ON THE CORROSION OF TWO TYPES OF BRONZES UNDER CAVITATION

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ABSTRACT

This article contains the results of the experiments concerning the mass loss of two types of bronze in seawater in the cavitation produced by ultrasound generated by a high-frequency generator. The mass loss models are presented for the experimental conditions when the generator worked at different powers - 80 W, 120 W, and 180 W. In all scenarios, the results show that the bronze with Sn has the highest mass loss in the cavitation field.

KEYWORDS: cavitation, bronze, mass loss, gravimetric index

1. Introduction

The phenomena related to the mechanical erosion of materials in the cavitation field are of major importance for selecting the alloys used in the naval industry. Some are copper alloys employed for building propellers, bilge systems, ballast installation, and other connection pieces that work in cavitation conditions. Due to the necessity of materials with high resistance to corrosion in this industry, different authors analysed the behavior of some copper alloys in seawater [1-3], while only a few investigated their behavior under cavitation and studied the corrosion type [4-5]. Ivanov [6] showed that some bronzes with Sn have gravimetric index 0.004 -0.015 g/m^2h^{-1} at a concentration of 0.19% (at 15 ºC) and have high corrosion resistance in seawater vapors at high pressure. The same study [6] emphasized that the resistance of bronzes with Al and Ni can be nine times bigger than that of the bronzes with Sn, depending on the percentages of Al and Ni. Adding Ni in a bronze containing Al and Fe increases its mechanical resistance, resistance to cavitation, and corrosion in conditions of fatigue stress is four times greater than for the bronzes with Mn.

In this article, we present the results of the experiments concerning the mass loss of two types of bronzes in seawater under cavitation, using an experimental setup built by us [7]. The equations of the mass loss in time are determined, and the gravimetric indices are provided for comparing the materials' resistance to corrosion.

2. Materials and methods

The studied materials are two bronzes, with the following composition:
• A bronze with 83.09% Cu, 6.4% Sn, 4.40% Pb, 4.07% Zn, called in the following Bronze 1;
• A bronze with 80.54% Cu, 9.85% Al, 4.59% Fe, 4.40% Ni, called in the following Bronze 2.

These materials have been chosen because they are used for elements of ships working under pressure and cavitation, as pipes, fittings, joining components, and propellers.

Bronze 1 belongs to the class of the bronzes with Sn, Zn, and Pb, while Bronze 2 is a bronze with Al and Ni.

The composition of the seawater used for all the experiments is the following: salinity: 22.17 g/L NaCl, 0.31 g/L, pH = 7, 6.27 meq/L - total water hardness, 0.051 mg/L Fe, 0.0033 mg/L Ni.

The experimental setup used for studying the mass loss in the cavitation field is presented in Fig.1 [7-10]. It is mainly formed by the tank where the studied liquid is introduced (1); the high frequency (20 Hz) generator (8); a ceramic transducer (7) that is excited by the generator; a pair of copper electrodes (13), with the role of collecting the electrical signals produced during the periods when the generator works; a cooling fan (11) utilized for preserving a constant temperature (in this case 20 ºC) of the liquid during the experiment (given that the cavitation is an exogenous process); the command block (12) used for selecting different powers for the generator regime (80 W, 120 W, or 180 W).

The samples were kept in saline water under cavitation produced by ultrasound for a total of 1320

