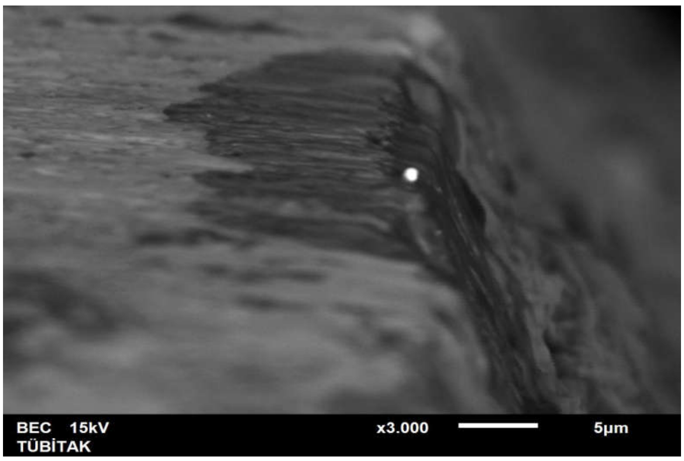

Fig. 4. The SEM images of the worn out TiN coated CBN insert after turning

These parts in the surface are seen as voltage drops. These results indicate that wearing occurs less in the experiments in which low feed rate is used. During the process of turning AISI 4140 steel materials, it has a tendency to stick on rake and flank face beginning from the cutting edge of the cutting tool. With the increasing wear on the cutting tool, these attached layers and TiN covering pull away with chip. From SEM micrograph, abrasion was the main mechanism of wear in hard turning. Grooving wear was also observed at the flank surfaces.

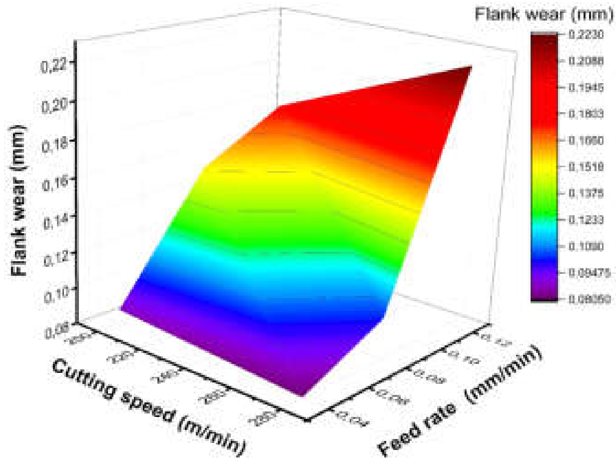

Fig. 5. Effect of cutting speed and feed rate on tool flank wear for CBN cutting tool covered with TİN at constant depth of cut

Fig. 5 shows the tool flank wear in relationship with cutting speed and feed rate, while the depth of cut is kept at the constant dept of cut for CBN cutting tools. According to this figure, the increase in feed rate from 0.04 to 0.12 mm/rev leads to the increase of tool wear both cutting speeds 200 and 280 m/min. For every specimen on which the wearing test was performed, wearing occurred increasingly during the cutting process from the beginning. The relation of voltage change wearing (1) caused by this situation (Çakan,2006) was determined in terms of mm.

A comparison of flank wear values measured in mm and V resulted in the following equations: The amount of cutting edge wear (mm) = -0.0061 + 0.0472 wear rate (V)

(R^2 = 86.3%; RMSE =0.003; P<0.001) **(1)**

- 200 m/min cutting speed 0.04 rpm/min speed of wear progress = -0.0061+(0.0472*(4.3185-2.33)) = 0.0877 mm
- 200 m/min cutting speed 0.08 rpm/min speed of wear progress = -0.0061+(0.0472*(6.9900-3.6180)) = 0.1530 mm
- 200 m/min cutting speed 0.12 rpm/min speed of wear progress = -0.0061+(0.0472*(6.9815-3.0905)) = 0.1775 mm
- 280 m/min cutting speed 0.04 rpm/min speed of wear progress = -0.0061+0.0472*(6.9835-5.1475) = 0.0805 mm
- 280 m/min cutting speed 0.08 rpm/min speed of wear progress = -0.0061+0.0472*(6.167-4.3235) = 0.1021 mm
- 280 m/min cutting speed 0.12 rpm/min speed of wear progress = -0.0061+0.0472*(6.988-2.1395) = 0.2227 mm

With 200 and 280 m/min cutting speeds and 0.12 mm/rev feed rate, similar results were observed in the experiments performed on wearing levels of cutting edges by using CBN cutting edges. However, according to the wearing values acquired at the cutting speed of 280 m/min, it was observed that less wearing occurred in the cutting edge. In the cutting parameters used for turning hardened AISI 4140 materials, the best wearing performance was observed at the feed rate of 0.04 mm/rev and the cutting speed of 280 m/min. Consequently, the use of weak feed rate is advised during turning operation.

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