Measuring the fracture toughness of single WC grains of cemented carbides by means of microcantilever bending and micropillar splitting

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Introduction

The main goal of this work is to obtain a reliable value of the fracture toughness of single grains of tungsten carbide (WC). It is attempted by testing microcantilever and micropillar samples shaped out, by means of focused ion beam milling, of individual WC particles embedded within a WC-Co cemented carbide grade. Experimental results are compared with those previously assessed through implementation of the indentation microfracture technique.

Testing and Data analysis

Micropillar splitting

5 μm

Pillars of 3 and 5 μm of diameter with an aspect ratio ≥ 1 were milled.

Indentation microfracture

5 μm

With this method, Kc is calculated from the the length of the cracks (c) emanating from the corners of the cube-corner indenter induced imprint. Assuming that a Palmqvist crack system is developed, typical of cemented carbides, Kc can be calculated as:

\[ K_c = \frac{\sigma \sqrt{a}}{F(2)} \]

Where \( a \) is a constant empirically determined that depends on the crack geometry (0.015 for WC [3]).

Microcantilever bending

For this method, FIB is used to mill the cantilever. House shape was selected and a notch was introduced near the clamped edge. The fracture toughness was calculated using the equation:

\[ K_c = \frac{\sigma \sqrt{a}}{F(2)} \]

The dimensionless shape factor, \( F(a/b) \), may be calculated by using the equation provided by Di Maio and Roberts [1].

Cantilevers with a width of 20 μm, a height of 25 μm and a depth of 15 μm approximately, were milled to create a house-shape cross section with a 45°. For introducing the notch, a line was carved a current of 100 μA during 35 s.

Results and discussion

Micropillar splitting method exhibits a larger scatter and a more noticeable difference between prismatic and basal orientations than the cantilever bending method.

Micropillars fractured just in one of the induced indentation cracks. In several cases induced cracks did not follow radial directions from the vertices of the imprint. This can be related to the pronounced anisotropy in WC plastic behaviour, due to its hexagonal crystal structure, which implies a more favourable crack propagation along specific directions.

Fracture phenomena evidenced in microcantilever bending tests may be described as purely brittle. Loading-displacement curves were linear until sudden failure and resulting fracture surface appeared to be smooth. Values obtained from this tests can be considered to fulfil the requirements of linear elastic fracture mechanics.

The mean value determined for the \( K_c \) of WC using this method – 5.6 ± 0.8 MPa-m\(^{1/2}\) – is in agreement with values reported in the literature, indirectly estimated from other macromechanical tests.

Micropillar splitting tests give the lowest values, ranging between 1.5 and 6.0 MPa-m\(^{1/2}\). Higher values - between 5.0 and 6.4 MPa-m\(^{1/2}\) - are attained from microcantilever bending tests. However, these values are lower than the ones obtained by means of the IM method, and relative differences could be explained by considering the plastic deformation features evidenced within and around indentation imprints, as well as the irregular cracking patterns observed in single WC grains.

Conclusions

Bending of notched microcantilevers has shown to be a successful technique to assess the fracture toughness of single WC grains embedded within the phase assemblage of cemented carbides. Bending of notched microcantilevers yielded more consistent results than those measured out of micropillar splitting tests. In this regard, the average value of fracture toughness for single WC grains, within the two-phase interpenetrated network existing in cemented carbides, is found to be 5.6 ± 0.8 MPa-m\(^{1/2}\). Such a relatively high value – coherent with local plastic features evidenced in nanoindentation imprints – is in satisfactory agreement with results indirectly estimated from other macromechanical tests.