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MACHINABILITY OF A Ti-6Al-4V ALLOY WITH CRYOGENICALLY TREATED CEMENTED CARBIDE TOOLS

OBDELOVALNOST ZLITINE Ti-6Al-4V S KRIOGENSKO OBDELANIMI ORODJI IZ KARBIDNE TRDINE

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In this study, the effects of the treatment (applied to cutting parameters and cutting tool) on the cutting forces, surface roughness and tool life were investigated. Part of the cutting tools was subjected to a cryogenically treatment at –145 °C for 24 h. The effects of the cryogenically treated and untreated cemented carbides (uncoated) on the cutting forces, surface roughness and wear behaviors were investigated. Machinability tests were carried out at four different cutting speeds (30, 45, 60, 75) m/min, three different feed rates (0.20, 0.25 and 0.30) mm/r and the 1 mm cutting depth. Wear tests were made for four different chip volumes (20, 40, 60 and 80) cm^3, four different cutting speeds (30, 45, 60, 75) m/min, the 0.25 m/r feed rate and the 1 mm cutting depth. At the end of the tests, the cryogenically treated inserts gave better results compared to the untreated tools with respect to the wear behavior, cutting forces and surface roughness.

Keywords: Ti-6Al-4V, tool wear, cryogenic process, cutting forces, surface roughness

V tej študiji je bil preiskovan vpliv obdelave (uporabljene za rezalne parametere in rezalno orodje) na sile pri rezanju, hrapavost površine in zdržljivost orodja. Del orodij iz karbidne trdine je bil kriogensko obdelan 24 h pri –145 °C. Preiskovan je bil vpliv kriogensko obdelanih in neobdelanih orodij iz karbidne trdine (brez prevleke) na sile rezanja, hrapavost površine in vedenje pri obrabi. Preizkusi obdelovalnosti so bili izvršeni pri štirih različnih hitrostih rezanja (30, 45, 60, 75) m/min, pri treh različnih hitrostih podajanja (0,20, 0,25 in 0,30) mm/r in pri globini rezanja 1 mm. Preizkusi obrabe so bili izvršeni pri štirih volumnih odrezkov (20, 40, 60 in 80) cm^3, pri štirih hitrostih rezanja (30, 45, 60, 75) m/min, pri podajanju 0,25 m/r in pri globini rezanja 1 mm. Preizkusi so pokazali, da dajejo s stališča obrabe, sil pri rezanju in hrapavosti površine, kriogensko obdelani vložki boljše rezultate v primerjavi z neobdelanim orodjem.

Ključne besede: Ti-6Al-4V, obraba orodja, kriogenski postopek, sile rezanja, hrapavost površine

1 INTRODUCTION

Titanium and its alloys have high strength, heat and corrosion resistance. They are used in the medical, electronics and computer, aviation and space industries.[1,2] These alloys preserve their properties even at high temperatures during machining. Therefore, titanium belongs to the group of hard-to-machine materials. Among these alloys with different properties, Ti-6Al-4V has the lion's share with a 60 % usage in industrial applications.[3,4] While at the higher temperatures during the treatment, a titanium alloy can preserve its strength, the cutting tool loses its strength due to the high temperature and pressure. The reaction with the cutting-tool material at high temperatures and the build-up edges (BUE) on the cutting-tool tip significantly affect the cost and efficiency of the treatment.[5–7] Siekman indicated that the machining of these alloys is always problematic no matter which classical method is used.[8] From this aspect, an investigation of suitable machining conditions is important for the machining of these alloys.

Cryogenic treatment is a supplementary process for the heat treatment applied to increase the wear resistance of the materials subjected to high wear. It is also known as the below-zero cryogenic treatment. Contrary to the coatings, it is a cheap, long-lasting process; it is carried out once and it affects the whole piece. With this method, a conversion of the residual austenite into martensite in a conventionally heat-treated material, a formation of thin carbide precipitates and a uniform carbide distribution are obtained. In this way, serious improvements in the mechanical properties of the materials such as the hardness and wear resistance are achieved. Cryogenic treatment used to be applied to molding materials, but nowadays, due to its application to the cutting tools in the machining practice, significant developments have been made with respect to tool wear, tool life and cutting conditions. It was found that by applying cryogenic treatment to certain tool materials, improvements in the tool wear by 91 % to 817 % were achieved.[9–12]

In this study, during the turning of an Ti-6Al-4V alloy under dry cutting conditions with cryogenically treated and untreated, uncoated cemented carbide tips, the effects of different combinations of the cutting depth, cutting speed and feed rate on the cutting forces, surface roughness and tool wear were examined.

2 EXPERIMENTAL PROCEDURES

2.1 Materials

In the tests, the Ti6Al4V alloy having the AMS 4928 characteristics was used. The chemical constituents and the physical properties of the material are given in **Tables 1** and **2**, respectively.

