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Cavitation erosion of silver plated coatings considering thermodynamic effect

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ABSTRACT

Cavitation often occurs in inducer pumps of space rockets. Silver plated coating on the inducer liner faces the damage of cavitation. In this study, we carried out cavitation erosion tests using silver plated coatings with different thermodynamic parameter at a constant cavitation number. Then we carried out cavitation erosion tests using some liquid with the same thermodynamic parameter and cavitation number as liquid oxygen condition. Thermodynamic parameter Σ proposed by Brennen was used as a thermodynamic parameter. The fluids used for the cavitation erosion tests were water, ethanol and hexane. We discussed the relation between thermodynamic parameter and mass loss rate, and the relation between acoustic impedance and mass loss rate.

1. Introduction

Cavitation bubble collapse impact loads act repeatedly on a material surface to produce plastic deformation, crack initiation, crack growth and material removal. Cavitation erosion is a kind of fatigue phenomena. This phenomenon sometimes occurs on the components which contact flowing liquids such as pumps, piping systems and ship propellers. The erosion reduces the machine performance and the lifetime.

It is well known that cavitation occurs in inducer pumps used for space rockets [1–3]. Kamijo and Yamada [1] reported that backflow cavitation at the inlet of the pumps was suppressed by using a specially developed inducer with a change of flow coefficient and lower operating pressure. Yamada et al. [2] reported several examples of the accidents and unstable vibrations caused by cavitation in pumps. Uchiumi et al. [3] proposed an analytical method for cavity type evaluation in terms of the blade shape of rocket inducer. Cavitation in the inducer may cause the erosion of inducer and liner. However, there have been no reports on the cavitation erosion prevention method or the cavitation erosion behavior. Silver plated coating is now used for the clearance between pump inducers and liners to reduce the damage and the temperature rise when the inducer contacts the coating [4,5].

Hattori et al. [6] carried out the cavitation erosion tests for silver plated coatings using the vibratory specimen method in deionized water, ethanol and liquid nitrogen. They discussed the effect of test liquid and temperature on erosion mechanism. They found that cavitation erosion occurs in deionized water and ethanol, but it hardly occurs in liquid nitrogen. The reason was that bubbles generated by the pressure drop in liquid nitrogen did not collapse because the surrounding pressure increases to the atmospheric pressure, when the saturation pressure increased with the temperature rise. However, the verification was not performed.

On the other hand, Brennen [7] found a thermodynamic parameter Σ based on the thermodynamics of single vapor bubble in flowing system. He discussed the relation between liquid temperature and the parameter Σ in hydrogen, oxygen, nitrogen, water, methane and freon. Brennen [8] also reported that cavitation number of pump head decreasing point in centrifugal pump and rocket inducer can be estimated by a nondimensional parameter Σ^*. Recently, Watanabe and Furukawa [9] reported the review on the thermodynamic effect of cavitation and the theoretical analysis. These researches discussed the thermodynamic effect on cavitation inception but not cavitation erosion.

In this study, we carried out cavitation erosion tests using silver plated coatings in liquids with different thermodynamic parameters at a constant cavitation number. Hardness tests were

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also carried out by using a Shore hardness tester as a function of specimen temperature. Another set of cavitation erosion tests was carried out using three kinds of liquid with the same thermodynamic parameter and cavitation number as liquid oxygen condition. The fluids were water, ethanol and hexane. We discussed the relation between thermodynamic parameter and mass loss rate, and the relation between acoustic impedance and mass loss rate.

2. Materials and experimental procedure

The specimen was a silver plated coating on a SUS304 base metal. Fig. 1 shows the dimensions of a vibrating tip specimen with a diameter of 16 mm. The coating was 150 μm to 200 μm in thickness and 10.5 mg/mm^3 in density. Table 1 shows the designation, coating metal, base metal, heat treatment, Vickers hardness and surface finish. Base metal is SUS304 steel. Table 2 shows the chemical composition. Table 3 shows the physical and mechanical properties. The specimen was not heat-treated and the Vickers hardness (HV0.2) of Ag was 72.5. The surface finish was the same as the real inducer pump.

