Available online at www.sciencedirect.com
ScienceDirect
International Journal of Refractory Metals & Hard Materials 26 (2008) 68–76
International Journal of REFRACTORY METALS & HARD MATERIALS
www.elsevier.com/locate/IJRMHM

Fracture of WC–Ni cemented carbides with different shape of WC crystals ☆

A.V. Shatov [a,b,*], S.S. Ponomarev [a], S.A. Firstov [a]

[a] Frantsevich Institute for Problems of Materials Science, 3 Krzhizhanovsky St., 03680 Kiev-142, Ukraine
[b] Mercer Management Consulting, Inc., 125 Village Boulevard, Suite 270, Princeton, NJ 08540, USA

Received 25 February 2007; accepted 18 March 2007

Abstract

The dependences of fracture toughness and crack propagation on the shape equiaxiality of WC crystals are studied on WC–Ni cemented carbides with small addition of TiC. The fracture toughness K_{1C} linearly correlates to mean linear path in binder phase regardless of the shape and contiguity of WC crystals as well as despite of the fracture path change in studied WC–Ni cemented carbides. It is experimentally shown that the fracture toughness K_{1C} does not correlate versus contiguity of carbide crystals on WC–Ni cemented carbides when shape of WC crystals is changed. The relative amount of trans-crystalline fracture through the carbide crystals and the total area of fracture through the carbide phase increase, whereas, the relative amount of inter-crystalline fracture along carbide–carbide boundaries decrease on WC–Ni cemented carbides with flatter WC crystals and lower values of contiguity of WC crystals.

Keywords: Cemented carbides; Fracture toughness; Crack path; Shape of carbide crystals

1. Introduction

The fracture of cemented carbides is believed to be a two-step process. The brittle inter- and trans-crystalline fracture of carbide phase is followed by the ductile rupture of binder phase and carbide–binder interfaces [1–12]. The area fraction of crack path through the carbide phase accounts for at least 50–80% of the fracture surface area of cemented carbides and increases with the amount of carbide phase V_V^C in the alloy [5–7,13–17]. The increasing value of the mean linear intersect d of WC crystals causes the increase of the ratio of the surface area of trans-crystalline fracture through the carbide crystals (C) versus the inter-crystalline fracture of the carbide phase (C/C) and at the same time the increase of the ratio of the surface area of the fracture through the binder phase (B) versus the fracture along the carbide–binder interfaces (B/C) regardless of the volume fraction of the carbide phase V_V^C in the alloy [5–7,13–17]. However, it is believed that the rupture of the carbide phase makes a minor contribution to the fracture toughness of the cemented carbides due to relatively low value of the critical strain energy release rate of carbides (for WC $G_{1C} \approx 50$ J/m^2) compared to that of the cemented carbides (200–500 J/m^2) [4,5,7,18–20]. The major contribution is made by the plastic deformation and rupture of the binder phase ligaments and carbide–binder interfaces.

Despite the theoretical estimations of fracture energies, two experimental correlations of fracture toughness versus the mean linear path in binder phase λ and versus the carbide crystals contiguity G are observed simultaneously (Fig. 1) [1,17]. The fracture toughness K_{1C} increases linearly with λ (Fig. 1a) but decreases with the contiguity G (Fig. 1b).

☆ This paper was partially presented at the 16th Plansee Seminar, Reutte, Austria, May 2005.
* Corresponding author. Address: 8 Parkside Drive, Jamesburg, NJ 08831, USA. Tel./fax: +1 732 605 0416.
E-mail address: alex_shatov@hotmail.com (A.V. Shatov).

0263-4368/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijrmhm.2007.03.002

