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Three-point bending fatigue behavior of WC–Co cemented carbides

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ABSTRACT

WC–Co cemented carbides with different WC grain sizes and Co binder contents were sintered and fabricated. The three-point bending specimens with a single edge notch were prepared for tests. In the experiments, the mechanical properties of materials were investigated under static and cyclic loads (20 Hz) in air at room temperature. The fatigue behaviors of the materials under the same applied loading conditions are presented and discussed. Optical microscope and scanning electron microscopy were used to investigate the micro-mechanisms of damage during fatigue, and the results were used to correlate with the mechanical fatigue behavior of WC–Co cemented carbides. Experimental results indicated that the fatigue fracture surfaces exhibited more fracture origins and diversification of crack propagation paths than the static strength fracture surfaces. The fatigue fracture typically originates from inhomogeneities or defects such as micropores or aggregates of WC grains near the notch tip. Moreover, due to the diversity and complexity of the fatigue mechanisms, together with the evolution of the crack tip and the ductile deformation zone, the fatigue properties of WC–Co cemented carbides were largely relevant with the combination of transverse rupture strength and fracture toughness, rather than only one of them. Transverse rupture strength dominated the fatigue behavior of carbides with low Co content, whilst the fatigue behavior of carbides with high Co content was determined by fracture toughness.

1. Introduction

WC–Co cemented carbides are widely used in applications where mechanical stressing occurs, especially metal cutting tools used in milling or intermittent cutting processes [1]. It is very important to acquire a deep understanding of mechanical fatigue characteristics of WC–Co alloys, because cemented carbide cutting tools are generally applied under strong cyclic stresses in machining processes [2,3]. Unfortunately, there has been a lack of reliable laboratory test standards or methods to evaluate the mechanical fatigue behavior and to choose suitable compositions that are matched to the performance requirements [4]. Moreover, the performance testing is expensive and a suitable laboratory test method to aid material selection and to guide efficient usage would be welcomed by practical engineers.

The properties of cemented tungsten carbide (WC–Co) primarily depend on the microstructure, especially the cobalt content and WC grain size [5–8]. Changes in WC grain size and/or Co content can also be expressed in terms of changes in Co mean free path, and Co mean free path was considered as the predominant factor in controlling the thermo-mechanical fatigue behavior of WC–Co hardmetals [8]. The bending fatigue limit of fine-grained WC alloys was higher than that of coarse-grained ones and that of low Co alloys was higher than that of high Co alloys [9]. It has been convinced that a strong correlation existed between three-point bending fatigue limit of un-notched specimens and transverse rupture strength, and the bending fatigue limit was nearly equivalent to 45–55% of the transverse rupture strength [9]. Many investigations focused on the room-temperature and high-temperature behavior of cemented carbides [10–12]. It was indicated that, at low temperatures cobalt binder ligaments are subjected to a phase transformation from fcc to hcp structure. However, at higher temperatures, oxidation of the binder ligaments near crack tips and brittle–ductile transitions of mixed carbides seem to play an important role in the fatigue behavior.

Fatigue mechanics and fatigue crack growth behavior of cemented carbides is receiving growing attention and is widely discussed. Linear elastic fracture mechanics (LEFMs) was a quite effective analytical approach to assess fatigue life and fatigue crack growth of WC–Co hardmetals [13], considering that fatigue lifetime of cemented carbides is given by subcritical crack growth of preexisting defects and neglecting the fatigue crack nucleation behavior. Torres et al. [13–16] pointed out that the microstructure, loading mode, load ratio (R) and notch radius even R-curve behavior have a great effect on the fatigue crack growth characteristics of WC–Co cemented carbides. WC–Co cemented carbides are markedly sensitive to fatigue, and their fatigue crack growth rates exhibit an extremely

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Table 1
Averages and standard deviations of properties of the WC–Co cemented carbides.

No.	Co content (wt.%)	Average grain size d (μm)	Vicker's hardness HV_{30}	Transverse fracture strength R_{tr} (MPa)
1	3	1.4 (0.21)	1727 (36)	1121 (100)
2	6	1.3 (0.18)	1598 (24)	2087 (434)
3	8	1.5 (0.30)	1504 (18)	2271 (195)
4	10	1.6 (0.15)	1263 (35)	3048 (302)
5	15	1.5 (0.20)	1187 (22)	3084 (159)
6	20	2.4 (0.38)	915 (15)	2471 (88)
7	3	0.93 (0.17)	1853 (18)	1389 (214)
8	6	0.86 (0.23)	1672 (24)	2645 (203)
9	8	0.89 (0.22)	1612 (16)	3126 (131)
10	10	0.84 (0.16)	1493 (16)	3376 (227)

The experimental standard deviation is shown in parentheses.

large dependence on K_{max} [14]. The fatigue sensitivity of hardmetals was found to increase with rising effective ductility of the metallic binder [15]. Klaasen et al. [17,18] believed that the performance of cemented carbides in cyclic loading conditions is also controlled by the fatigue sensitivity and plasticity of the cemented carbides. Gee et al. [4] applied Electron back scattered diffraction (EBSD) to the evaluation of plastic deformation in the four-point bending mechanical fatigue tests. The microstructure in a region close to the origin of fatigue cracks induced in the samples was analyzed. Plastic deformation in WC grains rather than in the Co phase was observed. A better understanding of the mechanical testing of WC hardmetals can also be obtained in another potential application such as hardness and Palmqvist toughness testing.

