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Effect of Plasma Nitriding on the Performance of WC-Co Cutting Tools

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This paper presents the effect of nitriding process parameters on the cutting performance of WC-Co tools. The cutting performance was measured by CNC machining of GG25 cast iron parts. The hardness and phase composition of nitrided layer were determined for different plasma nitriding temperatures and times. The hardness of the nitrided layer increased at all plasma nitrided conditions investigated. However, the machining performance of the cutting inserts varied in the range between a 60% increase and a 40% decrease after plasma nitriding. The maximum number of machined parts was seen when the insert was nitrided at 600 °C-4 h and at 500 °C-4 h.

Keywords cutting performance, cutting tools, hardness, indentation, ion implantation, wear

1. Introduction

The increase in temperature and stresses occurring during machining cause wear of the cutting tool used. The amount of time it takes for a cutting tool to reach the allowed wear limit can be expressed as tool life. Therefore, reducing the wear rate will prolong tool life. Improving surface properties by surface treatment is one method of increasing tool life. Plasma nitriding is a surface treatment method that improves wear resistance of the materials and maintains dimensional stability and surface quality (Ref 1, 2). Plasma nitriding improves the surface properties of sintered carbides and causes phase transformations and formations depending on plasma nitriding conditions and the composition of the sintered carbide being plasma nitrided (Ref 3, 4). In this work, WC-Co cutting inserts were first plasma nitrided under different conditions and then used to machine cast iron components to investigate the effect of plasma nitriding on their cutting performance.

2. Experimental Details

The samples used were WC-Co based cutting inserts with the theoretical volume fraction of 96.5% WC (calculated with law of mixture and measured density of insert). The geometry of the cutting insert and the tool holder is shown in Fig. 1.

The nitriding process was performed in a continuous plasma flow installation, in a hydrogen-nitrogen atmosphere at a ratio of 4 H_2: 1 N_2 at 10 mmHg at 500, 600, and 700 °C for 2, 4, and 9 h, constituting nine different plasma nitriding conditions.

Plasma nitrided inserts were used in CNC machining of GG25 cast iron components, having a hole which was 19.5-mm diameter and, 28 mm deep was bored to 19.96-19.97 mm diameter. The cutting process applied coolant to the tool, and the cutting speed and feed rate were 226 and 0.2 m/min, respectively. Machined components were under constant measurement, and, when the measured diameter started to diverge from the required dimension range, the next cutting edge of the three-sided cutting insert was used. The number of parts machined by each side of an insert was recorded to investigate the cutting performance after plasma nitriding.

The phase compositions of the nitrided surfaces were investigated using x-ray diffraction analysis (XRD). XRD measurements were performed using a Bruker diffractometer with monochromatic Cu-Kα (λ = 1.542 nm) radiation in a glancing geometry (2°). All XRD patterns were obtained with a scan step of 1° and a counting time of 1 min. Surface hardness of the samples was tested by a Shimadzu HMV-2L microhardness tester with a Vickers indenter under the load of 3 N, taking the average of five different measurements. Used cutting inserts were also examined under a Nikon SMZ800 optical microscope to observe the wear in the cutting inserts.

3. Results and Discussion

The average number of components that were machined by nitrided inserts is shown in Fig. 2. The average number of parts that were machined by unnitrided inserts is also shown in Fig. 2 for comparison.

The nitriding conditions of 600 °C-4 h and 500 °C-4 h yielded the best result for number of parts machined. The nitriding conditions of 500 °C-2 h and 700 °C-2 h also provided better results than unnitrided inserts. However, there was a decrease in the average number of parts machined by the insert nitrided at 700 °C-4 h and 700 °C-9 h (Fig. 2).

The change in hardness of the cutting inserts after plasma nitriding is shown in Fig. 3. The average hardness of untreated cutting inserts (1704.6 HV) is given in Fig. 3 for comparison.

