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Cavitation erosion resistance of plastics

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ABSTRACT

Cavitation erosion tests were carried out for plastics, *i.e.* for epoxy resin, polypropylene, high-density polyethylene and polyamide 66, and the relation between cavitation erosion resistance and the mechanical properties was examined. Cavitation erosion resistance of plastics ranges between half and 30 times that of carbon steel. The cavitation erosion of plastics was caused by fatigue fracture similar to metals. Since plastics have relatively small acoustic impedance, the impact loads applied by bubble collapse become very small. Therefore, the resistance and the incubation period of cavitation erosion of plastics can be evaluated in terms of bubble collapse impact energy and the strain energy obtained from the fatigue strength.

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1. Introduction

In order to reduce the erosion rate for new components or to repair damaged components, which suffered the cavitation erosion, surface coatings such as metal plating and weld overlays are usually employed. However, unlike solid and liquid impact erosion, very few studies have been made for the cavitation erosion of nonmetallic materials. Early studies on cavitation erosion of plastics and plastic coatings were made by Lichtman et al. [1–3] using a rotating-disk apparatus. The erosion resistance of nylon, dense borosilicate glass and neoprene showed a similar resistance to that of satellite 6B, and the resistance of polyvinyl chloride (PVC) showed a similar resistance to that of SAE1030. Styrene acrylonitrile had a resistance equivalent to pure aluminum. Nylon has a superior elongation to fracture of 300%, as compared with polyvinyl chloride, which has an elongation to fracture of 60%. Topchiashvili et al. [4] reported that polymeric plastics having a high erosion resistance were used for the repairs of the runner chamber of hydraulic turbines, suction turbines and butterfly valves on hydroelectrical power plants. Knapp et al. [5] reported that rubber was found to be satisfactory at low cavitation intensities but, at higher levels, peeled off in large strips. This is because the cavitation impact energy is converted into heat, which cannot be dissipated and the resulting temperature rise causes structural changes, which lead to fracture [6]. Hammitt et al. [7] carried out vibratory cavitation erosion tests using a stationary specimen method for natural rubber, four kinds of neoprene, estane, Epon-828 and Plexiglas, and reported that a rough correlation between Shore hardness and erosion resistance was obtained. However, the mean depth of erosion vs. time curves was not reported. Heathcock et al. [8] also reported that 5 h cumulative volume loss has a good correlation with Shore hardness. Barletta and Ball [9] carried out cavitation erosion tests using twenty-six different polymeric materials. They reported that the materials can be classified into three distinct groups in accordance with their cumulative volume loss. But, the test exposure time was up to 10 h, and this time is considered to be within the incubation period for polyamide 66 and high-density polyethylene. Yamaguchi et al. [10] carried out cavitation erosion tests for various plastics and metals, and reported that erosion resistances of polyetheretherketone (PEEK) and polytetrafluoroethylene (PTFE) are between that of austenitic stainless steel and aluminum alloy (Al–Mg). Moreover, Hojo and Tsuda [11] carried out the tests on 9 thermoplastic resins, 1 thermosetting resin and 5 composites, and obtained cumulative volume loss curves. They reported that brittle materials such as polystyrene showed high erosion rates and ductile materials such as polyethylene and FRP showed low erosion rates. However, they did not discuss the influence of cavitation bubble collapse.

In this study, vibratory cavitation erosion tests were carried out for four different plastics and the mechanism of the cavitation erosion is discussed through a measurement of the mass loss and the observation of the eroded surface. The erosion resistances of plastics were evaluated quantitatively by measurements of the bubble collapse impact forces and of the fatigue strength.

2. Test specimen and procedures

2.1. Test materials

The test materials were four kinds of plastics. They were thermosetting plastics of epoxy (EP), thermoplastic plastics

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Nomenclature

Al	pure aluminum with a purity of 99.9%
HDPE	high-density polyethylene
E	Young's modulus
EP	epoxy
PA66	polyamide 66
PP	polypropylene
SS	low carbon steel with a tensile strength of more than 400 MPa
σ_B	tensile strength
σ_W	fatigue strength at 10^7 cycles
$\sum F_i^2$	impact energy by cavitation bubble collapse

of polypropylene (PP), high-density polyethylene (HDPE) and polyamide 66 (PA66). Pure aluminum A1050 (Al) and a roll steel for general structure SS400 (SS) were also used for comparison. SS400 is a Japanese standard low carbon steel with a tensile strength of more than 400 MPa, but not a stainless steel. Physical and mechanical properties of the test materials and the test liquid are listed in Table 1. Shape and dimensions of the specimen was a plate with 25 mm × 25 mm in area and 3 mm in thickness.