minutes (380 minutes at 80 W, 480 minutes at 120 W, and 480 minutes at 180 W of the generator power) and weighted every 20 minutes.
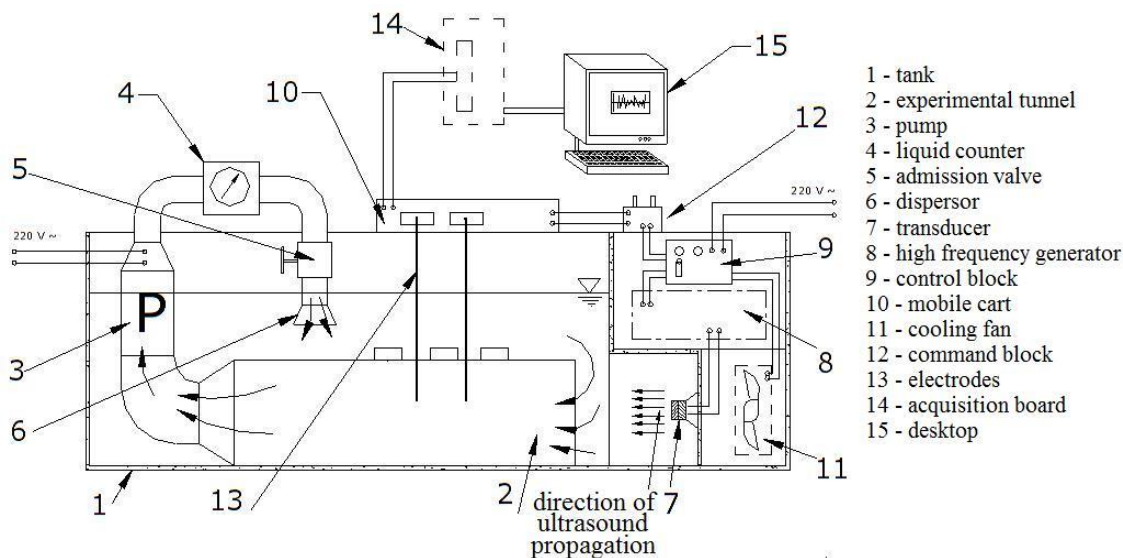

1 - tank
2 - experimental tunnel
3 - pump
4 - liquid counter
5 - admission valve
6 - dispersor
7 - transducer
8 - high frequency generator
9 - control block
10 - mobile cart
11 - cooling fan
12 - command block
13 - electrodes
14 - acquisition board
15 - desktop

Fig. 1. The experimental setup

The mass loss trend of each material at each power level has been determined and validated by statistical methods. The determination coefficients (R^2) and the residuals' standard deviation (s) are reported. An R^2 close to 1 and a residual standard deviation close to zero indicate a good fit.

The Kolmogorov-Smirnov, the portmanteau, and the Levene tests [11] have been performed for testing that the residual forms a Gaussian white noise. The tests have been performed at a significance level of 5%.

To determine if the mass loss series at the three-power level come from the same distribution, the Kruskal-Wallis test [12] has been performed. If the null hypothesis was rejected, the non-parametric Wilconxon test [13] has been performed to test the same hypothesis for pairs of series.

To quantitatively appreciate the corrosion-erosion, the absolute mass variation on the surface (S) and the gravimetric indexes (mass loss in time and per surface) have been determined.

3. Results and discussion

Let us denote by:
- t - the time,
- m_t - the sample mass at the moment t,
- R^2 - the determination coefficient,
- s - the residual standard deviation,
- S - the total surface of a sample.

Figures 2 (a)-(c) (Figure 3 (a)-(c)) show the mass evolution of the sample of Bronze 1 (Bronze 2)

at each power level of the generator. Figure 2 (d) (Figure 3 (d)) shows the overall evolution of the mass of the same sample.

For Bronze 1, the equations of the mass variation are polynomial of the second degree, when the generator worked at 80 W and 120 W, while when working at 180 W is, the polynomial is of the third order. In all cases, R^2 (Fig. 2 (a)-(c)) is above 0.92, and the residual standard deviations are lower than 0.0002, indicating a good fit of the recorded values. Residuals' analysis shows all the residuals in the models form a white noise.

Kruskal - Wallis and the Wilconxon tests rejected the null hypotheses, so one cannot find enough evidence that there is no difference between the time series. Hence, the corrosion trend depends on the generator's power.

For Bronze 2, the mass loss is described by third-degree polynomials at 80 W and 180 W and a second-degree polynomial at 120 W. The corresponding R^2 are higher for Bronze 2 than for Bronze 1, with the residuals standard deviations less than 0.00007. The residuals in the models form white noises. Again, the null hypotheses have been rejected by Kruskal - Wallis and the Wilconxon tests, confirming that the generator's power influences the mass loss.

The studied samples mass variation during the experiments is:
• for Bronze 1:

$$m_t = 17.244908 - 5.075136 \cdot 10^{-6} t + 1.887143 \cdot 10^{-10} t^2, \tag{1}$$

with a standard deviation s s =0.00019783 and R^2 = 0.9911;

- for Bronze 2:

$$m_t = 23.445849 - 8.922002 \cdot 10^{-6} t + 2.798266 \cdot 10^{-10} t^2, \tag{2}$$

with s = 0.000228 and R^2 = 0.9904.

