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Evaluation of the Performance of Cryogenically Treated Carbide İnserts in the Turning of AISI 1040 Steel

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***Abstract*--In this study, the effects of cryogenic treatment on tool wear and surface roughness of tungsten carbide inserts coated with TiAlN were investigated as a function of cutting speed and feed rate. It is observed that the surface roughness increases with increased cutting speed, feed rate and also applied cryogenic processing. In other words, the effect of feed rate and cutting speed is very high on the surface roughness. On the other hand, the results showed that the cryogenic treatment is a non-effective process to enhance the wear resistance and tool life of inserts due to brittle region between coated layer and surface.**

***Keywords*-- tungsten carbide; wear; cryogenic, treatment; tempering, inserts**

I. INTRODUCTION

The wear performance and tool life of tool steels plays a major role in increasing productivity and consequently is an important economic factor [1]. Therefore, considerable effort is expended on the improvement of these properties of tool steels. Previous results have shown that tool wear can be reduced by selecting tool materials, coatings, or treatments [2-4]. Corresponding to this, it has been shown that using cryogenic treatment (CT) on these materials increases the wear strength, decrease the friction coefficient, and improve tool life [5-7]. Some literatures have also reported the influence of CT on residual stress, micro-structural evolution, tensile properties, fatigue properties and other mechanical properties of many kinds of metal materials [8,9].

Tungsten carbide (WC) is a high performance material formed from tungsten and carbon [10,11]. The WC is primarily used in the production of a wide variety of industrial tools and wear parts that are subject to a great deal of stress. The studies reveal the contribution of CT in improving the properties of WCs.

Corresponding to this, Thakur et al.[12] confirmed a slight increase in the micro-hardness in WC tools due to CT, which was due to formation of additional complex carbides such as Co6W6C or Co3W3C. In addition to this, the cryogenically treated WC is more wear resistance due to increase in the population density of carbides [13]. On the other hand, it has been noted that the CT of WC inserts improves tool life performance to a certain extent[14]. This is largely dependent on the machining conditions and the length of machining time.

The literature review reveals the contribution of CT in improving the properties of WCs, but the work does not adequately clarify the choice of the number of post-tempering cycles during CT and behaviors of cutting tools made of WC. In this study, we intend to determine the influence of the cryogenic treatment on the wear performance and surface roughness of WC cutting tools as a function of machining parameter (cutting speed and feed rate). The efforts are made to understand the mechanism behind the change in wear characteristics and surface roughness due to CT.

II. EXPERIMENTAL METHOD

In this study, the WC cutting tools of 0,4-0,8-1,6 mm nose radius, belonging to ISCAR companies were used in experiments. Firstly, the WC cutting tools were coated with TiAlN using Physical Vapor Deposition **(**PVD) method. After this process, cryogenic transaction was applied where the part of the coated WC cutting tools was gradually cooled from room temperature to -145 ° C with a cooling rate of about 1-2 ° C / min and after 24 hours at this temperature, it was gradually warmed to room temperature with a heating rate of 1-2 ° C / min. After cryogenic treatment, the cutting tools were tempered at 200 ° C for 2 hours. The schematic of cryogenic treatment processes and experimental conditions were shown Fig. 1 and Table 1, respectively.

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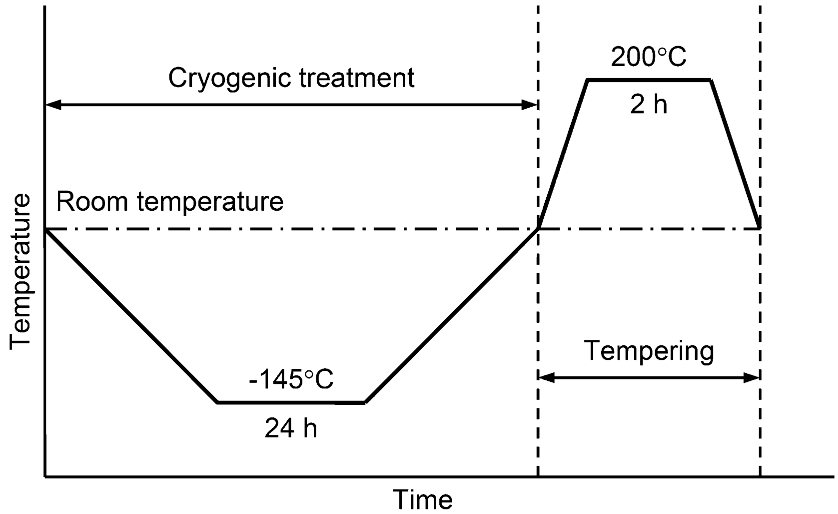

Fig. 1. Schematic representation of the cryogenic and tempering treatment cycles followed in the study.