Table 1: Chemical composition of Ti-6Al-4V (mass fractions, *w*/%)
Tabela 1: Kemijska sestava Ti-6Al-4V (masni deleži, *w*/%)

N	C	H	Fe	O	Al	V
0.08	2.00	0.75	0.045	0.03	16.0–18.0	10.0–14.0

Table 2: Mechanical properties of Ti-6Al-4V
Tabela 2: Mehanske lastnosti Ti-6Al-4V

Tensile strength	Yield strength	Hardness, Rockwell C	Elongation
900–1100 MPa	830 MPa	36	10 %

2.2 Machining tests

The tests were made using a JohnfordTC35 CNC turning center with no cooling liquid at four different cutting speeds (30, 45, 60, 75) m/min, three different feed rates (0.20, 0.25, 0.30) mm/r and a constant cutting depth (1 mm). The wear tests were realized for four different chip volumes (20, 40, 60 and 80) cm^3, four different cutting speeds (30, 45, 60 and 75) m/min, a 0.25 m/r feed rate and a 1 mm cutting depth. In the tests, the uncoated cemented carbide tips of the SANDVİK Coromant company were used. Half of these tips were cryogenically treated for the purpose of making a comparison. A graphic presentation of the steps of the cryogenic treatment is given in **Figure 1**.

The surface-roughness measurements on the machined surfaces of the samples were made with a Mahr Perthometer, type M1, surface-roughness-measurement device. The measurements were made parallel to the working-piece axis and on three different surfaces by rotating a workpiece 120° around its axis after each measurement. The average surface-roughness (R_a) values were determined by taking the arithmetical mean of the three values obtained at the end of the tests. The cutting force was measured with a Kistler 9257A three-component piezoelectric dynamometer and the associated 5019 B130 charge amplifiers connected to a PC employing the Kistler Dynoware force-measurement software.

The measurement of the tool flank wear obtained at the end of the turning operations was made with a scanning electron microscope (SEM).

3 RESULTS AND DISCUSSIONS

3.1 Flank wear

Tool wear is the result of the frictions and temperature taking place in the areas where the cutting-tool material and the workpiece material are in contact. Friction is the most important reason for the wear, whereas the temperature decreases the resistance to wear and, for this reason, it is the factor accelerating the wear.[13] One of the most common types of the wear occurring in machining is flank wear. Flank wear occurs because of the contact between the side surfaces of a cutting tool and the workpiece. In **Figure 2**, the formation of the maximum flank wear at different cutting speeds for normal and cryogenically treated, cemented carbide tools is given. The flank wear increased with the increasing cutting speed (**Figure 2**) because the contact area of the cutting tool increased with an increase in the cutting speed and because the temperature was raised due to the increasing cutting speed leading to flank wear.[14] The flank wear was lower for the cryogenically treated inserts compared to the normal tools. The reason for this was the fact that the cryogenically treated inserts had more uniform and more stable microstructures (**Figure 3**). The effects of more uniform structures on the wear behavior are also known.[9,15–17] When the wear values of the cutting tools are considered it is seen that the wear of the cryogenically treated inserts is lower by 10–22 %.

The tool wears depending on different cutting speeds are given in **Figures 4** and **5**. From these figures it is

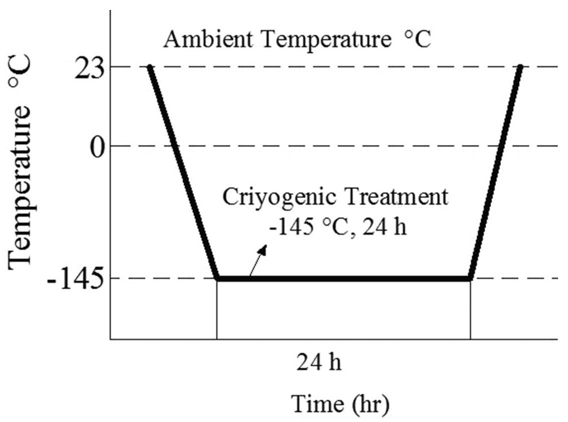

Figure 1: Schematic diagram of the cryogenic treatment
Slika 1: Shematski prikaz kriogenske obdelave

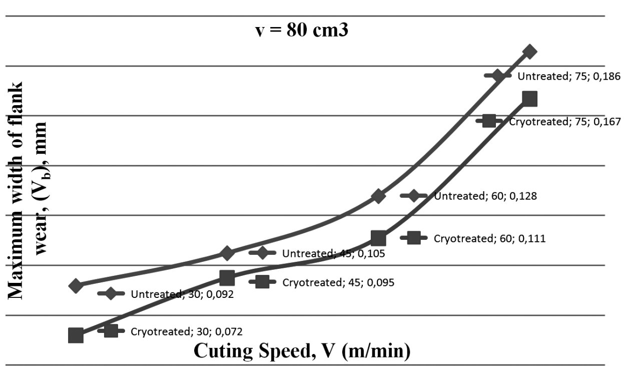

Figure 2: Maximum width of the flank wear at different cutting speeds
Slika 2: Največja širina obrabe boka pri različnih hitrostih rezanja