Cavitation erosion tests were carried out by using a vibratory apparatus as specified in the ASTM standard G32-03 [10]. The tests were carried out under controlled liquid temperature and pressure in a test chamber which was able to apply a pressure up to 0.7 MPa absolute and a temperature up to 423 K. Fig. 2(a) and (b) show a schematic drawing and a photograph of the test apparatus. The test temperature was controlled by a mantle heater and a temperature controller. Even when the mantle heater shut down at a predetermined temperature, the temperature continued to increase by cavitation bubble collapse. Therefore, we used a cooling coil in which water flowed to maintain the liquid temperature. The accuracy of the temperature control was $\pm 2\,^{\circ}$C. Test pressure was controlled by pumping air in the sealed chamber using a compressor. The erosion tests began after attaching a specimen tip to the horn. Then, the pressure was applied and the test liquid was heated up to the predetermined temperature. The peak-to-peak displacement amplitude of the tip was 50 μm. A precision balance (sensitivity 0.01 mg) was used to measure the mass of the specimen, and the results were evaluated in terms of mass loss. A profilometer (KEYENCE LT-8010) was used to measure the profile of the eroded surface. A Shore hardness tester and a silicon rubber heater were used to measure the hardness as a function of the specimen temperature.

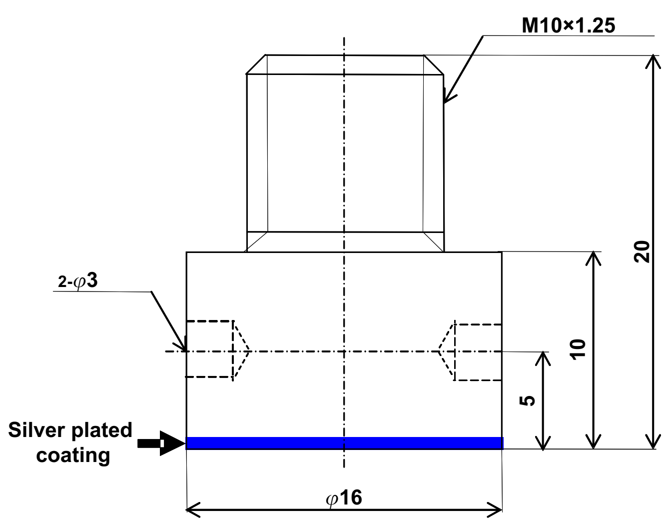

Fig. 1. Dimension of specimen.

Table 1
Condition of silver plated coating.

Designation	Coating metal	Base metal	Heat treatment	HV0.2 of Ag	Surface finish
C1	Ag	SUS304	None	72.5	Same as the product

Table 2
Chemical composition of SUS304.

(Mass%)							
Material	C	Si	Mn	P	S	Ni	Cr
SUS304	0.05	0.33	1.76	0.36	0.22	8.49	18.2

Table 3
Physical and mechanical properties of SUS304.

(Mass%)			
Material	Density [g/cm^3]	Tensile strength [MPa]	HV0.2
SUS304	7.93	672	215

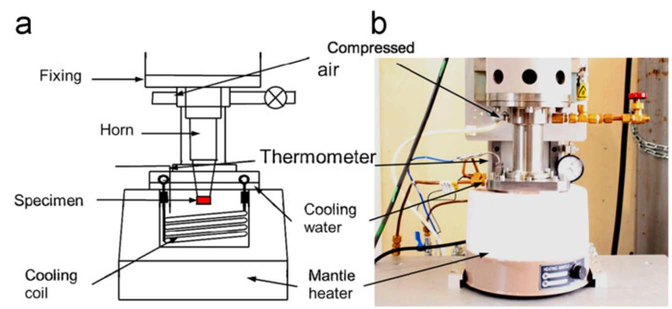

Fig. 2. Test apparatus. (a) Schematic drawing. (b) Set up photograph.

3. Results and discussions

3.1. Cavitation erosion tests based on deionized water at 298 K and 0.1 MPa

Cavitation erosion tests were carried out using test liquids at several temperatures to evaluate the effect of the thermodynamic parameter on the cavitation erosion rate. The Σ proposed by Brennen [7] was used as the thermodynamic parameter. Σ depends on the liquid temperature and was defined by

$$\Sigma(T_\infty) = (\rho_v L)^2 / (\rho_l{}^2 c_{pl} T_\infty \alpha_l{}^{1/2}), \tag{1}$$

where T_∞ is the test temperature, ρ_v is the vapor density, ρ_l is the liquid density, L is the evaporative latent heat, c_{pl} is the constant pressure specific heat of the liquid and α_l is the thermal diffusivity of the liquid.

Fig. 3 shows the variation in thermodynamic parameter Σ as a function of the nondimensional temperature calculated from the triple point to the critical point of the test liquid obtained from the p–T diagram (p:pressure and T:temperature).

Each data point was calculated by Eq. (1). Σ increased with the temperature in all test liquids. Deionized water, ethanol and hexane were used in this study because of their easy handling.