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Alfredo Márquez-Herrera[a], Gabriel Bermúdez-Rodríguez[a], Eric Noé Hernández-Rodríguez[b], Miguel Melendez-Lira[c], Martin Zapata-Torres[d]

[a] Departamento de Ingeniería Mecánica Agrícola, Universidad de Guanajuato, Irapuato, México
[b] Departamento de Ingeniería Mecánica, Universidad de Guanajuato, Salamanca, México
[c] Departamento de Física, CINVESTAV-IPN, Ciudad de México, México
[d] Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada, Instituto Politécnico Nacional, Ciudad de México, México

Boride coating on the surface of WC–Co-based cemented carbide

In this study, the structural properties and enhancement in the hardness of commercial WC–Co-based cemented carbide inserts are reported after the formation of a boronised layer on the surface. A boronising thermochemical treatment was given at 900 °C for 4 h. X-ray diffraction analysis verified the treatment in the presence of peaks associated with the Co_2B and W_2CoB_2 phases. The hardness of the samples used in the boronising process increased from 1492 HV up to 2000 HV. The typical values of the thickness of the boronised layer were measured to be around 28 μm. The results of a tool-life test suggest that boride coating effectively enhances the cutting performance of the samples.

Keywords: Coating; Wear; Hardness; Boride; WC–Co

1. Introduction

Cemented carbide materials are used in different metal cutting operations as tools. Usually, these are developed as a hard tungsten carbide (WC) based skeleton and a tough binder phase commonly prepared with cobalt (Co) [1]. The WC–Co-based tools operate on metals at speeds that cause the cutting edge to become red hot without affecting its hardness or sharpness. An adequate lifetime of a cutting tool plays an important role in improving productivity; therefore, it is a major economic issue. Presently, approximately 80 % of the cutting tools used in manufacturing industries apply hard coating for achieving higher productivity and precision [2]. Generally, the hardness is improved by coating the metal using processes such as nitriding, carburisation and carbonitriding, physical vapour deposition (PVD), chemical vapour deposition (CVD), etc. These treatments improve wear performance; however, they are expensive and require specific equipment. Recently, a low-cost alternative has been proposed to improve the hardness using a boronising process. It seems to be an excellent alternative for surface hardening, but it has been primarily used for the hardening of steels [3–7]. The simplicity of this boronising approach has led to high expectations. The primary objective of this research is to understand this process through a systematic study. In this paper, the effects of the boronising process on the hardness are reported by applying boron paste to WC–Co-based cemented carbide substrates. As evidence of the wear resistance, the as-prepared samples were tested to evaluate their cutting performance.

2. Experimental section

The boronising application was performed by applying a commercial Durborid© boron paste (which has a typical composition of 5 wt.% B_4C, 5 wt.% KBF_4 and 90 wt.% SiC) on commercially polished WC–Co-based cemented

carbide inserts (from Yueqing Nanfang Cemented Carbide Co., Ltd). To deposit a layer with a thickness of about 5 mm, 70 g of the boron paste was spread on the surface. The samples were placed on an alumina crucible and put into a preheated muffle furnace at 900 °C for 4 h. The microstructure of the coating was evaluated using optical microscopy (Olympus BX60) on cross-sections (ground and polished). To enhance the microstructural features, metallographic etching was performed using Murakami's reagent at room temperature for 4 min [8]. The composition and structure of the coating were studied using Rigaku X-ray diffraction (XRD) equipment. The hardness was measured using a micro-Vickers hardness tester, model SMVK-1000ZS. The ASTM E384 standard was followed to perform the hardness test. As evidence of the wear resistance, the boronised sample was wear tested and compared with an unboronised sample using the same procedure. The ISO 3685-1993 standard was followed to perform the tool-life test via the turning of an AISI 4140 steel bar (46 mm [diameter] × 800 mm [length]) using a lathe. The cutting conditions are given in Table 1. The flank wear was examined after 8 min and 16 min of the cutting test using optical microscopy.

