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# Effects of materials and solution temperatures on cavitation erosion of pure titanium and titanium alloy in seawater

Hiromi Mochizuki [a,1], Motohiro Yokota [b], Shuji Hattori [c,*]

[a] T/V Shinyo-maru III, National University Corporation, Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato-ku, Tokyo 108-8477, Japan

[b] Department of Ocean Mechanical Engineering, Independent Administrative Institution, National Fisheries University, 7-1 Nagatahonmachi 2-Chome, Shimonoseki 769-659, Japan

[c] Department of Mechanical Engineering, Faculty of Engineering, National University Corporation, Fukui University, 9-1 Bunkyo 3-Chome, Fukui 910-8507, Japan

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**Abstract**

Cavitation erosion was studied for various pure titanium and titanium alloy samples using a rotating disk method in seawater at 303, 318, and 333 K. Their respective erosion resistances were evaluated in terms of Vickers hardness (HV). The resistance increased in order with increasing hardness: pure titanium samples of first, second, and third types, and titanium alloy (Ti–6Al–4V). The relative temperature was defined as 273 K for freezing temperature and 373 K for boiling temperature under pressurized water. The volume loss rate of test specimens increased with rising seawater temperature of 289–316 K of the relative temperature, as well as in cases using cavitating liquid jet and vibratory apparatuses.


*Keywords:* Cavitation erosion; Hardness; Pure titanium; Titanium alloy; Seawater; Temperature; Rotating disk method; Volume loss curve; Volume loss rate curve; SEM

## 1. Introduction

Cavitation generation in fluid is a main cause of the failure of pipe, valve, and hydraulic machinery. Corrosion and cavitation erosion increases damage remarkably to seawater pumps that are used for cooling shipboard machinery. Such damage engenders problems for long-time operation. Therefore, it is planned to apply highly corrosion-resistant pure titanium to pump materials [1]. Toward that end, it is extremely important to clarify cavitation erosion resistance for pure titanium and thereby improve quality and endurance of machinery under a corrosive seawater environment.

One of the authors [2] studied the cavitation erosion resistance of pure titanium and titanium alloy using a vibratory apparatus in ion exchanged water. The crystal structure of Ti–6Al–4V titanium alloy is $\alpha + \beta$ type. Material removal occurs at $\beta$ phase (bcc), where the strength is lower than that of $\alpha$ phase (hcp), when the material was exposed to cavitation. However, the stress concentration is small, even if the $\beta$ phase is removed, because the microstructure is smaller than that of cast iron. Therefore, we reported that the cavitation erosion resistance of the titanium alloy could be evaluated in terms of Vickers hardness HV. Collectively, the authors [3] reported that erosion resistance of pure titanium and titanium alloy in seawater also is evaluated in terms of $HV^2/E$ ($E$: elastic modulus) using a cavitating liquid jet apparatus.

In addition, the effects on cavitation damage of cavitation number, velocity, viscosity, surface tension, pressure, acoustic impedance, the degree of air inclusion, etc., have been clarified for different fluid parameters [4]. Furthermore, one of the authors [5] has clarified the effects of temperature; cavitation intensity strengthens most at a temperature that is intermediate of the freezing and boiling points considering the downstream pressure by the cavitating jet method.

* Corresponding author.
*E-mail addresses:* motizuki@s.kaiyodai.ac.jp (H. Mochizuki), yokota@fish-u.ac.jp (M. Yokota), hattori@mech.fukui-u.ac.jp (S. Hattori).
[1] Tel.: +81 90 3022 7273; fax: +81 90 3022 7274.

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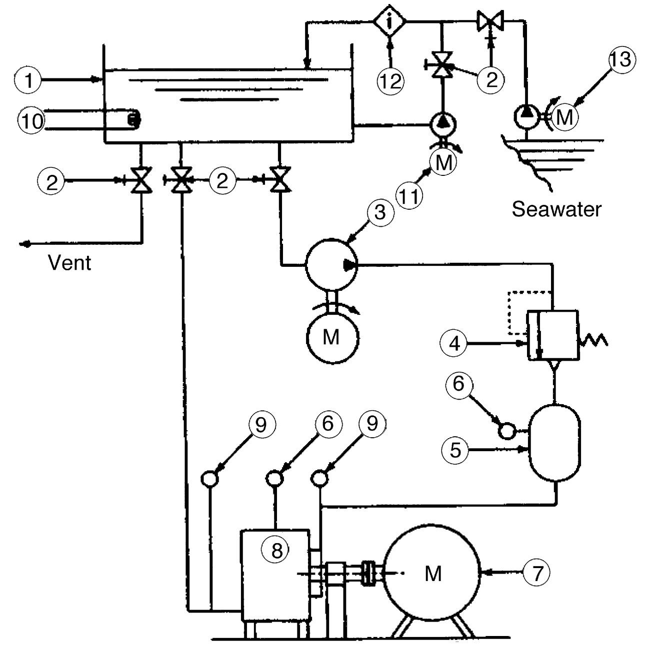


Fig. 1. Schematic diagram of flow loop. (1) Tank (4 $m^3$); (2) globe valve; (3) feed pump (0.8 kW); (4) relief valve; (5) accumulator (0.02 $m^3$); (6) pressure gauge; (7) variable speed motor (17 kW); (8) test section; (9) thermometer; (10) heater; (11) circulating pump (0.4 kW); (12) filter (5 μm); (13) supply pump.

