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Microstructural effect of α-Sialon ceramic on the resistance to cavitation erosion in deionized water

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Abstract

The resistance to cavitation erosion of one Yb-α-Sialon ceramic and two Dy-α-Sialon ceramics (Dy-α-Sialon-1 and Dy-α-Sialon-2) was investigated in deionized water using an ultrasonic vibratory apparatus. The incubation periods of Dy-α-Sialon-1, Dy-α-Sialon-2 and Yb-α-Sialon ceramic were 210 min, 300 min and 360 min, respectively. Surface roughness and area fraction of cavities were found good indicators for the evolution of ceramics erosion. The microstructural features, including main phase (α phase), inhomogeneities of the microstructures and type of rare earth oxide, were correlated to the cavitation erosion behavior. It was found that the elongated α-Sialon grains in Yb-α-Sialon and Dy-α-Sialon-2 produced a self-toughening effect to increase the incubation period. The aggregation of Dy_2O_3 in Dy-α-Sialon-1 had an adverse effect on the resistance to cavitation erosion. Impurity phases and type of rare earth oxide had impacts on resistance to cavitation erosion. The findings in this work indicate that the cavitation erosion resistance of α-Sialon ceramics could be improved by microstructure optimization.

Keywords: A. Hot pressing; C. Wear resistance; Sialon ceramic

1. 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 caused by high speed micro-jets, arising from the collapse of bubbles near a solid wall [2]. Hydraulic machines, such as pumps, hydraulic turbines, valves or ship propellers, are often 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 period and low erosion rate. Primary investigation on cavitation erosion of advanced ceramics could be dated back to 1994 [4]. Now it is well known that both microstructural parameters (e.g. grain size and shape) and surface finish have impacts on the cavitation erosion behavior of advanced ceramics. Ceramics with ultra-fine structure, smooth surface finish and without faults or porosity are expected to have long incubation period and good resistance to cavitation erosion [5]. In this sense, fine grain and well-polished surface (low surface roughness as well as very small amount of surface defects) render Sialon ceramics good cavitation erosion resistance. In recent years, investigation on design and property improvement of the Sialon ceramics, especially for the rare earth oxide doped Sialon ceramics, attracted much attention and achieved important findings [6,7]. However, knowledge on microstructural optimization of Sialon ceramics is still inadequate. On one hand, the grain size and

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shape of the main phase are important. On the other hand, the effects of inhomogeneities of the microstructures and the polished surfaces (grain boundaries, grain boundary phases, cavities at grain boundaries and their triple-points or within the grains as well as surface defects due to machining) are also important but still not available.

In this study, the microstructural effect of the three α-Sialon ceramics on resistance to cavitation erosion in deionized water is investigated. Material selection is based on three microstructural aspects, i.e. grain size and shape of α-Sialon phase, inhomogeneities of the microstructures, and types of rare earth oxide. The wear mechanism is also included.

2. Experimental details

2.1. Materials

2.1.1. Preparation and property

The material components were calculated based on the molecular formula $RE_{m/3}Si_{12-(m+n)}Al_{m+n}O_nN_{16-n}$ (RE represents the rare earth elements). In this study, m=2 and n=1 were chosen. The rare earth oxide of Dy_2O_3 or Yb_2O_3 was used as the phase stabilizer of α-Sialon. Si_3N_4, AlN, Al_2O_3 and Dy_2O_3 (or Yb_2O_3) powders were mixed in proportion in plastic containers with anhydrous ethanol. After being milled with silicon nitride balls for 24 h, the slurry mixture was stirred and dried, and then sieved to obtain powders with sizes < 80 mesh. The powder was hot pressed in a graphite die at a pressure of 30 MPa. The sintering temperature was 1600–1750 °C depending on the specific material and holding time was 60 min. The detailed information of the sintered ceramics is listed in Table 1.

2.1.2. Surface finish and surface quality

Before cavitation tests, all samples were ground to a thickness of 4.5 mm and finally polished with 1 μm diamond paste on a Buehler Phoenix Beta Grinder-Polisher. The surface quality of the polished surface was characterized by the area fraction of cavities and surface roughness. The area fraction of cavities and roughness values of the tested materials were comparable after polishing, see Table 2. The three α-Sialon ceramics could be polished to a low roughness surface with small amount of defects.

The surface roughness of the specimens was measured using a Nanomap 500LS stylus profilometry and characterized by roughness values, i.e. the arithmetic surface roughness R_a and the core roughness depth R_k. The average value of roughness was calculated from 7 random profiles of sampling length 3 mm at each test time near the central region of the cavitated area. In engineering application, the machined surfaces of many parts need to have specific features. The R_k parameter set, for the highly prestressed surface, was defined according to the DIN4776 standard [9].

The area fraction of cavities on the polished surfaces was determined using optical microscopy. It was analyzed by the contrast difference, since the cavitated area was much darker than cavities-free area. Area fraction of cavities was calculated through the following formula:

Area fraction of cavities = (area of cavities/nominal cavitated area)× 100%

2.2. Cavitation 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 [10]. The advantages of the method are as follows: high intensity of the bubble cloud enables it to measure the damage of materials in a relatively short time thereby making it possible to quickly evaluate and screen materials; and consumption of liquid in a cavitation erosion test is 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. The frequency of the ultrasonic transducer was 20 ± 0.5 kHz. The peak-to-peak amplitude was 50 ± 2 μm.

Table 2
Initial area fraction of cavities and surface roughness values of three α-Sialon ceramics.

Sample	Area fraction of cavities (%)	R_a (μm)	R_k (μm)	R_{pk} (μm)	R_{vk} (μm)
Dy-α-Sialon-1	0.5	0.018	0.058	0.030	0.020
Dy-α-Sialon-2	0.29	0.023	0.073	0.033	0.024
Yb-α-Sialon	0.25	0.023	0.075	0.033	0.024

Table 1
Sintering temperatures and material properties of three α-Sialon ceramics.

Material	Dy-α-Sialon-1	Dy-α-Sialon-2	Yb-α-Sialon
Sintering temperature (°C)	1600	1700	1750
Average grain size (μm)[a]	0.93	0.95	0.89
Density (g/cm^3) [b]	3.52	3.60	3.61
Vickers hardness (HV_{10}/GPa)[c]	19.9 ± 0.2	19.4 ± 0.4	19.4 ± 0.3
Indentation toughness (K_{1c}/MPa m$^{1/2}$)[d]	3.8 ± 0.3	5.2 ± 0.3	5.2 ± 0.3

[a]Calculated according to the FESEM (JSE-6701F, JEOL, Tokyo, Japan) micrograph of fractured surface.
[b]Measured by using the Archimedes principle.
[c]Determined at room temperature using Vickers diamond indenter with a load of 10 kg for 10 s.
[d]The same condition as that of Vickers hardness and method proposed by Faber and Evans [8].