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Investigation of the effects of cryogenic treatment applied at different holding times to cemented carbide inserts on tool wear

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ABSTRACT

Cutting tool costs is one of the most important components of machining costs. For this reason, tool life should be improved using some methods such as cutting fluid, optimal cutting parameters, hard coatings and heat treatment. Recently, another one of the methods commonly used to improve tool life is cryogenic treatment. This study was designed to evaluate the effects of different holding times of deep cryogenic treatment on tool wear in turning of AISI 316 austenitic stainless steel. The cemented carbide inserts were cryogenically treated at −145 °C for 12, 24, 36, 48 and 60 h. Wear tests were conducted at four cutting speeds (100, 120, 140 and 160 m/min), a feed rate of 0.3 mm/rev and a 2.4 mm depth of cut under dry cutting conditions. The wear test results showed that flank wear and crater wear were present in all combinations of the cutting parameters. However, notch wear appeared only at lower cutting speeds (100 and 120 m/min). In general, the best wear resistance was obtained with cutting inserts cryogenically treated for 24 h. This case was attributed to the increased hardness and improved microstructure of cemented carbide inserts. These improvements were confirmed through hardness, image processing, and XRD analyses.

1. Introduction

In modern metal cutting operations, it is of the utmost importance to increase the material removal rate with a good surface finish and high machining accuracy. Using existing conventional techniques and tool materials in the machining of difficult-to-cut materials is uneconomical, as the machining process results in high tool wear and takes a substantial amount of time [1]. It is well-known that nickel-based materials (e.g. superalloys) are difficult-to-cut materials due to their low thermal conductivity, their tendency for strain hardening and high strength at elevated temperatures [2]. Although machinability of austenitic stainless steels are comparatively easier than that of Ni-based superalloys, the high Cr and Ni contents in composition of these steels make their machinability difficult. Since higher cutting temperatures are generated during turning [3], milling [4], and drilling [5] operations of difficult-to-cut materials, cutting tool materials with high wear resistance and hot hardness must be developed or physical and mechanical properties of existing cutting tools must be improved. The life of cutting tools plays a major role in increasing productivity and, consequently, is an important economic factor. In order to increase the life of cutting tools, a common approach used in the past has been to heat-treat tool materials. This provides greater control over the range of properties that a given tool material may have [6]. Cryogenic treatment is a supplementary process to conventional heat treatment and it has recently been used to improve some properties of materials such as wear resistance, fatigue life and residual stress [7,8]. In deep cryogenic treatment, samples are gradually cooled to cryogenic temperatures from −125 °C to −196 °C, held at these temperatures for generally 24 h and then gradually heated to room temperature [9,10]. In this way, the wear resistance of materials such as HSS, cemented carbide, and tool steel is increased due to the transformation of austenite to martensite, the formation of fine carbide particles and the homogeneous distribution of the carbide particles [11–13]. Yong and Ding [14] investigated effect of deep cryogenic treatment (−196 °C) at different holding times (2, 4, 8, 24 and 72 h) on the mechanical and magnetic properties of WC–8 wt% Co cemented carbides. The results showed that after the cryogenic treatment, hardness, compression strength, wear resistance and fatigue resistance of the samples enhanced while the bending strength and toughness did not changed evidently. The highest hardness and wear resistance were obtained on the samples cryogenically treated for 2 h. Das et al. [15] applied deep cryogenic treatment to AISI D2 cold work tool steel in order to optimize the

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holding time in terms of its wear resistance. For this purpose, the samples were held at cryogenic temperatures for different times (1, 12, 36, 60 and 84 h). In the wear tests conducted using a pin-on-disk tester, it was observed that the samples treated for 36 h showed the best wear resistance. Similarly, Amini et al. [16] investigated the effects of holding times at liquid nitrogen temperature during deep cryogenic heat treatment on micro-structural changes, carbide distribution, carbide percentage, hardness and micro-hardness of AISI D3 tool steel. The samples were held at the deep cryogenic temperature for 24, 36, 48, 72, 96 and 120 h. It was shown that the hardness, micro-hardness, microstructure uniformity and carbide percentage reached their optimum values at a holding duration of 36 h. Firouzdor et al. [12] reported that improvements up to 77% and 126% were achieved in the tool lives of treated and treated and tempered HSS drills, respectively, during drilling experiments. Da Silva et al. [17] aimed to verify the effect of cryogenic treatment on M2 HSS tools by using either laboratories or shop floor tests in an automotive industry. After wear tests were conducted, improvements of 65% to 343% in tool performance were obtained. Çiçek et al. [18] studied the effects of deep cryogenic treatments on the tool life of M35 HSS drills in the drilling of austenitic stainless steels. It was reported that with treated drills, tool life improved by up to 218%. According to the study, treated cutting tools showed better performance in terms of tool life, especially at higher cutting speeds. Reddy et al. [19] evaluated the machinability of C45 steel in terms of the flank wear of cutting tool inserts, main cutting force and surface finish of the machined workpieces. The flank wear of deep cryogenically treated carbide tools was lower than that of untreated carbide tools in the machining of the C45 steel. The cutting force and surface roughness values were better with deep cryogenically treated carbide tools when compared to untreated carbide tools. Yong et al. [20] reported that under certain conditions, cryogenic treatment can be detrimental to tool life and performance. It was also shown that cryogenically treated tools perform better while engaged in intermittent cutting operations. Seah et al. [21] investigated the effects of various subzero thermal treatments on the tool life and wear characteristics of cobalt-bonded tungsten carbide cutting tool inserts. The inserts were subjected to six different conditions of treatment, namely: (a) as-received, (b) quenching treatment, (c) cryogenic treatment (−196 °C), (d) cryogenic treatment followed by tempering, (e) cold treatment (−80 °C) and (f) cold treatment followed by tempering. It was found that the inserts that had undergone the latter four conditions of treatment exhibited significantly longer tool life and wear resistance at higher cutting speeds, as well as an overall increased resistance to chipping. Gill et al. [22] reported that in the turning of C45 steel, improvements of 20% to 36% were observed in the tool life of cemented carbide inserts after cryogenic treatment at −196 °C for 38 h.