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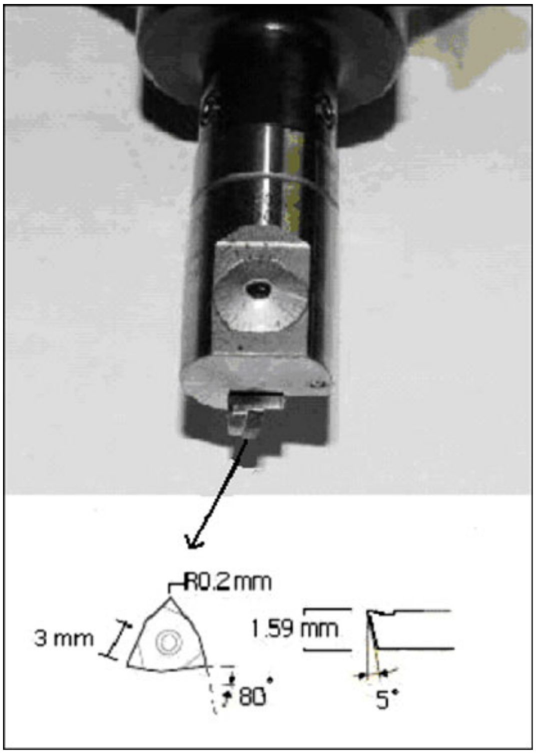

