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Evolution of Indentation Induced Cracks on WC Ceramic under Cavitation Loading in Water

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Abstract. For engineering ceramics, cracks produced in preparation process, i.e. sintering and surface finishing, have a profound impact on the mechanical strength and wear. Under cavitation loading, the flaws on the surface and subsurface are preferentially eroded. In this paper, artificial cracks are introduced on WC ceramic by indentation of a Vickers indenter at a load of 10 kgf. Five positions on the cavitation eroded area are selected. The average length of the cracks is 71.6 μm. The cavitation erosion tests are terminated at 1, 3, and 5 min to reveal the evolution of cracks. A single pattern for the evolution of cracks is recognized. Two new cracks at the tip of indentation cracks first nucleate and then propagate (accompanied by pullout of grains). The angle between the two new cracks ranges from 30° to 45°. The evolution of adjunct two groups of cracks gives birth to local breakout finally. Steps provided limited resistance to breakout are observed. The nucleation and propagation of the four indentation cracks do not always occur simultaneously.

Introduction

Cavitation describes the phenomenon of repeated nucleation, growth and violent collapse of clouds of bubbles when partial pressure within liquid is under the saturated vapor pressure [1]. It is widely accepted that cavitation erosion of a material is produced by high speed micro-jets generated by collapse of bubbles near a solid wall [2]. Hydraulic machines, such as pumps, hydraulic turbines, valves or ship propellers can be severely damaged by cavitation erosion [3]. It is of great interest to explore materials with high erosion resistance and to find the principle for selecting materials with long incubation time and low erosion rate. Microstructural parameters (e.g. grain size and shape) and also surface finish has impacts on the cavitation erosion behavior of advanced ceramics [4, 5]. The surface defects (cracks, indentations and scratches) on advanced ceramics are preferentially attacked under cavitation loading. However, our knowledge on the effect of surface defects is very limited. In this study, indentation induced cracks on WC ceramic are intentionally produced by using a Vickers indenter. The evolution of indentation induced cracks under cavitation loading is investigated.

Experimental details

Material. The WC powder was commercially available from Xiamen Jinlu Company. WC ceramic was prepared by spark plasma sintering in a graphite die at 1650 ^{o}C and 40 MPa for 5 min. The detailed information of the sintered WC ceramic was listed in Table 1. The sintered WC sample had a size of 25 mm in diameter and 6 mm in thickness.

Preparation of indentation cracks. WC sample was ground and polished on a Buehler Phoenix Beta Grinder-Polisher using a standard process. The surface roughness Ra of a polished WC sample was 0.07 µm. Surface polishing enabled a clear observation of indentation induced cracks and their evolution. The indentation cracks were introduced on polished WC ceramic by using a Vickers indenter at a normal load of 10 kgf. The cracks were located at five positions on the cavitation eroded area, see Fig. 1.

Table 1 Material property of sintered WC ceramic.

Material	Density (g/cm^3) [a]	Vickers hardness (HV_{10}/GPa) [b]	Indentation toughness (($K_{1c}/MPa\cdot m^{1/2}$) [c]
WC	15.50	28 ±0.1	5.9 ±0.2

[a] measured by using the Archimedes method. [b] determined at room temperature using Vickers diamond indenter with a load of 10 kgf for 10 s. [c] determined at room temperature using Vickers diamond indenter with a load of 10 kgf for 10 s and method proposed by Faber and Evans [6].

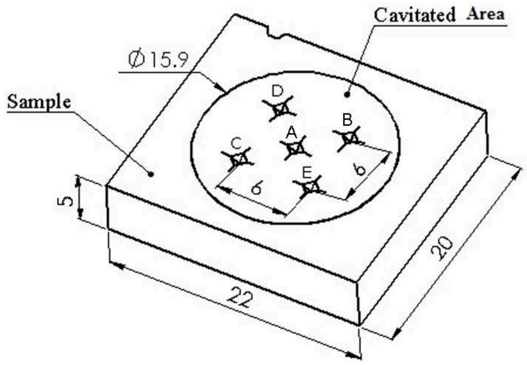

Fig. 1 Illustration of artificial cracks introduced on WC ceramic surface

Cavitation erosion tests. The cavitation erosion tests were carried out on a commercially available UVA-1 ultrasonic vibratory apparatus. This apparatus was jointly designed and manufactured by Hangzhou Chenggong Ultrasonic Company and the Lanzhou Institute of Chemical Physics according to ASTM standard G32-06 [7]. The advantages of the method included: high intensity of the bubble cloud enable it to measure the damage to materials in a relatively short period of time and thereby make it possible to quickly evaluate and screen materials; consumption of liquid in a cavitation erosion test was less than that used in other kinds of apparatus. The cavitation erosion tests were conducted in deionized water at a temperature of 25±2 °C, frequency of the ultrasonic transducer was 20±0.5 kHz, peak-to-peak amplitude was 50±2 µm, the test (dummy) specimen button diameter was 15.9±0.02 mm, depth of the specimen immersion was 12±1 mm, height of the test liquid was 100±5 mm, and distance between the faces of the dummy tip and the test specimen was 0.5±0.005 mm. The cavitation erosion tests were terminated at 1, 3, and 5 min to reveal the evolution of cracks.