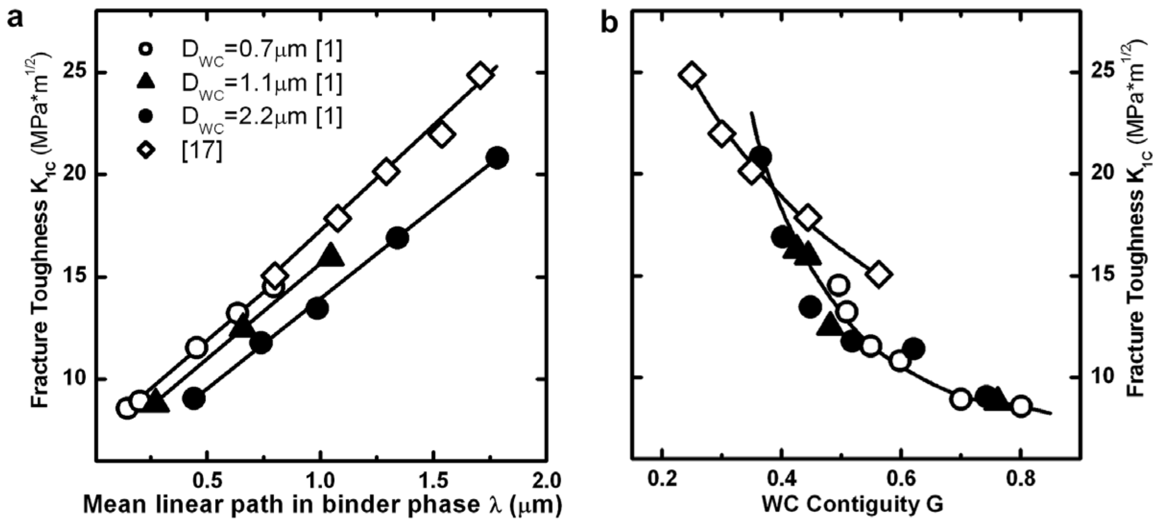

Fig. 1. The correlation of the fracture toughness K_{1C} with the mean linear path in binder phase λ (a) and with the carbide crystals contiguity G (b) of WC–Co cemented carbides with different mean diameters of WC crystals (D_{WC}) and volume fraction of the binder phase between 5 and 37 vol% [1]; and with the mean linear intersects of WC crystals from 2.1 to 3.6 μm and volume fraction of the binder phase between 13 and 36 vol% [17].

The mean linear path in binder phase λ is related to the contiguity G through the well-known stereological equation:

$$\frac{\lambda}{d} = \frac{1 - V_V^C}{V_V^C \cdot (1 - G)} \quad (1)$$

where V_V^C is the volume fraction of carbide phase, and d is the mean linear intersect of the carbide crystals. It is shown by numerous experiments on cemented carbides with unchanged shape of WC crystals that the contiguity G mainly depends on the volume fraction of the carbide phase V_V^C [21–23]. Obviously, the change of the volume fraction of the carbide phase V_V^C should be considered as a main even though not direct reason for the observed correlations of K_{1C}. To experimentally separate the effects of these stereological parameters on the value of K_{1C}, λ and G need to be changed regardless of the volume fraction of the carbide phase and the size of carbide crystals.

In addition, no results were reported in regard to the dependence of the crack propagation on the contiguity and the shape of WC crystals in cemented carbides, whereas, the volume fraction of carbide phase V_V^C is kept constant in the alloy. Partially, this is due to the fact that the contiguity of carbide crystals is believed to be mainly determined by the volume fraction V_V^C of the carbide phase for conventional cemented carbides [21–23]. On the other hand, not many results were reported about changing the shape of the carbide crystals in cemented carbides.

As it was recently reported, the contiguity of WC carbide crystals can change even for a fixed volume fraction of carbide phase when the shape of the WC crystals is changed [24]. The change of the shape to a flatter triangular prism is produced by the addition of very small amount of TiC into WC–Ni cemented carbides [25]. The flatter shape of WC crystals corresponds to a lower value of the shape equiaxiality P_{WC} shape factor that was introduced and measured in [25]. As it was found, the contiguity of carbide crystals G decreases when the shape equiaxiality of WC crystals P_{WC} decreases [24]. The current study concentrates on the effect of the shape of WC crystals on the correlations of fracture toughness versus the mean linear path in binder phase λ and versus the carbide crystals contiguity G on WC–Ni cemented carbides. In addition, the effects of the shape equiaxiality and the contiguity of WC crystals on the crack propagation in WC–Ni cemented carbides are studied by the qualitative comparison of the SEM micrographs and Auger electron spectroscopy of fracture surfaces of the alloys.

2. Experimental details

A set of WC–Ni cemented carbides with binder contents of 8, 14, 22 wt% and small additions of TiC was produced by liquid phase sintering in vacuum for 1 h [25]. Quantitative electron-probe X-ray wavelength dispersive microanalysis (Superprobe-733, JEOL) with relatively large diameter of electron beam of about 50 μm was used to measure the chemical composition of the alloys. The measured values of Ti content in the alloys were between 0.04 and 0.4 wt%. The concentration of Ti in Ni binder phase was then calculated under assumption that Ti does not dissolve in WC.

The specimens were sectioned, polished, and etched by the standard techniques for cemented carbides. Scanning electron microscopy (JSM T-20, JEOL) was used to produce micrographs. Standard quantitative metallographic parameters were measured on enlarged micrographs. That includes phase volume contents; mean linear intersects of carbide and binder phases; and the contiguity of WC crystals. In addition, the shape equiaxiality of WC crystals P_{WC} was measured [25].

The critical stress intensity factor a.k.a. the fracture toughness K_{1C} was measured by three-point bending of