This study performed erosion tests for pure titanium samples of first (TB270H, equivalent to ASTM G-1), second (TB340H, equivalent to ASTM G-2), and third types (TB480H, equivalent to ASTM G-3), and titanium alloy (Ti–6Al–4V) at 303 K in seawater. The respective erosion resistances were examined using a rotating disk apparatus that generates vortex and cloud cavitation, which engenders damage in the case of actual hydraulic machinery [6]. In addition, the effects of seawater temperatures at 303, 318 and 333 K were evaluated experimentally for cavitation damage quantities using titanium samples of the second type.

## 2. Experimental apparatus and procedure

Fig. 1 shows the flow loop. Test seawater in tank (1), whose volume is 2.2 $m^3$, has a heat exchanger to maintain temperature constant flows into test section (8) through four 12 mm diameter holes using the feed pump (3). Pressure in test section (8), in which a disk rotates at 4750 rpm, is maintained at 0.225 MPa by a relief valve (4). The seawater circulates into the tank constantly at 20 l/min. The chamber has eight sets of stilling vanes spaced 15 mm at equiangular distances on both sides of the disk. They prevent water circulation. The test seawater salinity was 3.5%. It was changed every 5–20 h to prevent effects of pollution and temperature change. The seawater in the tank underwent circulation filtration through a 5 μm mesh filter (12). Notwithstanding, the outlet temperature increased about 8 K from the inlet temperature. To prevent corrosive effects of material as much as possible, the test water line was made of polytetrafluoro ethylene; valves and connecting parts were made from stainless steel and brass.

Fig. 2 shows a schematic diagram of the test section. Galvanic corrosion [7] of test specimens and rotating disk does not increase the test specimens' volume loss. Therefore, we produced a pure titanium (TP49H) disk. The rotating disk had 222 mm diameter and 10 mm thickness. It had two 10.5 mm diameter through-holes to induce cavitation and two test specimens placed at opposite sides (Fig. 3).

The cavitation number $\sigma$ of such a rotating disk is defined in terms of static pressure $p_{\rm d}$ measured in the test section (0.225 MPa) and peripheral velocity at the center of the inducer holes $U$ (44.7 m/s), as in the following equation:

$$\sigma = \frac{2(p_{\rm d} - p_{\rm v})}{\rho U^2} \tag{1}$$

where $p_{\rm v}$ is the saturation vapor pressure of seawater; it is less than 2% that of fresh water [8]. Seawater temperatures had mean temperature of entrance and exit. Furthermore, $\rho$ is the density of seawater of 2.5% higher value from that of fresh water at 318 and 333 K.

Values of $\sigma$ in the following experiments were 0.212 (303 K), 0.208 (318 K), and 0.199 (333 K) under developed cavitation condition and $\sigma$ remained almost unchanged. All available physical and mechanical properties and chemical components of test specimens are presented in Tables 1 and 2. The specimens were titanium of first (TB270H), second (TB340H), and third types (TB480H), and titanium alloy (Ti–6Al–4V). The specimens had

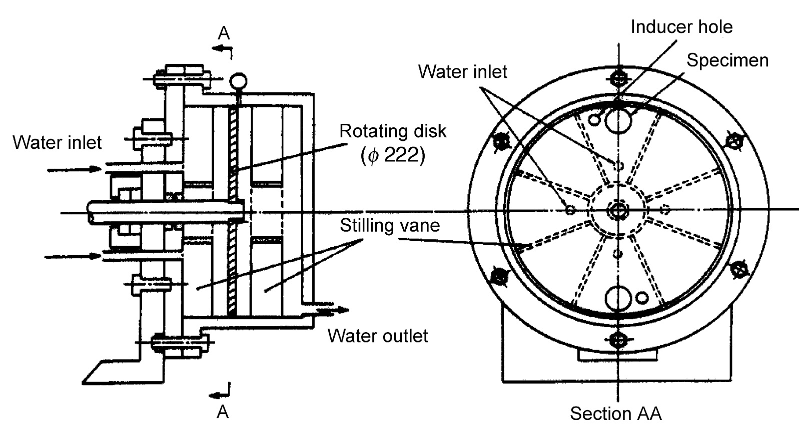


Fig. 2. Schematic diagram of the test section.