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Effect of liquid properties on cavitation erosion in liquid metals

Shuji Hattori[a,*], Fumitaka Inoue[b], Katsumi Watashi[c], Takashi Hashimoto[d]

[a] Graduate School of Engineering, University of Fukui, 9-1 Bunkyo 3-chome, Fukui-shi 910-8507, Japan
[b] University of Fukui, 9-1 Bunkyo 3-chome, Fukui-shi 910-8507, Japan
[c] Japan Atomic Energy Agency. Tokai-mura, Ibaraki 319-1195, Japan
[d] Japan Atomic Energy Agency, Tsuruga, Fukui 919-1279, Japan

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ABSTRACT

A cavitation erosion vibratory apparatus was developed to test in low-temperature melting alloys. The temperature of the test can be changed from room temperature to 150 °C. The erosion tests of SUS304 were carried out in liquid lead–bismuth metal and in deionized water. The erosion rate was discussed in terms of a relative temperature defined as the percentage between freezing and boiling points. At 14 °C relative temperature, the erosion rate was 10 times in lead–bismuth, and 2–5 times in sodium, compared with that in deionized water. The erosion rate can be evaluated as a function of material density and sound velocity. Finally the temperature dependence of the erosion rate is discussed in terms of liquid parameters.

1. Introduction

Research on cavitation erosion in liquid metal is very important to confirm the safety of fast breeder reactor using sodium coolant and to understand cavitation erosion of spallation in the liquid-mercury target of a neutron source [1].

Thiruvengadam et al. examined the temperature dependence of the erosion rate of pure titanium [2] and of SUS316 [3] in sodium using a vibratory test apparatus. They reported that the erosion rate has a maximum at 750 °F for pure titanium, and that the erosion rate for SUS316 decreases with increasing temperature. But, they only used the terminal erosion rate of the last stage. Since terminal erosion rates are optional in the ASTM (American Society for Testing and Materials) standard, it has the disadvantage of not comparing well with other test results.

Garcia and Hammitt [4] carried out vibratory cavitation erosion test of SUS304 in water, mercury, lithium, and lead–bismuth alloy. So, they referred to the sodium data by Thiruvengadam, and reported that the erosion rate in sodium at 260 °C is about nine times larger than in water of 18 °C. Moreover, they [4] found that heat-transfer controlled collapse in a liquid metal occurs only near the boiling point and inertia controlled collapse occurs at temperatures below the boiling point.

Young and Johnston [5] carried out vibratory cavitation erosion tests of a cobalt alloy (L-605) in sodium at various pressures and temperatures. They found that the erosion rate increased with increasing pressure, and they obtained a dome-shaped curve as a function of temperature. However, a detailed study on the temperature effect has not yet been performed.

In our study, a cavitation erosion test apparatus was developed to carry out erosion tests in low-temperature liquid metals. Cavitation erosion tests were carried out in liquid lead–bismuth alloy and deionized water. We discuss the effect of liquid parameters and temperature effects on the erosion rate.

2. Test material and experimental procedures

2.1. Test material and test apparatus

A low melting point lead–bismuth alloy and deionized water were used as test liquids. The chemical composition and the physical and mechanical properties of the lead–bismuth alloy are listed in Tables 1 and 2, respectively. By addition of Sn and Cd, the melting point of a lead–bismuth alloy can be widely changed from 47 °C to 180 °C. The lead–bismuth alloy used here included Sn 13.3% and Cd 10%. The melting point was measured as an average temperature of the plateau in the heat analysis curve and found to be 68.4 °C. The boiling point was obtained from a heat mass measurement. The data from density to coefficient of linear expansion in Table 1 were supplied by the metal manufacturer.

The chemical composition and the physical and mechanical properties of the test specimen are listed in Tables 3 and 4, respec-

* Corresponding author. Tel.: +81 776 27 8546; fax: +81 776 27 8546.
E-mail address: hattori@mech.fukui-u.ac.jp (S. Hattori).

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Table 1
Chemical composition of lead–bismuth alloy mass %

	Pb–Bi
Bi	50
Pb	26.7
Sn	13.3
Cd	10

Table 2
Physical and mechanical properties of lead–bismuth alloy

Freezing point (°C)	68.4
Boiling point (°C)	460
Density at 20 °C (g/cm^3)	9.38
Tensile strength at 20 °C (g/cm^2)	421
Brinell hardness at 20 °C	9.20
Conductance at 20 °C (% pure copper)	4.00
Specific heat (fluid) (cal/(g °C))	0.04
Specific heat (vapor) (cal/(g °C))	0.04
Fusion linear thermal (cal/(g °C))	6.67
Coefficient of linear expansion	0.22×10^{-5}

Table 3
Chemical composition of test material mass %

	SUS304
C	0.05
Si	0.33
Mn	1.76
P	0.36
S	0.22
Ni	8.49
Cr	18.18

tively. Since SUS304 stainless steel is used for pipes of sodium in a fast breeder reactor, SUS304 was used as test specimen in this study. The Brinell hardness was measured in this study, and the Vickers hardness was obtained using a conversion table based on SAE J417b [6].