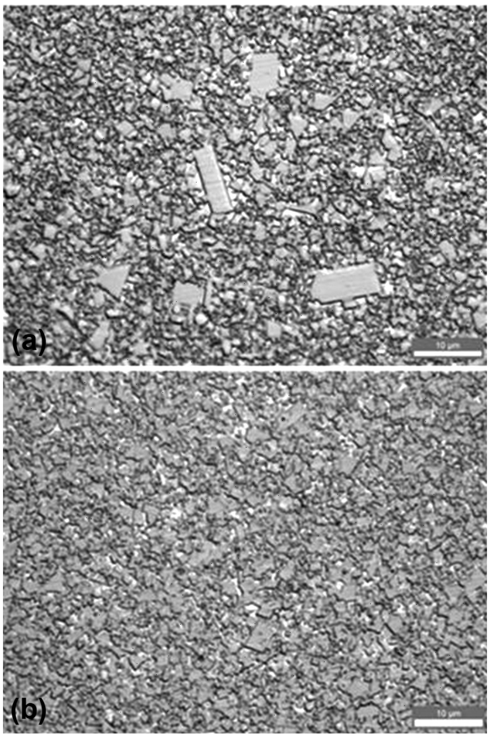

Figure 3: Microstructures of cutting inserts: a) untreated insert, b) cryogenically treated insert
Slika 3: Mikrostruktura vložka za rezanje: a) neobdelan vložek, b) kriogensko obdelan vložek

clear that the wear is higher for the untreated cutting tools compared to the cryogenically treated inserts. In **Figures 4** and **5**, it is observed that, at all the cutting speeds, the flank wear is lower when the chip volume is 20 cm^3 and 40 cm^3. However, depending on the increasing chip volume, there is a rapid increase in the flank wear. For both cutting tools (cryogenically treated and untreated) when the chip volume is 80 cm^3 and the cutting speed is 75 m/min, the flank wear is maximum. The main reason for this is the fact that the high temperatures at the tool-chip interface depend on the increasing cutting speed and the chip volume.[18]

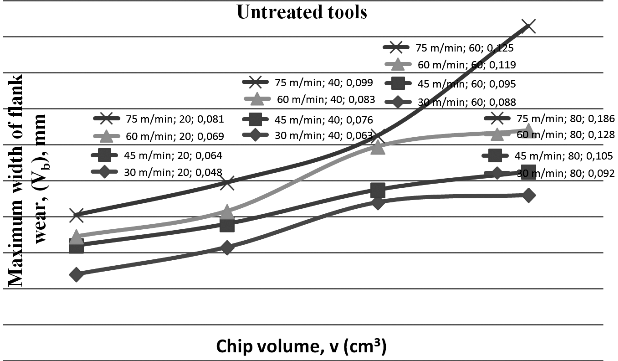

Figure 4: Maximum width of the flank wear at different chip volumes for the untreated insert
Slika 4: Največja širina obrabe bokov pri različnih volumnih ostružkov pri neobdelanem vložku

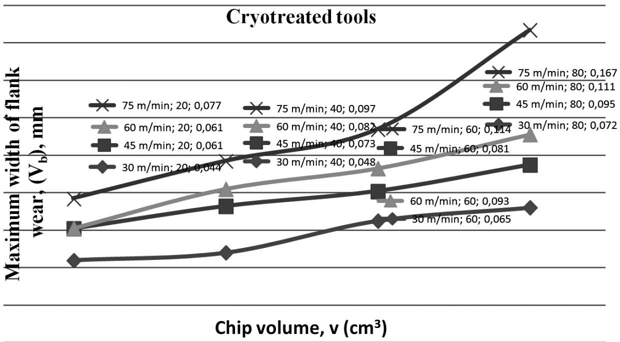

Figure 5: Maximum width of the flank wear at different chip volumes for the cryogenically treated insert
Slika 5: Največja širina obrabe bokov pri različnih volumnih ostružkov pri kriogensko obdelanem vložku

3.2 Cutting forces

In **Figure 6** the changes in the main cutting forces of the cryogenically treated and untreated inserts are given. It is clear that a decrease in the main cutting force is due to the increasing cutting speed. It is understood that this tendency is the same for both tools, as the power used in the machining is usually converted into heat on the sliding plane, at the circumference of the cutting tip. Most of the heat created on the sliding plane is removed with the chip, but a certain portion is conducted to the workpiece. This conducted heat decreases the hardness of the workpiece. When the hardness decreases, the ductility increases making the chip removal easier. However, if this conduction of the heat continues to increase, the changes in the cutting forces can occur[18–20] due to a start of the BUE tendency. In the cryogenically treated inserts, the main cutting forces are lower compared to the untreated inserts. This situation can be explained with a low heat at the cryogenically treated insert tip and a lower flank wear. The best result with respect to the main cutting forces was 75 m/min for the cryogenically treated inserts.