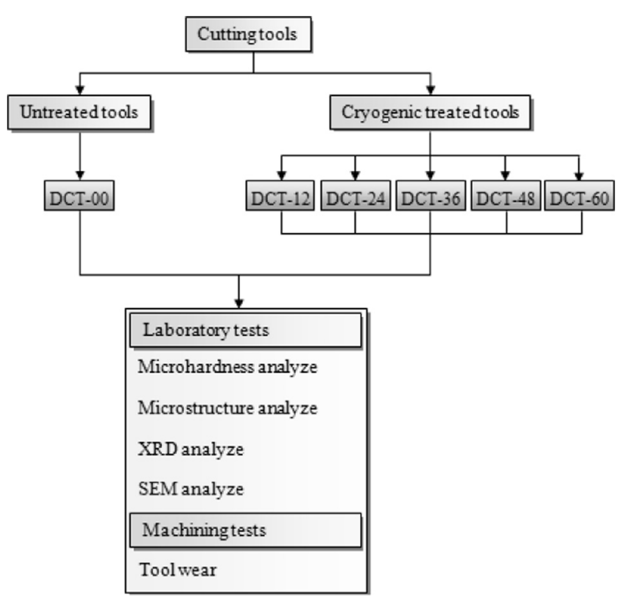

Fig. 1. Flow chart for experimental procedure.

This study aimed to find the optimal holding time for deep cryogenic treatment implemented on cemented carbide inserts in terms of wear resistance in the turning of AISI 316 austenitic stainless steel. For this purpose, a number of turning wear experiments were carried out on a CNC machine tool with untreated cemented carbide inserts and cemented carbide inserts cryogenically treated for 12, 24, 36, 48 and 60 h. The workpiece material was selected as AISI 316 stainless steel having excellent physical and metallurgical properties and appropriate mechanical properties along with a high resistance to corrosion.

2. Experimental details

The experimental procedure adopted in the present work is shown in Fig. 1. As illustrated in the flow chart, the experiments were carried out separately for all cutting tools.

The chemical composition of the AISI 316 stainless steel used in this study is shown in Table 1. In the experiments, AISI 316 stainless steel bars with a diameter of 100 mm and length of 250 mm were used. The SNMG 120412-TF uncoated cemented tungsten carbide inserts produced by ISCAR were employed. Details of the cryogenic treatments applied to the carbide inserts are shown in Fig. 2. After cryogenic treatment, all samples were tempered at a temperature of 200 °C for 2 h.

Micro-hardness measurements on the samples were performed under the load of 200 g applied for 15 s using the SHIMADZU micro-hardness tester. The average value of six tested samples was used to plot the micro-hardness graph. To determine the effects of different holding times at −145 °C on the wear resistance of the cemented carbide inserts, wear tests were performed at different combinations of cutting parameters. The wear tests were conducted on a CNC machine tool at four cutting speeds (100, 120, 140 and 160 m/min), a feed rate of 0.3 mm/rev and a 2.4 mm depth of cut. The types of wear formed on the cutting inserts are shown in Fig. 3. It was observed that flank wear and crater wear were formed on all inserts at all combinations of cutting parameters. However, notch wear was observed only at lower cutting speeds. In order to observe wear progress at certain periods, the cutting processes were stopped and the amount of flank and notch wear were measured using a digital microscope. The depth of the craters on the rake faces of the inserts was measured using the Mahr Conturograph device with an accuracy of 1 μm.

3. Results and discussion

3.1. Microstructural observations

There are three main phases in the microstructure of cemented carbides: α phase (tungsten carbide), β phase (cobalt binder), and η phase (multiple carbides of tungsten and at least one metal of

Table 1
Chemical composition of the AISI 316 stainless steel.

C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Ni (%)	Mo (%)	Cu (%)
0.04	1.18	0.41	0.038	0.012	16.3	10.09	2.02	0.49