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Cavitation erosion of silver plated coatings in a low-temperature environment

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ABSTRACT

It is well known that cavitation occurs in inducer pumps used for space rockets. The silver plated coating on the inducer liner faces erosion damage. In this study, we carried out cavitation erosion tests on seven silver plated coatings with the stationary specimen method using a vibratory apparatus. We analyzed the erosion behavior of these coatings and discussed their erosion resistance. The erosion resistance of silver plated coatings can be evaluated in terms of material hardness and was ranked between pure aluminum and pure copper. Moreover we carried out erosion tests using the vibrating specimen method in deionized water, liquid nitrogen and ethanol for the silver coating which showed the highest erosion resistance in the stationary specimen method. We found that erosion occurred in low-temperature ethanol, but not in liquid nitrogen.

1. Introduction

Cavitation erosion is a kind of fatigue phenomena. Bubble collapse loads act repeatedly on a material surface to produce plastic deformation crack initiation, crack growth and material removal. This phenomenon sometimes occurs on components contacting flow 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 [1–6]. Kamijo et al. [1] reported that backflow cavitation at the inlet of the pumps was suppressed using a specially developed inducer with a change of flow coefficient and lower operating pressure. Yamada et al. [2] reported several examples of 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 the rocket inducer. Cavitation in the inducer may cause erosion of the inducer and the liner. However there have been no reports on the prevention of cavitation erosion and cavitation erosion resistance from a material science viewpoint. Silver plated coating is now used for clearance between pump inducers and liners to reduce the damage and the temperature rise when the inducer impeller contacts the coating [7,8]. For silver plated coatings in aerospace industry, SAE Aerospace Specifications (AMS 2410 [9] and AMS2412 [10]) specify the silver purity, heat treatment, etc. For soft materials like silver, the erosion behavior and the resistance have previous been discussed for aluminum and copper [11–13]. It is well-known that the erosion rate of soft materials is higher than that of hard materials [11]. However, there are no reports on the erosion behavior of silver plated coatings. Therefore, the erosion resistance of silver plated coatings should be discussed for the repeated usage of space rockets in future developments.

In this study, we carried out cavitation erosion tests using seven silver plated coatings with different plating methods, heat treatments and surface finishes applying the stationary specimen method using a vibratory apparatus to discuss erosion behavior and resistance. Moreover, we carried out erosion tests using the vibratory specimen method in deionized water, liquid nitrogen and ethanol for the silver plated coating which had the highest erosion resistance in the stationary specimen method and discussed the resulting erosion rates. Finally, we discussed the erosion mechanism and the relation between erosion particle diameter and the particle count through the observation of eroded surfaces and removed particles.

2. Test materials and methods

Specimens used for the stationary specimen method were silver plated coatings on a SUS304 disk surface with 25 mm in diameter and 5 mm in thickness. The coatings were 150 to

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Table 1
Standard, heat treatment and surface finish of silver plated coatings.

Designation	Standard	Heat treatment	HV0.5	Surface finish
C1	-	None	68.5	Same as the product
C2	AMS2410	High bake, 20–30 min	68.1	Same as the product
C2	AMS2410	High bake, 50–60 min	70.4	Same as the product
	AMS2410	None	84	Emery paper, buff finish
	AMS2410	High bake, 20–30 min	69	Emery paper, buff finish
	AMS2410	High bake,50–60 min	70.7	Emery paper, buff finish
	AMS2412	Low bake	83.5	Emery paper, buff finish

Table 2
Chemical composition of the reference materials (mass %).

Materia	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
C1020	–	–	100	–	–	–	–	–
A1050	0.1	0.1	0.01	0	0	0	0	Ba

Table 3
Density and hardness of the reference materials.

Materia	Density (g/cm^3)	Vickers hardness HV0.2
C1020	8.96	98
A1050	2.71	33

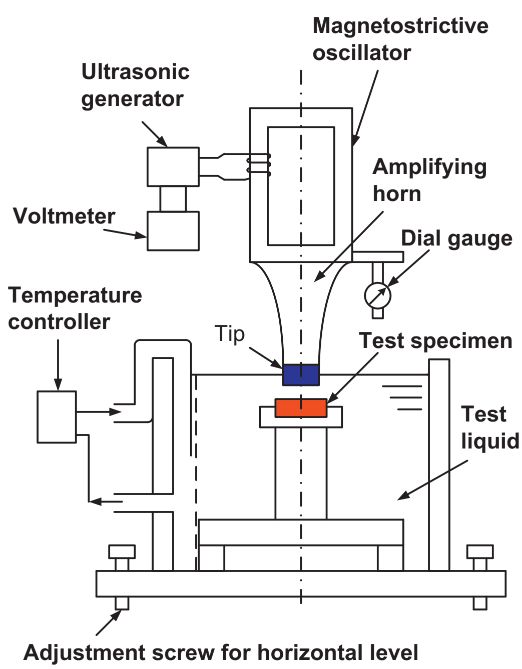

Fig. 1. Test apparatus.