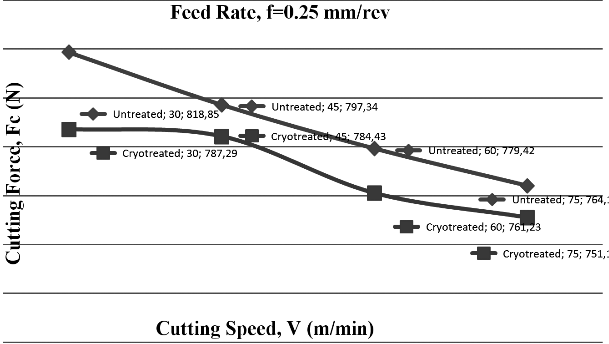

Figure 6: Main cutting force (F_c) at different cutting speeds
Slika 6: Sila rezanja (F_c) pri različnih hitrostih rezanja

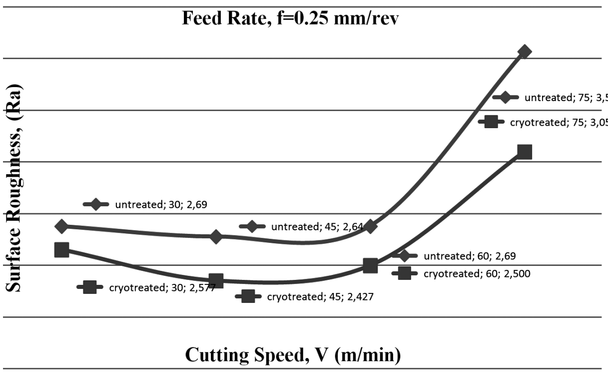

Figure 7: Surface roughness (R_a) at different cutting speeds
Slika 7: Hrapavost površine (R_a) pri različnih hitrostih rezanja

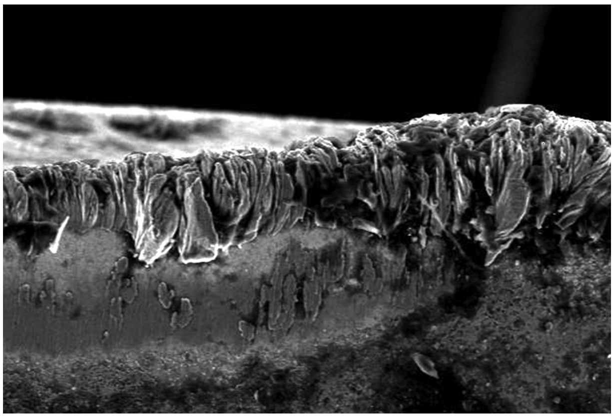

Figure 8: Wear image of cemented carbides
Slika 8: Posnetek obrabe karbidne trdine

3.3 Surface roughness

The surface quality and roughness obtained with each machining method changed. The correct selection of the surface roughness directly affects the product cost. Because of this, the surface roughness is one of the most important machining parameters. As it is seen from **Figure 7**, with the increasing cutting speed the surface-roughness values decrease at first, but when the cutting speed exceeds 60 m/min they are affected adversely, exhibiting a sudden increase. The improvement in the surface roughness with the increasing cutting speed, depending on the increasing temperature at higher speeds, can be explained with an easy deformation of the workpiece material at the cutting edge and the circumference of the tip radius, and the yielding formation at high temperatures.[19,20] However, as it is observed from the wear graphics in **Figures 4** and **5** and from the SEM image of the cutting tool in **Figure 8**, the reason for the rapid increase in the surface roughness at the 60 m/min cutting speed is caused by the formation of the wear of the cutting tools.

4 CONCLUSION

Cryogenically treated inserts gave better results than the other tools with respect to tool wear.

The wear of the cryogenically treated inserts was lower than the wear of the other inserts by 10–22 %.

At all the cutting speeds, cryogenically treated inserts gave better results with respect to the main cutting forces.

When the cutting speed was 30 m/min and 45 m/min, the surface roughness decreased, but when it increased to higher levels the average surface roughness increased too.

Cryogenically treated inserts gave better results with respect to the main cutting forces and the average surface roughness.

The cryogenic treatment made the microstructure of the cutting tool more uniform and more stable.

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