Table 1.
Experimental conditions

.Machine	Ecoca SL-8 CNC Lathe
Workpiece material	AISI 1040 steel (C: 0.41%, Mn: 0.70%, Si: %0.21, P: %0.007, S: %0.014, Cr: %0.05, Ni: %0.02, Cu: %0.05, Al: 0.025)
Cutting Tool	Triangular coated insert  tungsten carbide coated with TiAlN WNMG 080404-NM4 (WMG 20)
Coating	TiAlN (PVD)
Tool holder	Iscar WNMG 2525 M12
Cutting Method	Oblique
Cutting condition	Dry
Heat treatment	Deep cryogenic treatment
Cutting speed	180 and 250 m/min
Feed rate	0.2 and 0.3 mm/rev
Depth of cut	2 mm

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In the evaluation of surface roughness and wear properties, AISI 1040 steel is machined with cryogenic treated WC cutting tools at different feed rate and cutting speed. For wear performance, the work piece with $\phi 120 \times 250$ mm was machined with WC cutting tools at a cutting depth 2 mm, cutting speed 400 mm/min and a feed rate of 0.25 mm/cycle. It was tried to determine the effect of cryogenic treatment on WC cutting toosl wear by calculating the machined volume of the material until the cutting tool is broken by the determined parameters. SEM images of the cutting tools were taken after wear tests to clearly see the erosion of the cutting tool.

III. Results And Discussion

Surface Roughness is a measurable surface characteristic quantifying high frequency deviations from an ideal surface.

It is usually described by the arithmetic mean value (Ra) based on the mean of the normal deviations from a nominal surface over a specified "cutoff" length and is given in following equation:

$$R_a = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Where, 'R_a' is the surface roughness, 'n' is the number of measurement points and 'y_i' is the surface deviation at measurement point 'i.'. It is well known that the final geometry of surface roughness is influenced by various machining conditions such as spindle speed, feed rate and depth of cut. Feed rate is the rate at which the tool advances along its cutting path.

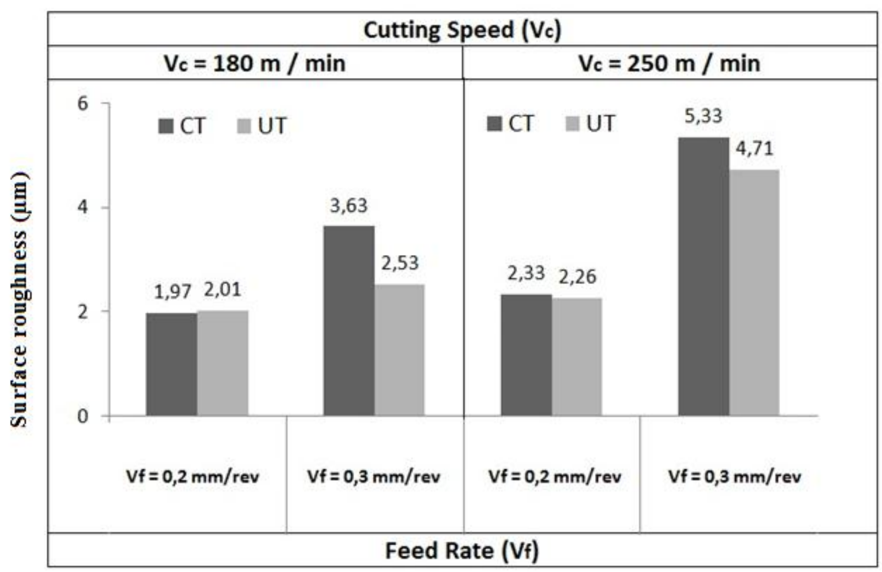

Fig. 2. Average surface roughness versus feed rate and cutting speed for the coated inserts.

In literature, Reddy et al. [15] showed that the roughness increases as a function of square of the feed rate flattening of ridges due to side flow or tool work relative vibrations. In addition to this, Abdullah et al. [16] realized that smaller feed rate and higher cutting speed can help to produce higher quality of surface. In contrast, depending on the increasing temperature with increasing cutting speed, deformation and chip flow are facilitated. Thus, surface roughness improves with increasing cutting speed [17]. In this study, the graphs of surface roughness as a function of feed rate and cutting speed is plotted for the CT and untreated (UT) cutting tools (Fig. 2).

The results regarding the effect of feed rate and cutting speed on the surface roughness obtained in this study is in agreement with the results of previous studies[18-23]. In addition, the surface roughness obtained from this study is close those of AISI 1015 steels coated with TiAlN and AlTiN using the PVD technique[24]. Fig. 2 shows that cutting conditions play an important role in surface roughness, and feed has a great influence on surface quality so increasing feed rate led to increase surface roughness also cutting speed the same effect in roughness which introduce tool wear.