Fig. 1 Cutting tool geometry

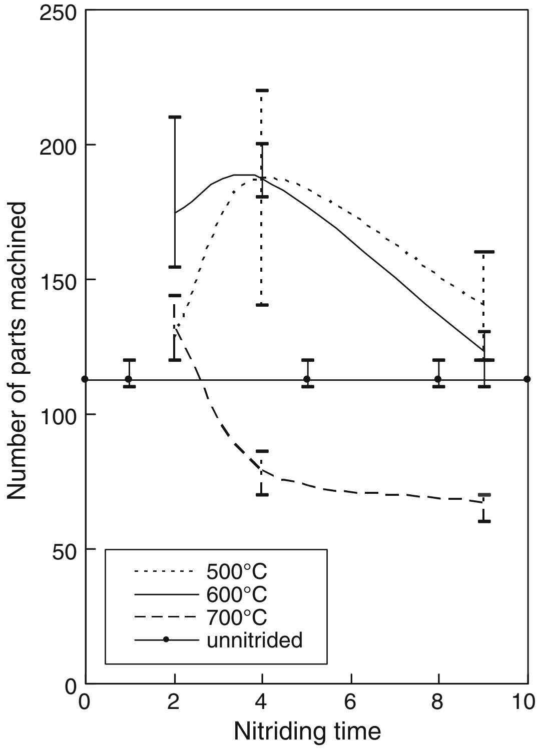

Fig. 2 Cutting performance vs. nitriding time

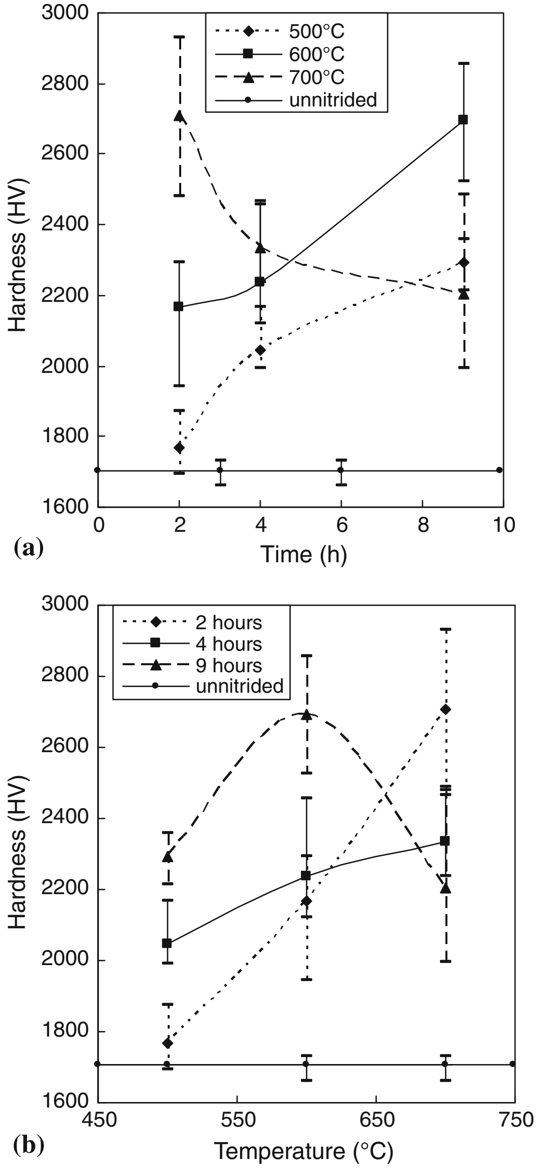

Fig. 3 The effect of nitriding conditions on cutting performance. (a) Hardness vs. nitriding time and (b) hardness vs. nitriding temperature

As seen in Fig. 3, the surface hardness of all samples increased after plasma nitriding treatment. Since the error bars of findings belonging to different duration time and temperature were generally not overlaps, the limited number of tests carried out in this work was able to indicate the general trend of ion nitriding effects on the performance of cutting inserts. Increasing duration increased the hardness at nitriding temperatures of 500 and 600 °C (Fig. 3a). Similarly, increasing nitriding temperature increased the hardness at duration time of 2 and 4 h (Fig. 3b). At the nitriding temperature of 700 °C, the surface hardness values started to decrease after a duration of 2 h, although the nitrogen diffusion amount increased (Fig. 3a). However, the surface hardness value was still higher than that of untreated tools. Therefore, the cutting performance reduction of samples nitrided at 700 °C-4 h and 700 °C-9 h, as reported above, cannot be explained by surface hardness. The best result for number of parts machined was obtained at the nitriding conditions of particularly 600 °C-4 h, although the nitriding conditions of 700 °C-2 h yielded the highest surface hardness. Similarly, the cutting performance increment of samples nitrided at 600 °C-4 h, as reported above, cannot also be explained by surface hardness.