To determine the material with the best behavior in cavitation conditions, the absolute mass variation per surface [in g/m^2] has been computed, using the formula:

$$\Delta m_t / S = (m_1 - m_t)/S \tag{3}$$

where S is the surface of the sample, m_1 is the sample mass at the beginning of the experiment, and m_t is the mass of the sample at the moment t.
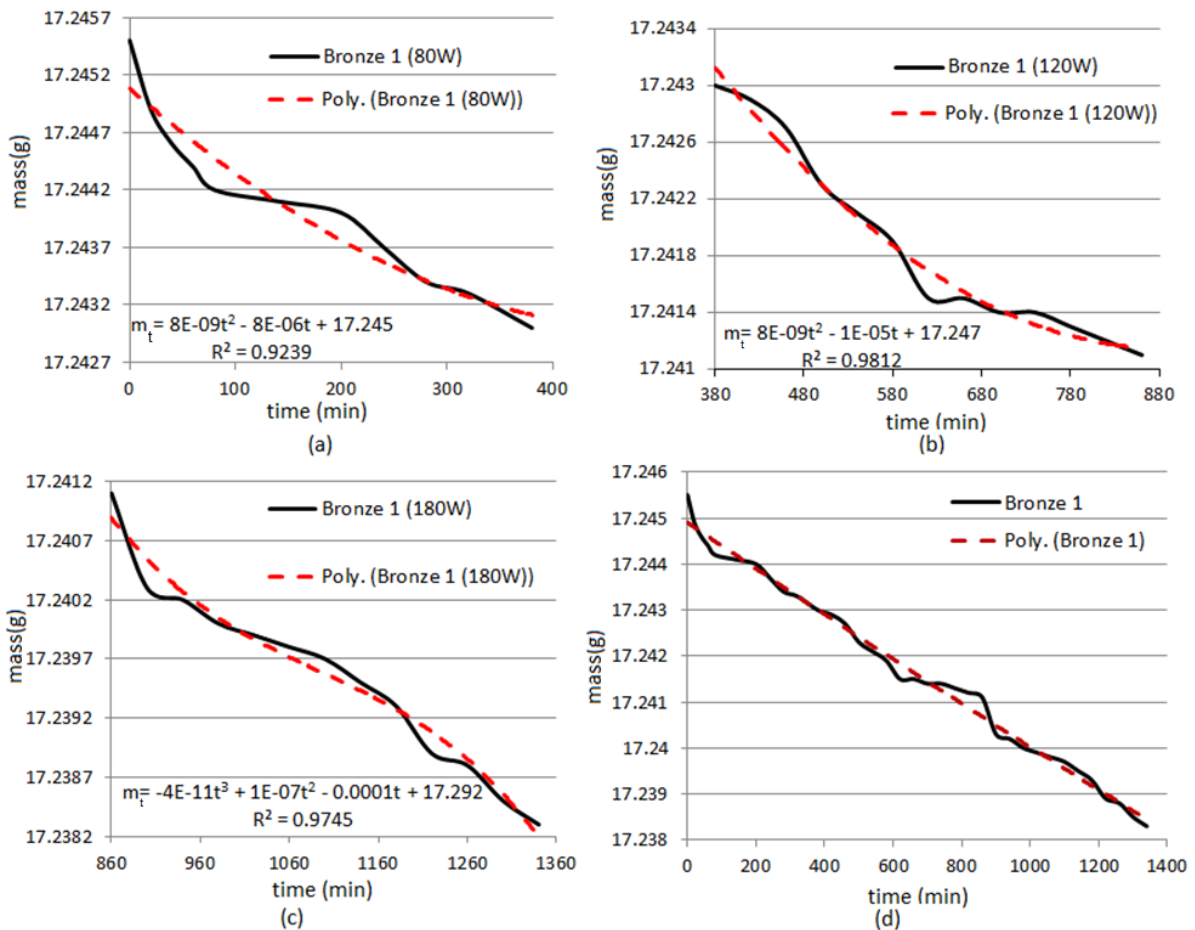

Fig. 2. *The mass variation of Bronze 1: (a) at 80 W, (b) at 120 W, (c) at 180 W, (d) during the entire experiment. The continuous line represents the recorded data, and the dotted ones the fitted trend*

The charts of mass variation per surface for both materials are presented in Fig. 4. The continuous curves represent the data series, whereas the dotted ones are the fitted trends. Remark that Bronze 2 experiences the highest values compared to Bronze 2, significantly higher at the third power level. All the models fitted for the series trends have R^2 greater than 0.97.