Fig. 1 shows the vibratory test apparatus for liquid metals which we developed for our study. The test apparatus consists of a vibratory apparatus specified in the ASTM G32-98 standard [7] and a liquid metal reservoir kept at constant temperature. A copper pipe with cooling water was wound around the vibration horn in order to avoid heat conduction from the test liquid. The reservoir was a stainless steel beaker of 0.8 L surrounded by a mantle heater of 300 W. The temperature of the test liquid was measured by a thermo couple in the beaker, and kept constant by ON–OFF control of a heater. However, the liquid temperature continued to increase with the test duration after the liquid temperature reached a predetermined value. This was caused by the vibration energy of the oscillator which transformed into heat energy. Therefore, the test liquid needed to be cooled with the copper pipe immersed in the test liquid to keep the temperature constant. Cooling water circulated when an electromagnetic valve was opened and thus the liquid temperature was controlled.

2.2. Experimental procedure

Cavitation erosion tests were carried out in a vibratory specimen method using the developed apparatus. The exposed area

Table 4
Mechanical properties of test material

Tensile strength (MPa)	672
HB	180
HV	189

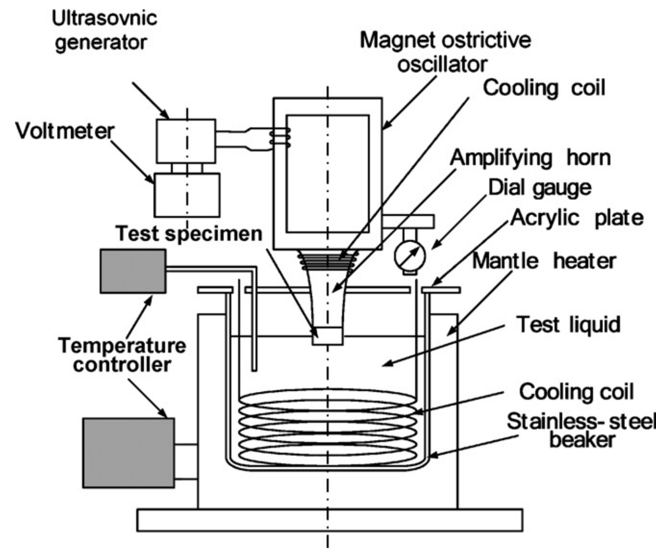

Fig. 1. Vibratory apparatus.

of 201 mm^2 corresponds to a circular test specimen area with a diameter of 16 mm. The facility was operated at a frequency of 19.5 kHz and a double amplitude of 50 μm. Liquid lead–bismuth alloy was used and its temperature was kept at 75 °C, 100 °C and 150 °C. The test temperature of deionized water was kept at 10 °C, 25 °C and 40 °C. The immersion depth of the specimen test surface was 5 mm at every temperature. Test specimen in liquid metal was removed after every time interval and washed in boiled deionized water. Then, the specimen was washed in acetone with an ultrasonic cleaner and the erosion mass was measured with a precision balance having a sensitivity of 0.01 mg. The cavitation erosion was evaluated in terms of mass loss and MDER (mean depth of erosion rate) of the test specimen. The MDER was defined as the mass loss divided by the material density, the eroded area and the exposure time interval.

3. Experimental results and discussion

3.1. Cavitation test results

Fig. 2 shows the mass loss curves in the lead–bismuth alloy and deionized water at each temperature. The mass loss passes through an incubation period (of low mass loss) and then increases linearly

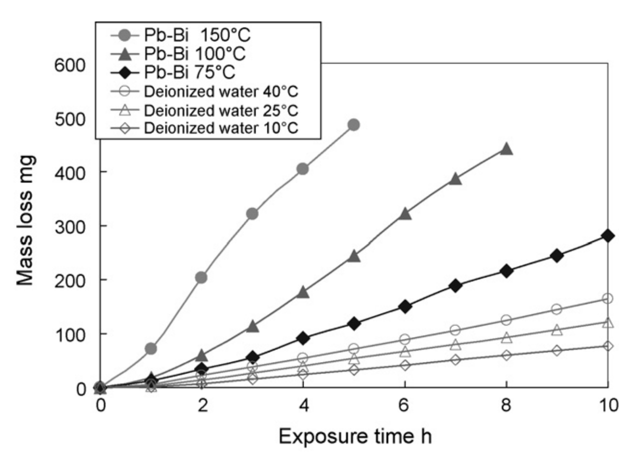

Fig. 2. Mass loss curves.