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ScienceDirect

Applied Surface Science 254 (2008) 2967–2974

applied surface science

www.elsevier.com/locate/apsusc

Evaluation of the tool life and fracture toughness of cutting tools boronized by the paste boriding process

I. Campos [a,*], M. Farah [b], N. López [a], G. Bermúdez [a], G. Rodríguez [a], C. VillaVelázquez [a]

[a] *Instituto Politécnico Nacional, SEPI-ESIME U.P. Adolfo López Mateos, Zacatenco, México 07738, D.F., Mexico*
[b] *Tecnológico de Monterrey, Campus Ciudad de México, Calle del Puente 222 Col. Ejidos de Huipulco, México 14380, D.F., Mexico*

Received 13 September 2007; received in revised form 16 October 2007; accepted 16 October 2007
Available online 23 October 2007

Abstract

The present study evaluates the tool life and the fracture toughness of AISI M2 steel cutting tools boronized by the paste boriding process. The treatment was done in selective form on the tool tips of the steels. The temperatures were set at 1173 and 1273 K with 4 h of exposure time and modifying the boron carbide paste thicknesses in 3 and 4 mm. Microindentation fracture toughness method was used on the borided tool at the temperature of 1273 K and a 4 mm paste thickness, with a 100 g load at different distances from the surface. Also, the borided cutting tools were worn by the turning process that implied the machining of AISI 1018 steel increasing the nominal cutting speed, of 55 m/min, in 10 and 25% and maintaining the feed and the depth cut constants. The tool life was evaluated by the Taylor's equation that shows the dependence of the experimental parameters of the boriding process.

Keywords: Boriding; Tool life; Fracture toughness; Borided layers; Wear resistance; Cutting tools

1. Introduction

The aim of the surface modification of high speed steels used as cutting tools is to improve its performance in the machining process, the tool life (defined as the period of time that tool cutting edges lose their usefulness through wear) and to modify the mechanisms (chipping, partial fracture, plastic deformation, thermal crack, etc.) that promote their failure in normal cutting condition.

In hard metal tools, depending on the cutting conditions, a severe wear is present at either the flank or the face of the tool. In some instances, flank wear and face wear reach the limit values simultaneously. Flank wear results in a wear land of a constant or a variable length. When the face and flank wear away simultaneously, the width of the face portion between the crater and the cutting edge gradually decreases from both sides and the strength of the cutting edge diminishes. This type of wear predominates at low cutting speed, also being affected by the feed speed and tool geometry [1–3].

Nowadays, coatings represent an important part in the present stage of development of cutting tool technology. The use of coated tools is essential in current trends for machining for many reasons. The great heat generation when machining without cutting fluid and high speed cutting, and more recently, dry high speed demand cutting tools with an elevated heat resistance or the presence of a heat insulating coating on the surface.

Within the diverse technologies of thermochemical treatments for the high speed steels, the paste boriding process is emphasized by its low cost, quality of products, and flexibility during the process [4,5]. Depending on the boron carbide paste thicknesses that surrounds the material surface, the chemical composition of the substrate, the temperature and the treatment time could form either one or two phases at the material surface [6,7]. The borided phases (FeB, Fe_2B[1]) must fulfill properties that retard or modify the proposed failure mechanisms in

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* Corresponding author. Tel.: +52 55 57296000x54768; fax: +52 55 57296000x54589.
E-mail address: icampos@ipn.mx (I. Campos).

[1] The phase FeB, found at the external material surface, is more fragile, due its orthorhombic crystalline structure, and its boron content, approximately 16 wt.%. The inner phase, Fe_2B, has 8.33 wt.% of boron, and its crystalline structure is tetrahedral.

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doi:10.1016/j.apsusc.2007.10.038

engineering components, which include low adhesion between the tool and the machining material, chemical stability, high hardness and abrasion resistance [8,9].

Likewise, the wear resistance of borided layers is related to the fracture toughness of the borided phases. In brittle materials, when a hard particle interacts with the surface, the fracture is generated, causing the separation of particles from the surface (spalling), the formation of wear particles and scratched. The method of microindentation induced-fracture in brittle materials is a nondestructive and simple technique, which requires solely a flat and polished surface. The cracks produced by mechanical contact between the indenter and the material surface, essentially depends on the geometry of the indenter and the applied load [10]. The cracks geometry models, radial-median and Palmqvist types, have been used in the determination of the fracture toughness in ceramic materials. The theoretical foundation of these models is based on classic concepts of Linear Elastic Fracture Mechanics (LEFM) (see [11,12] and references therein). For the Palmqvist cracks regime (Fig. 1), it has been determined for small loads, that the relation between the half diagonal length of the indentation (d) and the crack length generated at the corners of the indentation (a) must be ≤ 3. It would seem reasonable to assume that, for thin brittle layers on relatively tough substrates, such is the case of borided tool steel, then it would be more appropriate to use the relationships based on the Palmqvist crack morphology, as this model is based on cracking initiating at the surface where the material is more brittle. Niihara et al. [13] proposed a model based on the elastic–plastic indentation theory in which they modelled Palmqvist cracks as semielliptical surfaces flaws in the evaluation of the stress intensity factor K_{IC}:

$$\left[\frac{K_{IC}\Phi}{H_V a^{1/2}}\right]\left(\frac{H_V}{E\Phi}\right)^{0.4} = k_2\left(\frac{a}{d}\right)^{-1/2} \quad (1)$$