OM observation of evolution of indentation induced cracks. At each time interval of cavitation erosion tests, evolution of indentation induced cracks was monitored by optical microscopy (OM).

Results and discussion

Indentation cracks on WC ceramic. Fig. 2 shows the OM micrograph of an indentation and cracks on polished WC ceramic. Because WC ceramic has a low fracture toughness, cracks propagate with very insignificant deflection, see Fig. 2b. There is no difference for the morphology of the cracks at five positions. The average length of cracks from the edge of indentation is 71.60 µm.

Evolution of cracks on WC surface. The evolution of indentation cracks can be included in Fig. 3(a)-(c). At the tip of an indentation crack, the nucleation and propagation of two new cracks are found, see T_{A1}-T_{A3} in Fig. 3(a). The angle between the two cracks ranges from 30° to 45°. The propagation of crack is accompanied by detachment of WC grains (T_{A2} and T_{A3} in Fig. 3(a)). The evolution of T_{A2} and T_{A3} gives birth to a fan-shaped break-out, see Fig. 3(b). After the fan-shaped break-out occurs, the evolution of indentation cracks comes to an end, see Fig. 3(c). The break-out is a kind of severe damage of the surface. SEM micrograph in Fig. 4 reveals that the steps in the breakout provide limited resistance to breakout.

Local property. A single pattern for the evolution of cracks is recognized. In short, the nucleation and propagation (accompanied by pullout of grains) of two new cracks at the tip of an indentation

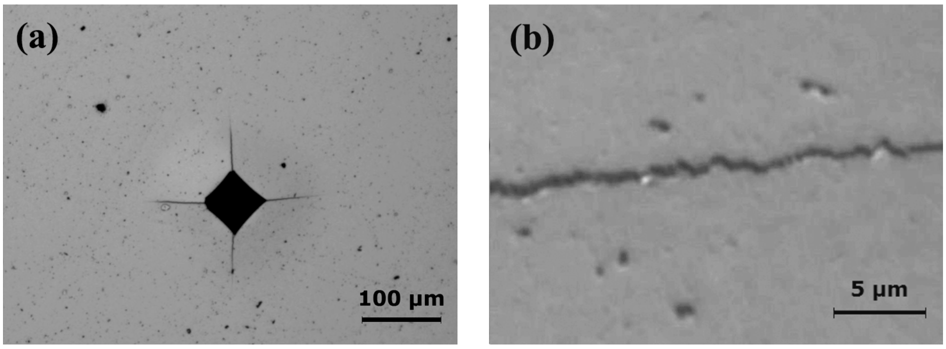

Fig. 2 (a) Top view of an indentation induced crack and (b) insignificant deflection of the crack.

