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Crack propagation characteristic and toughness of functionally graded WC–Co cemented carbide

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Abstract

The propagation characteristic of cracks produced at the corners of Vickers indent and the toughness change in functionally graded WC–Co cemented carbide with dual phase structure were investigated. It is shown that cracks tend to propagate both around and across WC crystal grain and in the presence of η phase across η(W_3Co_3C) phase with high resistance. The changes of toughness with the microstructure and an integrated strengthening effect, as well as high toughness characteristic of the alloy are revealed.

Keywords: Cemented carbide; Functionally graded material; Crack propagation; Microstructure; Fracture toughness

1. Introduction

The properties of sintered WC–Co cemented carbides are known to be critically dependent upon their final composition and structure. Slight deviation from the ideal carbon content brings about the occurrence of either graphite or ternary compound eta (η). Because η phase is usually very large in size with embedded WC grains and is distributed heterogeneously in the alloy, in the practical production of conventional cemented carbide, both these phases are highly undesirable, for they can result in deterioration in the mechanical properties and cutting performance. Nevertheless, intensive research on η phase has successfully brought functionally graded cemented carbide with dual phase structure (DP cemented carbide) on to the market.

DP cemented carbide is characterized by three-zone structure, i.e. surface zone with low cobalt content, intermediate zone (cobalt-rich zone) with cobalt graded structure, both with $WC + \beta$ (cobalt based solid solution binder phase) structure, and core zone with $WC + \beta + \eta$ structure in which the grain size, distribution and volume fraction of η phase are strictly controlled. Because of its perfect combination of high wear resistance and high toughness, it has been successfully applied in the modern tools for rock drilling, mineral cutting, oil drilling and in tools for concrete and asphalt milling [1–6].

It is well established that wear resistance of conventional cemented carbide can only be increased if toughness is reduced and vice versa. However, high wear resistance and high toughness can be unified within coated cemented carbide and functionally graded cemented carbide. Because of the existence of η phase in the core zone, the reason for high toughness of DP cemented carbide must attract a lot of attentions.

Based on the facts that Palmqvist fracture toughness can be inferred from the total length of cracks produced at opposite corners of a Vickers indent, and that it has been proved by the present authors and other authors that hardness profile measurement can directly reflect the change in the microstructure of functionally graded cemented carbide [7,8], then the question whether there exists a change of toughness with the microstructure is raised. The aim of this

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work is to investigate the crack propagation characteristic in DP cemented carbide so as to have an in-depth knowledge about the effect of the phase and structure characteristic on its toughness.

2. Experimental

2.1. DP cemented carbide preparation and the structure related character

WC–Co DP cemented carbide button insert, 25 mm in diameter and 34 mm in height, was prepared by two steps technique, i.e. the preparation of precursor with WC + β + η structure by vacuum liquid phase sintering, followed by carburizing treatment i.e. gradient sintering above the eutectic temperature. The nominal composition of the alloy is WC–6 wt% Co. X-ray diffraction analysis shows that η phase in the core of the alloy is in the form of W_3Co_3C. The average grain size of η phase distributed homogeneously in the core zone is smaller than the one of tungsten carbide. The average WC grain size in the surface zone and intermediate zone is approximately 6.5 μm. The average WC grain size in the core zone is approximately 5.0 μm. The morphology of the WC grains in the core zone is less sharp than the one in the surface zone and intermediate zone. Fig. 1 shows a sketch diagram of the cross section of the button insert. Fig. 2 shows the Vickers hardness with a load of 19.6 N (HV2) profile along line ab labeled in Fig. 1. It can be observed that Vickers hardness along the gradient changes regularly from high to low, then from low to high, corresponding to surface zone (zone I), intermediate zone (zone II) and core zone (zone III) and thus microstructure change in the alloy. The formation of the cobalt gradient during gradient sintering process is due to the inward diffusion of carbon in the liquid phase and reaction of carbon with W_3Co_3C phase [9], as well as the difference in migration pressure caused by the difference in WC grain sizes within the gradient structure [10].