2.2. Cavitation erosion test

The test apparatus was a magnetostrictive vibratory device as specified in ASTM G32-03 [12]. The vibrating tip of stainless steel with a diameter of 16 mm was screwed into an amplifying horn. The distance between the tip and the surface of the specimen was 1 mm. The horn frequency was 19.5 kHz and the double amplitude (peak to peak) was 50 μm. The test liquid was ion-exchanged water, which was kept at 25 ± 1 °C.

After the cavitation test, the specimens were washed in ion-exchanged water with an ultrasonic cleaner. The specimens were evaporated in a vacuum chamber for 10 min, and then weighed by a precision balance with a sensitivity of 0.01 mg.

2.3. Tensile and fatigue tests

The specimen employed in tensile and fatigue tests was a plate with the dimensions shown in Fig. 1. Plastics usually have high water absorption. Therefore, in order to perform the test under the specified conditions, all specimens were immersed in ion-exchanged water for 24 h before the test. The tensile test was performed at a rate of 1 mm/min under controlled stroke conditions. In the fatigue test, a stress controlled tension-compression test was carried out with fully revised sinusoidal loading at a frequency of 5 Hz. The fatigue test apparatus was an electric-hydraulic servo controlled testing machine.

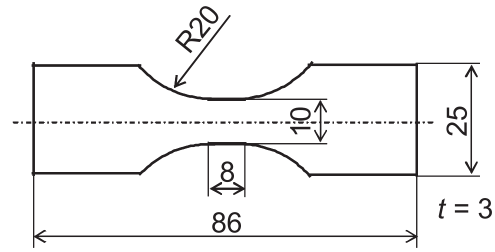

Fig. 1. Shape and dimensions of specimen employed in tensile and fatigue tests (mm).

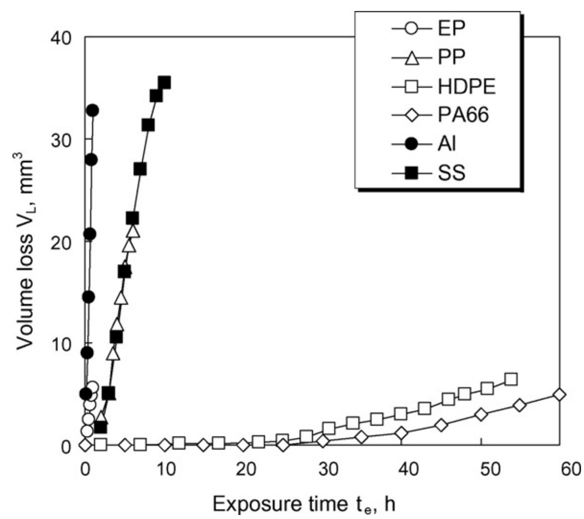

Fig. 2. Volume loss curves.

3. Experimental results and discussion

3.1. Cavitation erosion test results

Fig. 2 shows the volume loss curves of four plastics along with Al and SS. The volume loss, V_L, is defined as the mass loss divided by the material density. After showing an incubation period in the early stage, V_L increases proportionally with increasing exposure time, t_e. A similar result was reported previously [8]. The volume loss rate was defined as the slope of the linear portion. The volume loss rate of PA66 is approximately 1/60 that of EP and 1/30 that of SS. Therefore, PA66 has the highest cavitation erosion resistance in

Table 1
Physical properties (at 25 °C) of the test materials and the test liquid.

Materials			Density (ρ kg/m^3)	Elastic modulus E (GPa)	Acoustic impedance Z (N s/m^3)	Vickers Hardness HV	Glass Temp. T_g °C	Melting Point T_m °C	Thermal Conductivity q (W/m °C)
Thermosetting resin	Epoxy resin	EP	1.22×10^3	1.54	1.37×10^6	21	140	–	0.78
Thermoplastic resin	Polypropylene	PP	0.91×10^3	1.17	1.03×10^6	8	−10	176	0.18
	High-density polyethylene	HDPE	0.95×10^3	0.87	0.91×10^6	4	−120	137	0.49
	Polyamide 66	PA66	1.14×10^3	0.60	0.83×10^6	1	47	267	0.25
Metal	A1050	Al	2.71×10^3	61.7	12.9×10^6	35	–	660	221.9
	SS400	SS	7.87×10^3	206	40.3×10^6	113	–	1480	55.8
Liquid	Ion ex. water		1.00×10^3	2.22	1.49×10^6	–	–	0	0.58

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