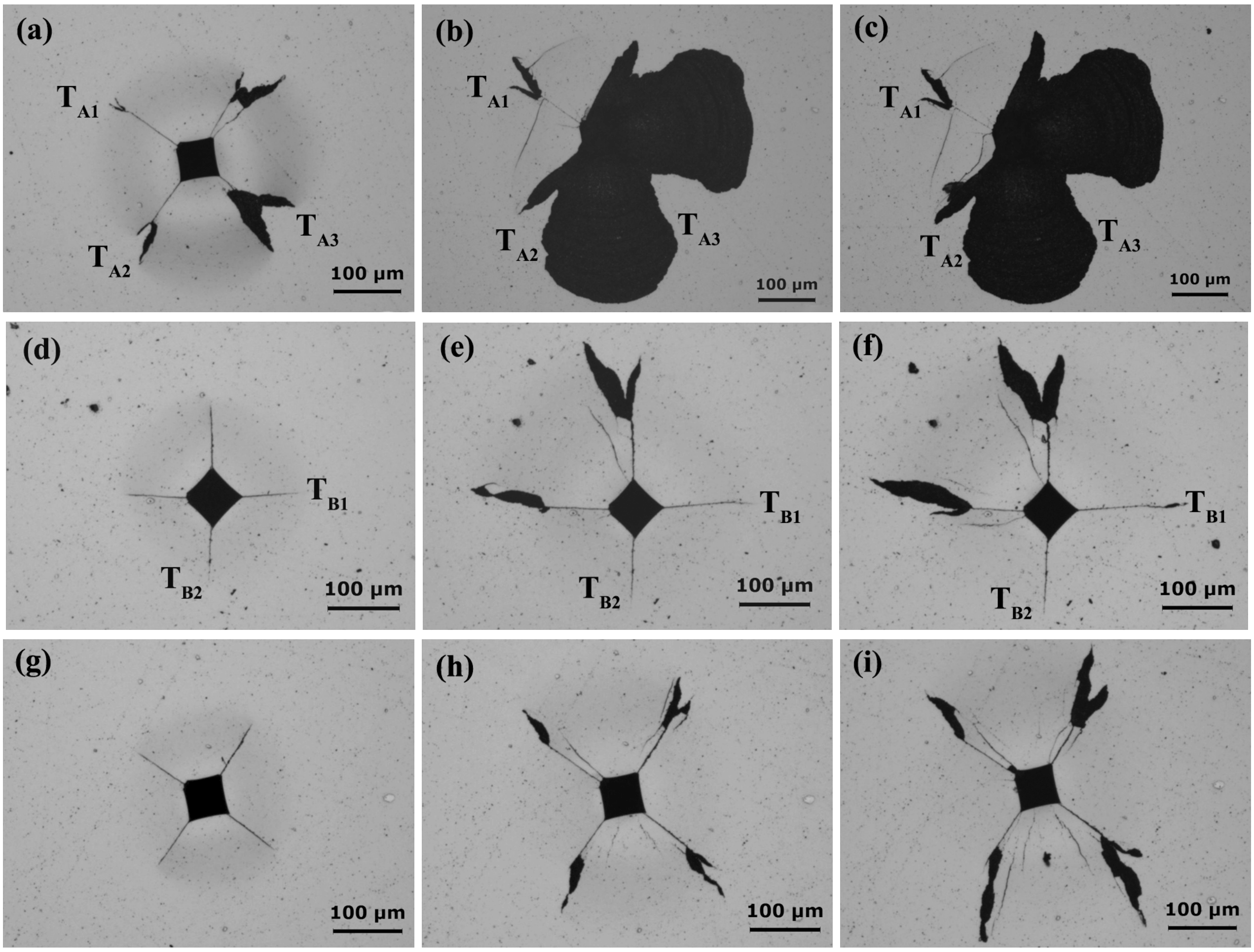

Fig. 3 (a)-(c) Evolution of cracks on WC surface labeled with A after 1, 3 and 5 min cavitation loading; (d)-(f) evolution of cracks on WC surface labeled with B after 1, 3 and 5 min cavitation loading; (g)-(i) evolution of cracks on WC surface labeled with C after 1, 3 and 5 min cavitation loading. T_{A1}, T_{A2} and T_{A3} represent tips of three indentation cracks labeled with A; T_{B1} and T_{B2} represent tips of two indentation cracks labeled with B.

crack are noticed, see Fig. 3(d)-(i). Finally, the evolution of adjunct two groups of cracks gives birth to local breakout. However, it can be seen in Fig. 3(d)-(f) that after cavitation erosion for 5 min, the nucleation and propagation of one indentation crack just start (T_{B1}) and no visible evolution of one indentation crack occurs (T_{B2}). In contrast, the nucleation and propagation of the four indentation cracks occur almost simultaneously, see Fig. 3(g)-(i). This might be attributed to the inhomogenous microstructure and property of polycrystalline WC ceramic at several tens of micrometers.

Cracks from the edge of the indentation mark. If one takes a look at Fig. 3, he will find new cracks from the edge of indentation mark generated by cavitation loading. The nucleation and propagation of these cracks are also deserved investigation but are not the topic of this study.

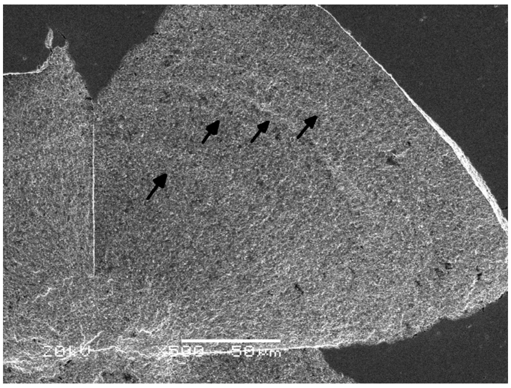

Fig.4 Local break-outs with steps labeled with black arrows on WC surface after 5 min cavitation test.

Summary

Under cavitation loading, evolution of induced cracks on WC ceramic consists of two processes, i.e. two new cracks at the tip of the indentation crack first nucleate and then propagate. The angle between the two cracks ranges from 30° to 45°. The propagation of crack is accompanied by pullout of WC grains. The evolution of adjunct two groups of cracks gives birth to local breakout finally. The nucleation and propagation of the four indentation cracks do not always occur simultaneously. This might be attributed to the inhomogenous microstructure and property of polycrystalline WC ceramic.

Acknowledgments

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