3. Results and discussion

Figure 1 shows the X-ray diffractograms of the unboronised and boronised samples. The positions of the diffraction peaks are also shown, which are associated with the structure of WC, TiC, Co, Co_2B and W_2CoB_2 from the 251 047, 321 382, 150 806, 751 063 and 721 276 cards, respectively, of the powder diffraction database file. The XRD analysis suggests that the boride coating consisted of at least Co_2B and W_2CoB_2 because there is a full correspondence between the diffraction and the position peaks mentioned in the database. The strong and sharp diffraction peaks from the boride layer suggest a polycrystalline structure.

Table 1. Cutting conditions for tool-life testing.

Cutting speed (m s^{-1})	3.3
Feed rate (mm rev^{-1})	0.15
Depth of cut (mm)	0.4
Cutting fluid	Dry
Material	AISI 4140

The X-ray results suggest that the boron atoms diffuse into the cemented carbides reacting with Co and WC [9]. It is assumed that the following reactions would take place simultaneously:

$$2Co + B \rightarrow Co_2B \quad (1)$$

$$Co + 2WC + 2B \rightarrow W_2CoB_2 + 2C \quad (2)$$

During the annealing process, B_4C becomes unstable and boron is liberated, and it then diffuses to interact with Co and WC. Reactions (1) and (2) take place simultaneously on the surface of the boronised samples increasing the hardness of the boronised cemented carbide inserts on the surface. Since the Vickers hardnesses of Co_2B and W_2CoB_2 phases have been measured as 17 GPa [10] and 23.4 GPa [11], the presence of these compounds results in a higher hardness of the final material.

Figure 2 shows an optical micrograph of the cross-sectional microstructure of the boronised sample. It is observed that the sample does not show a layer with sawtooth morphology as reported for the boronised steel [3, 12]. The obtained thickness of the boride layer is 28 ± 3 μm.

Even when the boronised layer is formed by a mixture of the C_2B and W_2CoB_2 phases, at this resolution, in Fig. 2 the outer layer seems to be formed by just one phase. Because of this layer the hardness of the sample before and after boronising was 1492 ± 62 HV and 2137 ± 42 HV, respectively. It is important to note that the hardness obtained from the boronising process is similar to that reported by other studies that applied different surface treatments [13–15].

Figure 3 shows images of the flank wear before and after the cutting test of AISI 4140 steel turned using the boronised and unboronised samples.

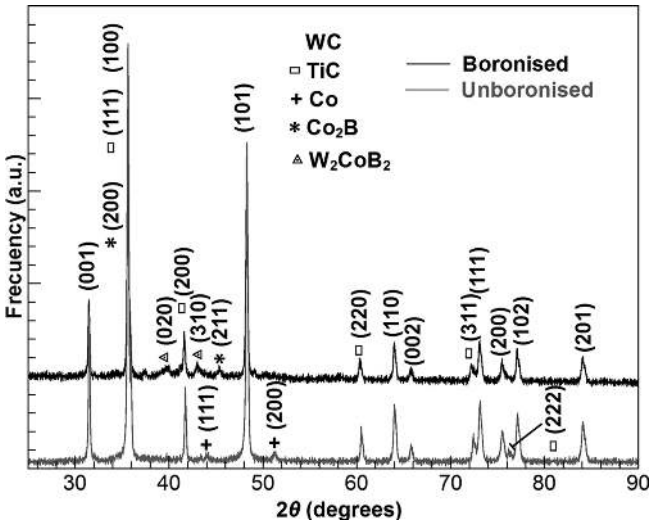

Fig. 1. X-ray diffraction pattern of boronised and unboronised samples.

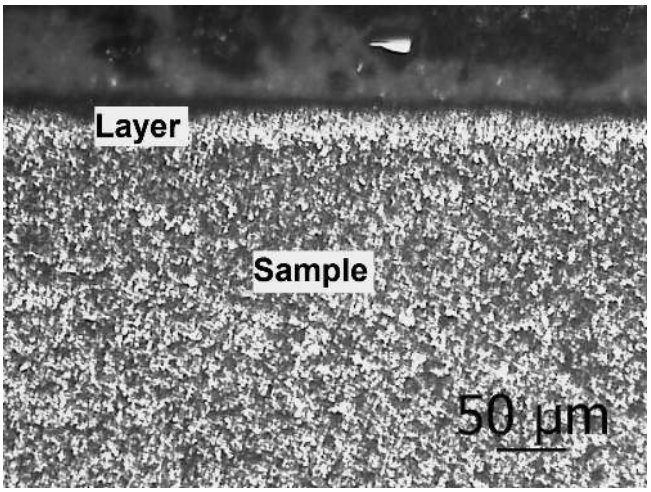

Fig. 2. Optical micrograph of the cross-sectional microstructure of the boronised sample.