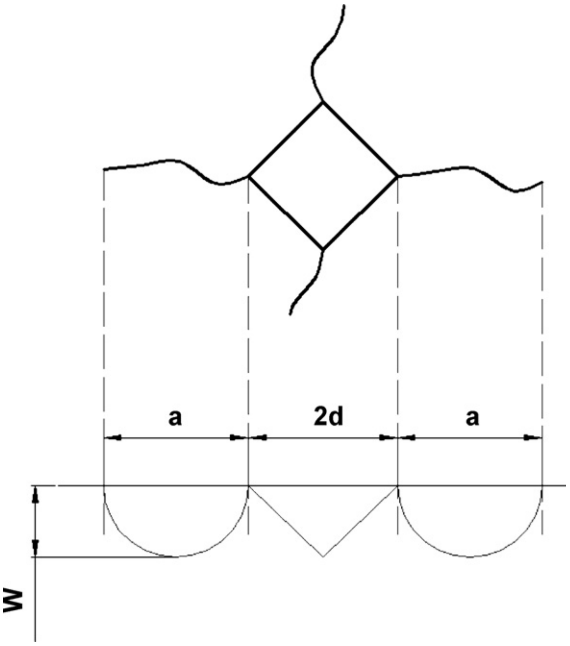

Fig. 1. Palmqvist cracks produced by Vickers indentation.

where E is the Young modulus, H_V is the Vickers microhardness, Φ is a factor ≈ 3 and k_2 is a constant equal to 0.085 $k_0 k_1$. The k_0 term corresponds to a free surface correction factor and k_1 is the crack depth factor, which is independent of the crack size. It has been suggested that the above equation will give an estimate of the crack arrest fracture toughness, K_{Ia}, rather than K_{IC}. However, the bulk of the literature does not discriminate in this way and so K_{IC} will be used in the present work. Also, the relations used by other researchers [14–16], to define the fracture toughness of borided layers are based on equations valid for radial-mean cracks, nevertheless, it has not thoroughly been explained the reason for this consideration.

The present work evaluates the tool life of borided AISI M2 steels employed for turning operations on AISI 1018 steel. The results of the time life and cutting speeds are represented by the Taylor equation. Also, the fracture toughness of the borided phases is determined, using the Palmqvist crack model proposed by Niihara et al. [13], which is valid and reliable for the borided layers formed at the surface of the samples.

2. Experimental procedure

2.1. Manufacturing of cutting tools

Tools were designed using simple end geometry typical for the turning operations. For the tools manufacturing, it was used an AISI M2 commercial steel with a nominal chemical composition 0.85–1% C (other carbon contents may be available), 5.50–6.75% W, 4.50–5.50% Mo, 3.75–4.50% Cr, 1.75–2.20% V, 0.03% P_{max}, 0.03% S_{max}. A 16 mm square base was designed, with an overall tool length of 50 mm, obtaining a robust cutting tool, with a high moment of inertia. The side-cutting edge angle is 30° and the end-cutting edge angle of 60°, therefore; a 60° angle in the face tool is obtained. The nose radius of the cutting tool was settled in 0.6 mm for grinding effects. The manufacturing of the cutting tools were carried out in a CNC HAAS VF-2 milling machine. Fig. 2 shows the final dimensions of the cutting tools.

2.2. Paste boriding process

Cold rolled steel moulds were made to cover the tool tips with boron carbide paste (with 76 wt.% of boron and cryolithe, Na_3AlF_6, like flux additive) in 3 and 4 mm of thickness, using a 0.2 water/paste relation. In order to control the boron carbide past thicknesses, tools were placed in cross-sectional form with respect to the moulds (Fig. 3(b)). At the end of the impregnation of the boron carbide paste over the cutting tools tips, illustrated in Fig. 3(c), it was necessary to dry the samples in two stages at a temperature of 373 K for 15 min, in order to get rid of any residue of water in the paste. The paste boriding treatment was carried out in a conventional furnace at the temperatures of 1173 and 1273 K with 4 h of treatment under a pure argon atmosphere. Working temperatures were selected inside the operation range for the boriding process [4,5]. Once the treatment was finished, the samples were quenched in oil and