The trend equations for the total variation of the mass in time per surface are respectively:

- for Bronze 1:

$$\Delta m_t / S = 0.0758 + 0.1237t - 0.0003t^2, \tag{4}$$

with $s = 0.11308$ and $R^2 = 0.9933$, and

 - for Bronze 2:

$$\Delta m_t / S = 0.1609 + 0.1513t - 0.0019t^2, \quad (5)$$

with: $s = 0.0894$ and $R^2 = 0.9908$.

Finally, the gravimetric indices have been computed in all scenarios, based on the data from Fig. 4. They are presented in Table 1.
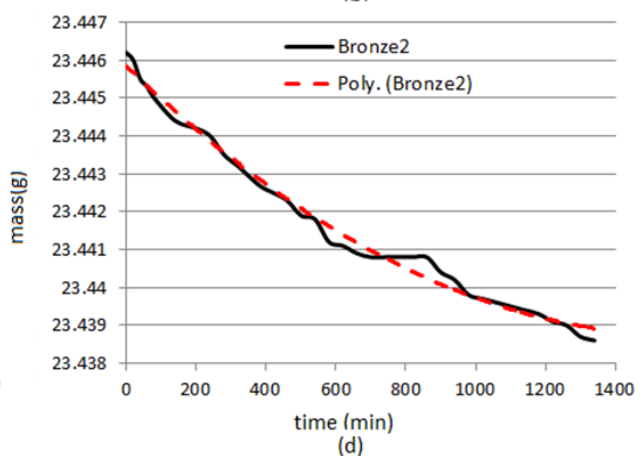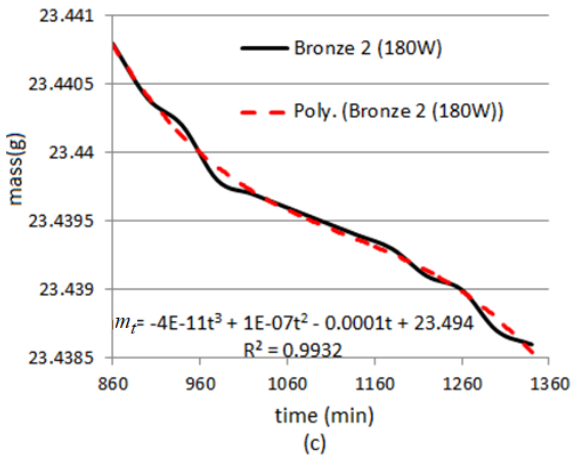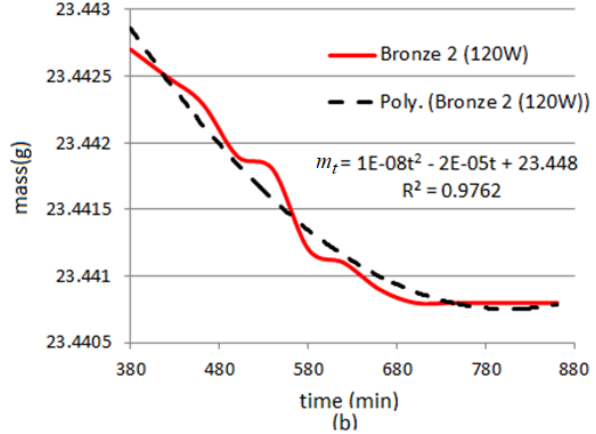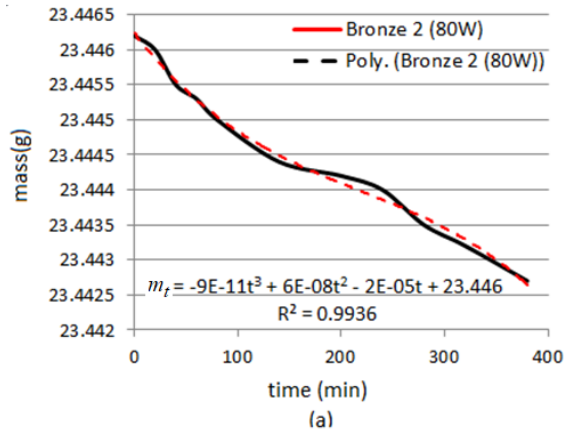

