Toughness and fatigue crack growth mechanisms of WC-Co ceramic-metal composites: A comparative study using controlled small indentation flaws and long through-thickness cracks

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Abstract

Crack growth mechanics and mechanisms under both monotonic and cyclic loading are investigated in a WC-Co cemented carbide by using small and long cracks, both of them artificially introduced by indentation and cyclic compression of unnotched and notched specimens respectively. Agreement and discrepancies on fracture toughness and fatigue crack growth behavior are discussed and rationalized, on the basis of the similitude evidenced in toughening and fatigue degradation mechanisms for both crack types, by taking into account the residual stress field arising after indentation in the unnotched specimens.

1. Introduction

WC-Co cemented carbides, usually referred to as hardmetals, are ceramic-metal composites extensively used in extremely demanding applications such as forming dies or cutting tools. This is mainly because their high hardness and excellent wear and abrasion resistance. However, they are also intrinsically brittle, a characteristic which make their reliability lower than desired. To reduce this serious drawback, the evaluation of the mechanical response of these materials should consider the existence of flaws and cracks. Hence, a more complete understanding of toughening and fatigue crack growth (FCG) behavior of these WC-Co composites seems to be required in order to use them effectively.

2. Results

A fine-grained WC-Co cemented carbide grade was studied. Controlled small flaws were introduced by performing Vickers indentations on the surface of unnotched and polished specimens. Special care was taken in order to obtain indentation cracks well aligned with the sample edges so that one pair of indentation cracks was perpendicular to the specimen axis. Meanwhile, long through-thickness cracks were achieved through application of cyclic compressive loads by reverse bending to a single-edge notched sample, followed by stable crack growth under far-field tensile stresses. A fully articulating four-point bend test fixture and a universal servohydraulic testing machine were used for all subsequent fracture and fatigue tests. Fracture toughness of the studied materials was evaluated by breaking both indented and precracked samples. Crack growth kinetics under cyclic loading was evaluated by interrupting the tests after given number of cycles and optically examining crack length. Detailed inspection of crack–microstructure interaction as well as the corresponding fractographic analysis on fractured specimens were carried out by means of scanning electron microscopy.

Fracture toughness and FCG kinetics were determined by means of fracture mechanics analysis of the gathered data. Simple consideration of the externally applied stresses resulted in effectively lower toughness and an anomalous crack extension behavior, under monotonic and cyclic loads respectively, for the indented specimens, as compared to the ones determined using long through-thickness cracks. Regarding fatigue, it implied evidence of subcritical crack growth at stress intensity factor values lower than the threshold measured for long cracks. Such discrepancies may be rationalized by consideration in the indented specimens of the residual field that arises, at full unload after indentation, from accommodation of the impression volume by expansion of the deformed zone against the constraining elastic.

Special attention was paid to assess crack-microstructure interaction, as well as documentation and understanding of toughening and FCG mechanisms. In doing so, specimens with three “alike” indentations were tested to rupture under monotonic and cyclic (under maximum applied load corresponding to 70% of the monotonic one) loading conditions. As a result, further extension of cracks emanating from the two dummy (unbroken) indentations (**Figures 1a** and **1b**) allowed to document, at the surface level, toughening and fatigue micromechanisms present during stable crack growth. Moreover, fractographic inspection of rupture that took place through the third indentation permitted to discriminate characteristic features linked to stable and unstable crack extension (**Figures 1c** and **1d**). Very interesting, similar findings were evidenced on the polished lateral sides and fracture surfaces of the specimens containing long cracks.

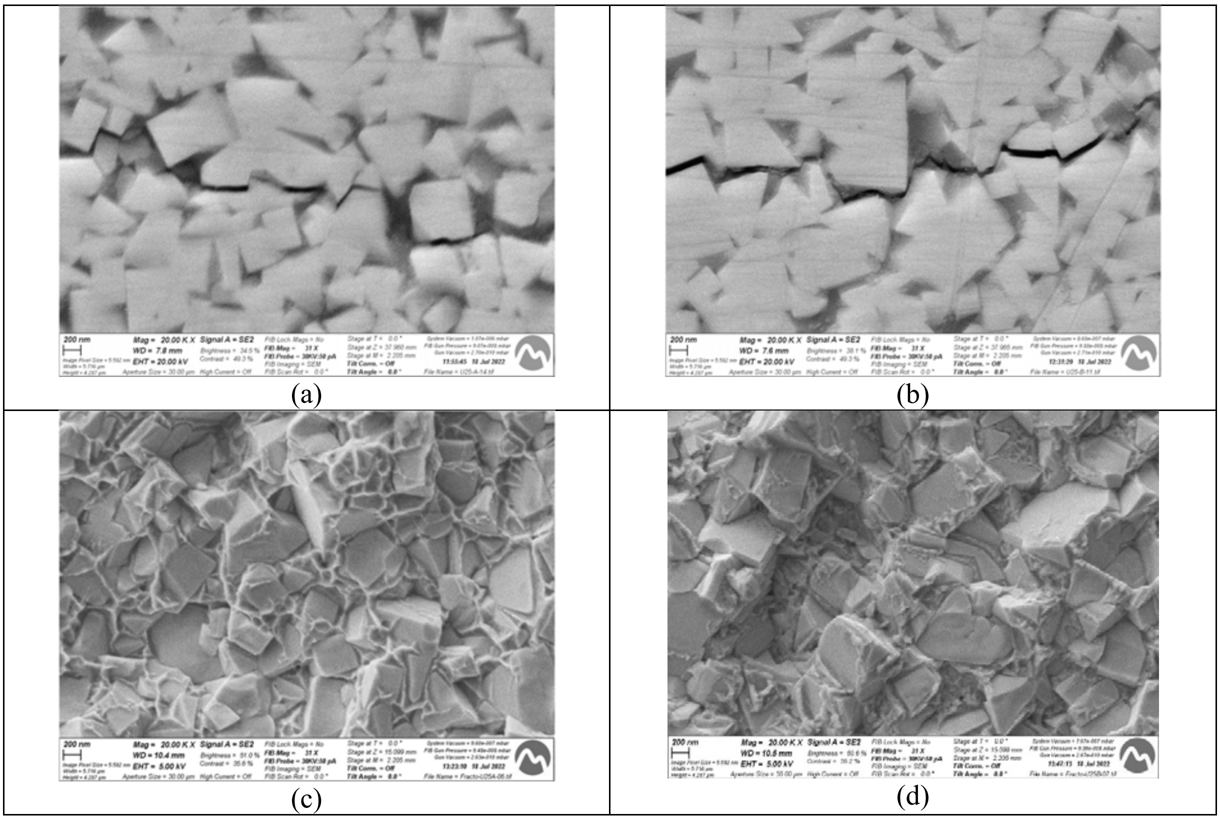

Fig.1 – Toughening and FCG mechanisms observed during stable crack growth under monotonic and cyclic loading: (a) ductile ligament bridging, and (b) localized plastic deformation within metallic binder, respectively. Specific fractographic characteristics within the metallic binder associated with unstable and stable crack extension: (c) ductile dimples, and (d) brittle-like step-like fatigue features.

3. Conclusions

Combined and complementary use of controlled small indentations flaws and long through-thickness cracks shows to be a valid and successful approach for studying, documenting and understanding both mechanics and mechanisms of the fracture and fatigue behavior of WC-Co ceramic-metal composites. Within this context, consideration of the residual stresses developed by indentation are key to rationalize experimental findings gathered in tests using the different crack types investigated in this work.

Acknowledgements

The research work was conducted within a cooperative effort between Xiamen Tungsten Co., Ltd. and Universitat Politècnica de Catalunya.