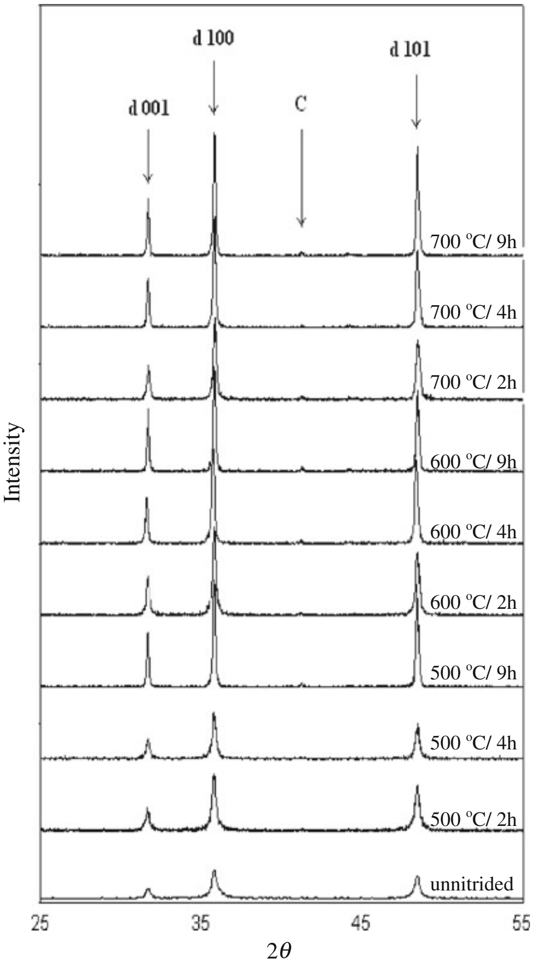

Fig. 4 X-ray diffraction measurements

XRD measurements performed on hardened surfaces of samples are shown in Fig. 4. The peaks of WN and WC phases are indistinguishable and almost overlap since the lattice parameters of WC are $c = 0.28367$ nm, $a = 0.29062$ nm, and that lattice parameters of WN phase are $c = 0.28260$ nm, $a = 0.28930$ nm (JCPDS cards 25-1256 and 25-1047, respectively). However, it was seen in Fig. 4 that free carbon was formed after 4 h when nitriding in vacuum at 500 °C and after any duration at 600 and 700 °C. W_2C and W_3C phases that were likely to form in the case of free carbon formation were not observed in any nitrided sample (Fig. 4). This evidence implies that a WN phase was formed. As seen in Fig. 4, the carbon content did not clearly increase with increasing time and temperature. As the XRD can only penetrate to a certain depth of the sample, it was not possible to see the free carbons that formed during the diffusion of nitrogen to inner regions with increasing time and temperature. The WN phase is harder [28-30 GPa (Ref 5, 6)] than the WC phases [13-22 GPa (Ref 7)]. We suggest additional possible hardening mechanisms for the increasing surface hardness of the WC-Co tool. First, the free nitrogen in the diffusion zone can cause the lattice stresses similarly to solid solution strengthening of alloys. Second, because the WC lattice parameter is bigger than the WN lattice parameters, the interface of the WC and WN phases can also cause coherency stress in the WC and WN lattices.

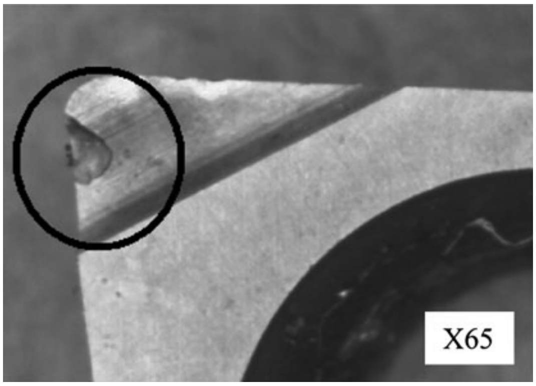

Fig. 5 Chipping damage at cutting tool nitrided at the condition of 700 °C-9 h

Chipping was observed in samples that were nitrided at high temperatures and durations as shown in Fig. 5. As Co has low affinity to N, Co is moved toward the interior of the insert with N diffusion (Ref 8), and a space can be opened for free C. The decrease in amount of binder Co on the surface and the lattice stresses causing brittleness can cause chipping of the insert during machining.

In addition, loss of coherency may be expected at the nitriding condition of high temperature and duration, similar to overaging of coherent precipitates in alloys. Thus, the hardness and cutting performance decrements shown in samples nitrided at 700 °C-4 h and 700 °C-9 h (Fig. 3) may point out the existence of these microstructural variations.

4. Conclusion

The machining performance of the cutting inserts varied in the range between a 60% increase and a 40% decrease after plasma nitriding. Maximum performance increase was seen in inserts that were nitrided at 600 °C-4 h and 500 °C-4 h. For all nitriding conditions, the surface hardness of cutting inserts was increased by plasma nitriding. Maximum surface hardness increase was achieved at the 700 °C-2 h nitriding condition, and minimum hardness increase was achieved at the 500 °C-2 h nitriding condition. X-ray diffraction analyses showed that free carbon was formed after 4 h at 500 °C and after any duration at 600 and 700 °C. Also, W_2C and W_3C phases that were likely to form in the case of free carbon formation were not found in any sample. Based on these studies, it is decided that WN was formed.

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