In the present investigation, the effects of microstructural parameters on mechanical fatigue behavior of WC–Co cemented carbides were studied by independently changing WC grain size and cobalt content. The fatigue characteristics of fine and medium grained WC–3 to 20 wt.%Co alloys was investigated under the same applied fatigue loading conditions and the microstructural observations of the fractured surfaces were performed to analyze the fatigue mechanisms of WC–Co cemented carbides.

2. Experimental details

2.1. Preparation and characterization of structure

The starting materials were WC powders with average grain size of approximately 0.2–2 μm, purity 99.8% (Xiamen Golden Egret Special alloy Co. Ltd., China), and Co powders with average grain size of approximately 0.95 μm, purity 99.8% (Zhuzhou Cemented Carbide Group Co. Ltd., China). VC, TaC, and Cr_3C_2 powders (Changsha Wing High High-tech New Material Co. Ltd., China) were used as grain growth inhibitors to inhibit the abnormal growth of WC grains during the fabricating process.

The raw powders were weighed according to the weight contents of WC and Co, mixed with small proportion of grain growth inhibitors, and dispersed with alcohol as the solvent using ultrasonic agitation to obtain well-agglomerated and uniform suspension. The mixed slurries were ball-milled for 48 h and then dried at 100 °C in vacuum (Model ZK-40, China). The powder mixtures were sieved through a 120 mesh sieve and then granulated by using paraffin as the forming agent. The mixed granulations were then compressed into the dimensions of 25 × 8.6 × 7.2 mm. The specimens were then sintered via removal of forming agent, sintering at suitable temperature in flowing Ar for 60 min under a fixed pressure of 5 MPa. And the sintered specimens are in dimensions of 20 × 6.5 × 5.25 mm.

Ten combinations of grain size and Co binder content for WC–Co hardmetal materials were selected for this investigation, and their composition, physical, and mechanical properties of the fabricated WC–Co cemented carbides are listed in Table 1. The microstructural morphologies of the WC–Co alloys with different WC grain size and Co content are shown in Fig. 1.

The samples 20 × 6.5 × 5.25 mm in size were sintered and prepared. In order to avoid the uncertainty of the fracture position of specimens in the fatigue tests, a single edge notched bending specimen was prepared. The prepared three-point bending specimen

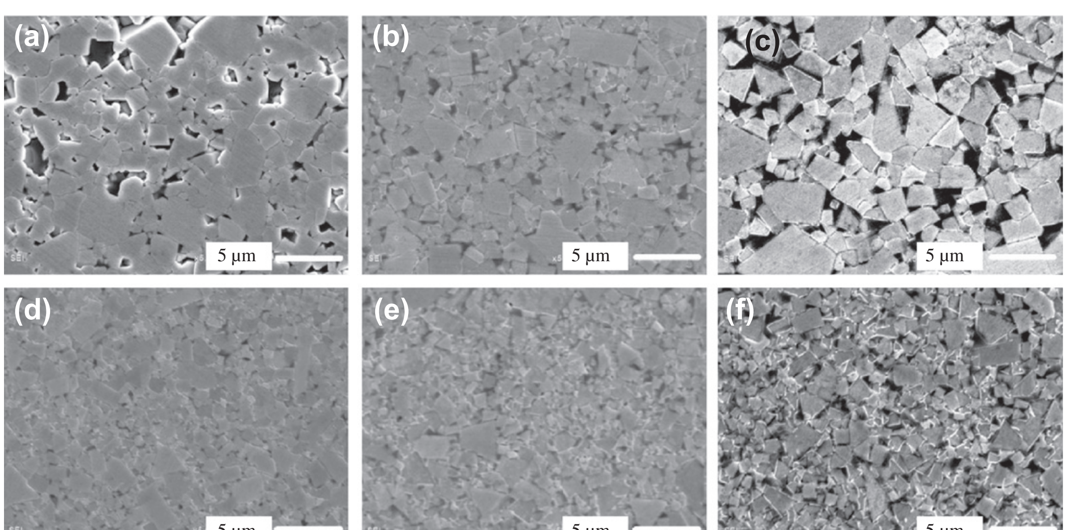

Fig. 1. SEM images of the microstructure of the WC–Co cemented carbides. (a) WC–3 wt.%Co, 1.4 μm, (b) WC–6 wt.%Co, 1.3 μm, (c) WC–10 wt.%Co, 1.6 μm, (d) WC–3 wt.%Co, 0.93 μm, (e) WC–6 wt.%Co, 0.86 μm, and (f) WC–10 wt.%Co, 0.84 μm.