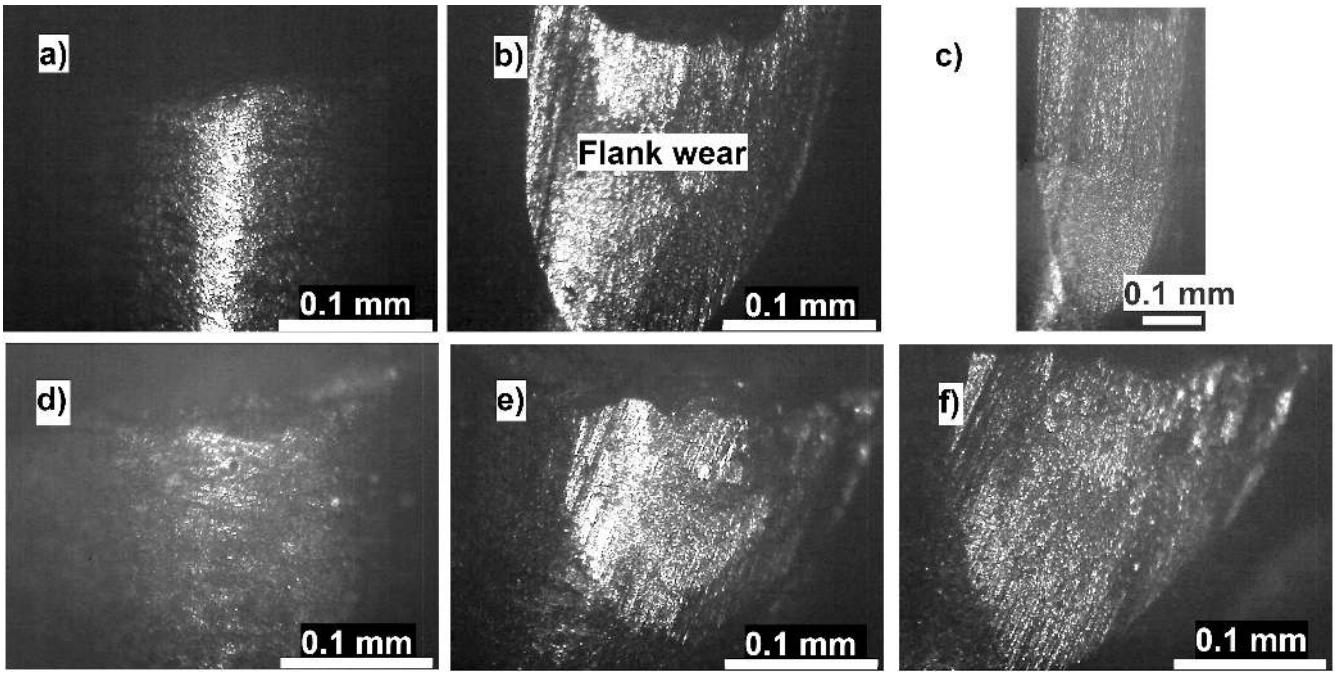

Fig. 3. Images of the flank wear progression of: (a–c) the unboronised sample, and (d–f) the boronised sample during the cutting test. Images (a) and (d) show the samples before the cutting test, while images (b) and (e) and images (c) and (f) show the wear after 8 min and 16 min of the cutting test, respectively.

Figure 3a shows the flank contact area of the unboronised sample before the cutting test. Applying the flank wear criterion, Fig. 3b shows that the unboronised sample had a 0.035 mm^2 flank wear area after 8 min of the cutting test, while Fig. 3c shows that the sample had a 0.043 mm^2 wear area after 16 min of the cutting test. Figure 3d shows the flank contact area of the boronised sample before the cutting test. Figure 3e shows that the boronised sample had a 0.014 mm^2 flank wear area after 8 min of the cutting test, while Fig. 3f shows that it had a 0.032 mm^2 wear area after 16 min of the cutting test. As shown in Fig. 3, the flank wear area of the boronised sample is smaller than that of the unboronised sample. After several tests, similar results were obtained suggesting that the boride coating effectively enhanced the cutting performance of the WC–Co-based cemented carbide inserts.