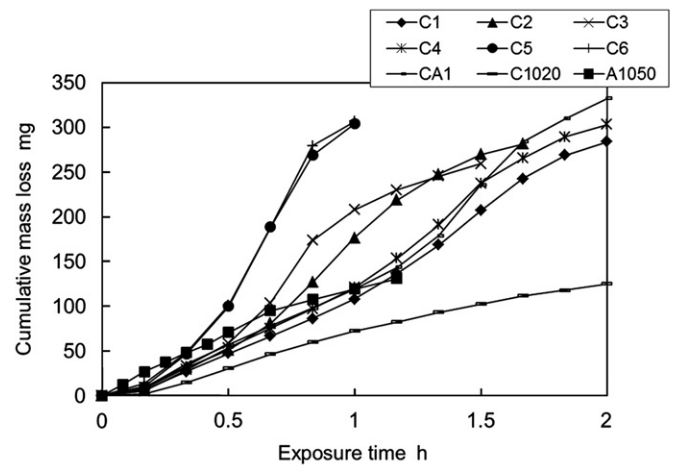

Fig. 2. Cumulative mass loss curves of silver plated coatings.

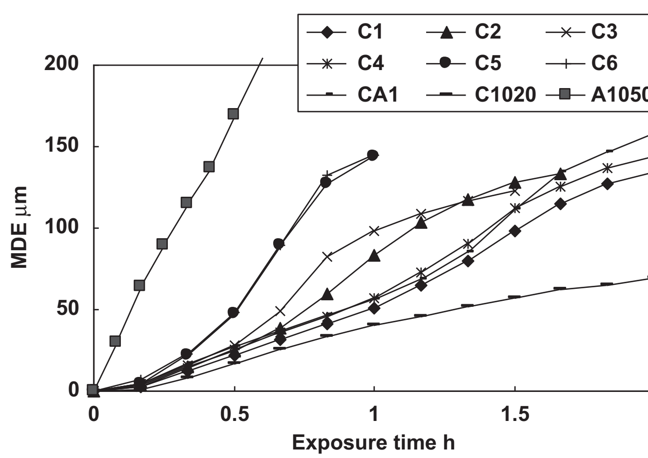

Fig. 3. MDE curves of silver plated coatings.

200 µm in thickness and 10.5 mg/mm^3 in density. Table 1 shows the designation, standard, heat treatment, Vickers hardness and surface finishes of the coatings. The specimens were all silver plated coatings of very high purity. The AMS2410 standard [9] was used for C2, C3, C5 and C6, and the AMS2412 standard [10] was used for CA1. The surfaces of C1 to C3 were lathe-finished similarly to the product. C4 to CA1 were polished with emery paper and buff-finished. The C1 and C4 coatings were supplied without heat treatment. C2 and C5 were held for 20 to 30 min at high bake temperature (502 to 518 °C). C3 and C6 were held for 50 to 60 min at the high bake temperature. CA1 was held for over two hours at low bake temperature (149 to 260 °C). The Vickers hardness was measured at a load of 0.5 N, excluding 0.2 N for C1 due to the limitation of the apparatus.

Pure copper C1020 and pure aluminum A1050 were used as reference materials. Table 2 shows the chemical composition of the reference materials. Table 3 shows the density and Vickers hardness. The purity is 99.96% for C1020 and 99.7% for A1050. The Vickers hardness (HV0.2) was 90 for C1020, and 33 for A1050. The hardness of the silver plated coatings was between that of the two reference materials. The material density was 8.96 g/cm^3 for C1020 and 2.71 g/cm^3 for A1050.

Cavitation erosion tests were carried out by using a vibratory apparatus as specified in the ASTM standard G32-03 [14]. The test method was the stationary specimen method. Fig. 1 shows a