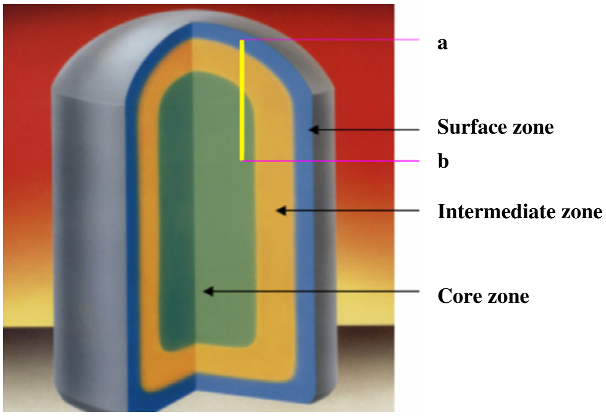

Fig. 1. Sketch diagram of the cross-section of WC–Co DP cemented carbide button insert.

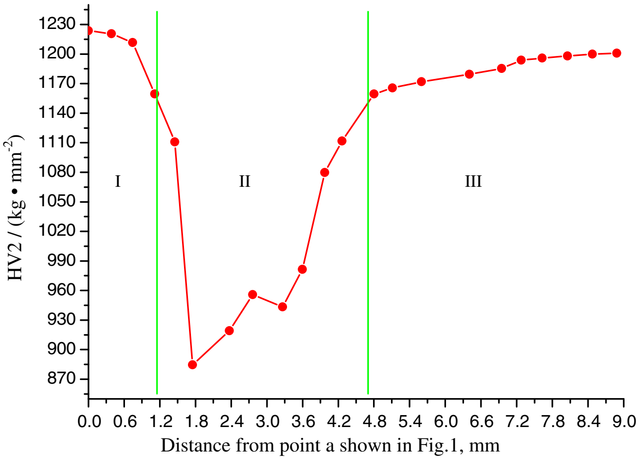

Fig. 2. Vickers hardness (HV2) profile on the cross-section of WC–Co DP cemented carbide button insert [7].

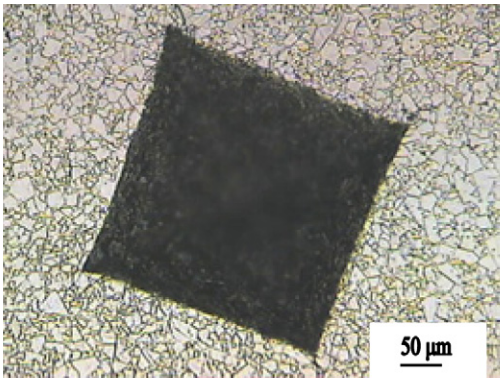

Fig. 3. HV50 indent image in the surface zone, with diagonal length of 285.31 μm and 287.63 μm, respectively.

2.2. Specimen preparation and obviation of Vickers hardness indentation

Quarter of DP cemented carbide button insert was cut out and then separated into two pieces in the direction of height by wire cutting. The head part was embedded in bakelite, grinded in sequence by a metal-bond diamond wheel of 181 μm and SiC-paper grinding disc of 120 μm, polished in sequence by diamond polishing suspension of 9 μm for 30 min and 3 μm for 8 min to remove the layer affected by residual stresses [11–13]. The grinding and polishing were carried out by Struers. Because of the existence of three different zones with different microstructure, and thus different light reflectivity characteristic, on the cut or polished section of DP cemented carbide, three different zones with different shine can be easily identified. Vickers hardness indentation experiment with a load of 490 N (HV50) in a line across three different zones was carried out on M4U 025 hardness tester. After Vickers hardness testing, the specimen was etched with Murakami's reagent (10 g NaOH, 10 g potassium ferricyanide and 100 ml distilled water) at room temperature for 3–4 min. Impression image observation and length measurement of the diago-