This can be explained as follows; at high feed rate, a continuous chip formed which is increase of temperature in the workpiece and tool interface which is increase friction that leads to high roughness. On the other hand, we realize that the surface roughness of UT cutting tools appears to be somewhat better than CT cutting tools in the present study. To summarize, the feed rate was found out to be dominant factor on the surface roughness of tungsten carbide inserts coated with TiAlN. A good combination of cutting speed and feed rate can provide better surface qualities

Now let us consider the wear properties of CT and UT cutting tools. It is well known that wear characteristics have significant contribution to the enhancement of the material tool life.

For this purpose, the wear properties has been investigated under a constant feed rate and cutting speed (0.25 mm/rev and 400 m/min.) for CT and UT cutting tools. Until the cutting tool breaks, the volumes of chips cut of the work pieces by CT and UT cutting tools are 47720 and 50240 mm^3, respectively (Table 2). We saw that the CT and UT application produced a brittle region between the coated layer and the bulk workpiece of the cutting tools. So, wear was done quickly and the cutting tool was broken due to their microstructural features (Fig.3). For this reason, the volume of chips removed using CT cutting tools was less than that removed by UT cutting tools (Table 2).

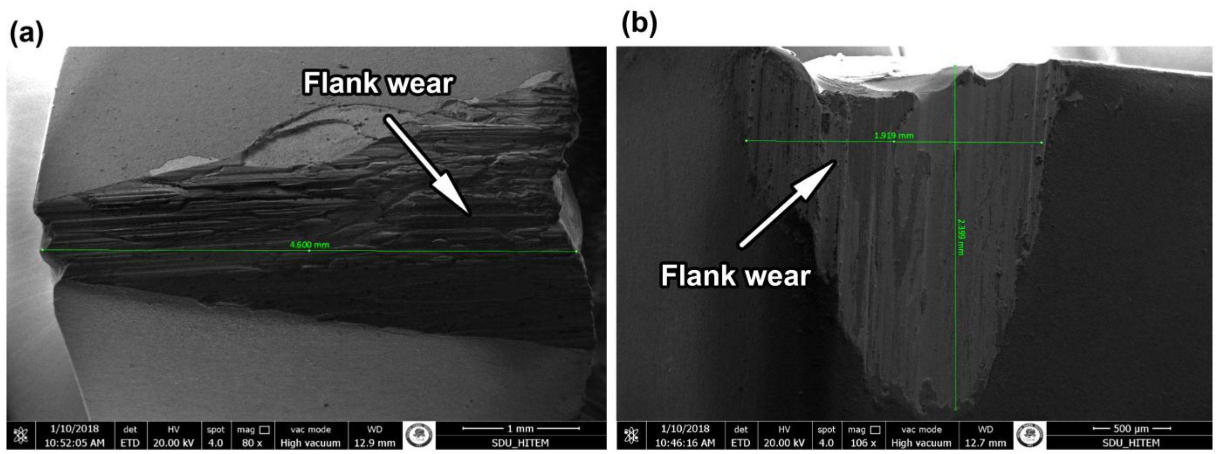

Fig. 3. SEM images displaying flank wear on the coated inserts tested at a feed rate of 0.25 mm/rev and cutting speed of 400 m/min.

Table 2.
Summary of total volume removed after wear testing.

Insert	Volume removed (mm^3)
PVD-UT	50240
PVD-CT	47720

Contrary to the results obtained in our study, positive effects on improving the wear properties of materials by cryogenic treatment have been noticed in tool steels, carburized steels, cast irons and other materials. Corresponding to this, the treated inserts showed a better performance than the untreated ones of up to 34%, 53% and 29% 67% in flank wear and crater wear for tungsten [25] and cemented carbide inserts [26], respectively. This improvement has been explained by the increases in grain size and improved micro-structure of cemented carbide inserts. Similar results have also obtained in previous studies by Naravade et al. [27] and Jaswin et al. [28.

They showed that the cryogenic treatment improves the wear resistance and the hardness of the D6 tool steel and En 52 and 21-4N valve steels due to homogenized carbide distribution and formation of fine carbides dispersed in the tempered martensite structure. These results show that the cryogenic treatment of tungsten carbide inserts improves tool life performance to a certain extent.In summary, the CT is a non-effective process to enhance the wear resistance of the WC cutting tools coating with PVD. This process decreases tool life and wear resistance of coated WC cutting tools.

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IV. CONCLUSION

Based on the results obtained in this study, the following conclusions can be drawn regarding the effect of CT on wear characteristic and surface roughness of WC cutting tools coated with TiAlN:

- The effect of feed rate and cutting speed is very high on the surface roughness. It may be concluded that better surface finish may be achieved at low feed rate and cutting speeds.
- WC cutting tools treated cryogenically showed the bad performance for the wear resistance and tool life.
- The CT could not produce a very fine carbides precipitation, and high volume fraction of the carbides due to the coating layer.

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