Fig. 3. *The mass variation of Bronze 2: (a) at 80 W, (b) at 120 W, (c) at 180 W, (d) during the entire experiment. The continuous line represents the recorded data, and the dotted ones, the fitted trend*

Table 1. *The gravimetric indices [g/m²h]*

Power [W]	Bronze 1	Bronze 2
80	0.2256	0.2166
120	0.1357	0.0931
180	0.2000	0.1078

The highest gravimetric index is that of Bronze 1, in the first scenario, while the lowest is that of Bronze 2, at 120 W. Unexpectedly, the highest gravimetric index was obtained at 80 W for both bronzes and the lowest for the second one.
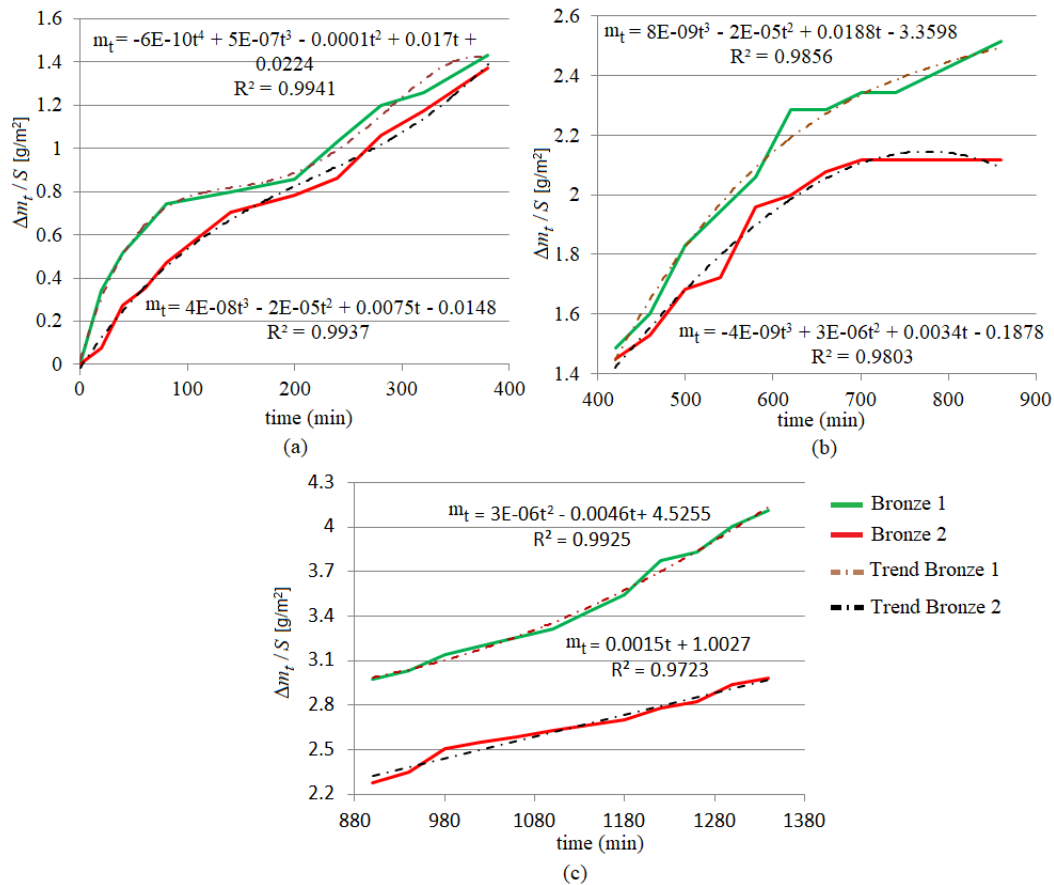
Fig. 4. *The variations in time of absolute mass per surface at: (a) 80 W, (b) 120 W and (c) 180 W*

4. Conclusion

The experiments of mass loss in ultrasound cavitation field proved that bronze with Sn has a lower resistance than that with Al. The gravimetric indices show the highest mass loss at the first stage of the generator. The study show that the corrosion speed is higher than in freshwater [10] due to the accentuated chemical corrosion that appears due to the salt content.

For future, it would be interesting to study the mass loss of the same materials in circulating liquids given the importance of these materials for the naval constructions.

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