4. Conclusions

The results of this study clearly show that the boronising process increases the hardness of the commercial Co-based tungsten carbide inserts. The boronising mechanism of the cemented carbides is driven by the application of the boron paste at the selected temperature to liberate elemental boron, which then diffuses to react with the Co and WC phases of the cemented carbide. The X-ray diffraction results confirm that the boride coating consisted of Co_2B and W_2Co_2 phases. A 28 µm boride layer obtained after a boronising process performed at 900 °C for 4 h increases the hardness to 2137.8 HV as compared with the 1492 HV value obtained for the unboronised sample. An enhancement in the cutting performance of the boronised WC–Co-based cemented carbide inserts is clearly obtained.

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References

[1] J. Weidow, E. Olsson, H.-O. Andrén: Int. J. Refract. Met. Hard Mater. 41 (2013) 366–369. DOI:10.1016/j.ijrmhm.2013.05.011
[2] M. Soković, J. Achiev: Mater. Manuf. Eng. 24 (2007) 421–429.
[3] I. Campos, M. Palomar-Pardavé, A. Amador, C. Villa-Velázquez, J. Hadad: Appl. Surf. Sci. 253 (2007) 9061–9066. DOI:10.1016/j.apsusc.2007.05.016
[4] M. Keddam, R. Chegroune: Appl. Surf. Sci. 256 (2010) 5025–5030. DOI:10.1016/j.apsusc.2010.03.048
[5] M. Keddam: Appl. Surf. Sci. 236 (2004) 451–455. DOI:10.1016/j.apsusc.2004.05.141
[6] M. Keddam: Int. J. Mater. Res. 100 (2009) 901–905. DOI:10.3139/146.110125
[7] M. Tabur, M. Izciler, F. Gul, I. Karacan: Wear 266 (2009) 1106–1112. DOI:10.1016/j.wear.2009.03.006
[8] X. Qi, S. Zhu, H. Ding, Z. Zhu, Z. Han: Appl. Surf. Sci. 282 (2013) 672–679. DOI:10.1016/j.wear.2009.03.006
[9] S. Hochstrasser, Y. Mueller, C. Latkoczy, S. Virtanen, P. Schmutz: Corros. Sci. 49 (2007) 2002–2020. DOI:10.1016/j.corsci.2006.08.022
[10] I. Campos-Silva, D. Bravo-Bárcenas, M. Flores-Jiménez, I. Arzate-Vázquez, C. López-García, S. Bernabé-Molina: Metallography, Microstructure, and Analysis, 4 (2015) 158–168. DOI:10.1007/s13632-015-0200-x
[11] Z.T. Zahariev, M.I. Marinov: J. Alloys Compd. 12 (1993) 1–3. DOI:10.1016/0925-8388(93)90852-E
[12] A. Márquez-Herrera, J.L. Fernandez-Muñoz, M. Zapata-Torres, M. Melendez-Lira, P. Cruz-Alcantar: J. Surf. Coat. Technol. 254 (2014) 433–439. DOI:10.1016/j.surfcoat.2014.07.001
[13] M. Rosinski, A. Michalski: J. Mater. Sci. 47 (2012) 7064–7071. DOI:10.1007/s10853-012-6532-x

[14] V. Martínez, J. Echeverría: J. Am. Ceram. Soc. 90 (2007) 415–424. DOI:10.1111/j.1551-2916.2006.01426.x
[15] B. Yaman, H. Mandal: Mater. Lett. 63 (2009) 1041–1043. DOI:10.1016/j.matlet.2009.01.086

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Correspondence address

Dr. Alfredo Márquez Herrera
Departamento de Ingeniería Agrícola, DICIVA
Campus Irapuato-Salamanca
Universidad de Guanajuato
Ex Hacienda el Copal
Carr. Irapuato-Silao km 9
Irapuato Gto 36500
México
Tel.: +52-462-624-1889 ext. 1857
E-mail: amarquez@ugto.mx

Bibliography
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