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Roughness and microstructure of the AMPCO 45 complex alloyed bronze eroded through cavitation

O.V. Oanca [a,b,*], I. Bordeasu [a], I. Mitelea [a], C.M. Craciunescu [a]

[a] Faculty of Mechanics, University "Politehnica" Timisoara, Romania

[b] National Research and Development Institute for Welding and Material Testing - ISIM Timişoara, Romania

* Corresponding e-mail address: octavian.oanca@yahoo.com

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ABSTRACT

Purpose: Paper analyses the influence between the ultrasonic cavitation erosion and the surface roughness of the complex alloyed bronze AMPCO 45 in two states: extruded and heat treated (quenched) and afterward hardened through dispersion.

Design/methodology/approach: The cavitation erosion was obtained in a laboratory facility which respects integrally the indication of the ASTM G-32 Standard. Roughens profile measurements of the eroded surfaces were done with the Mitutoyo device.

Findings: Supplementary, were realized scan electronic microscopy which show that the cavitation erosion begins at the interface of the two structural constituents and ends with grains expulsion from the α solid solution.

Research limitations/implications: Research carried out in the Cavitation Laboratory of University Politehnica Timişoara, on naval brasses and bronzes type CuNi showed a good resistance to cavitation erosion, which can be substantially improved by various treatments.

Originality/value: New researches by cavitation erosion are geared towards the development of new materials for construction of marine propellers, such as complex bronze alloys because of high mechanical properties obtained by applying such heat treatments.

Keywords: Cavitation erosion; Roughness; Microstructure; Complex alloyed bronze

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MATERIALS

1. Introduction

Cavitation erosion is present in all areas where fluid pressure falls below the value of saturated vapours and is due to concentration of generated mechanical energy on very small areas, from impacting the material with shock waves and micro-jets produced by the implosion of vapour bubbles. This concentration of energy causes high levels of mechanical stress that, in general, exceed the fatigue limit, yield strength and even tensile strength of all known current technique materials [1,2,3].

Research carried out in the Cavitation Laboratory of University Politehnica Timişoara, on naval brasses and bronzes type CuNi showed a good resistance to cavitation erosion, which can be substantially improved by various treatments. New researches by cavitation erosion are geared towards the development of new materials for construction of marine propellers, such as complex bronze alloys because of high mechanical properties obtained by applying such heat treatments. Active applications of ultrasounds, along with techniques for joining [4,5] is the most effective method to investigate the behaviour of materials under cavitation phenomena [10].

This paper deals with the establishment of a correlation between ultrasonic cavitation erosion resistance and surface roughness of a complex bronze alloy, which is either in a state of plastic deformation or subjected to heat treatment followed by dispersion quenching hardening. The heat treatment applied highlights a large increase in HV3 hardness, with 20.64%, in comparison to fresh material delivered. According to theories by Garcia and Hammitt [6], regarding the correlation between hardness and resistance to cavitation erosion significant changes occur referring to surface roughness resulted from exposure to cavitation attack compared to the heat treated material and fresh material supplied respectively on the average depth of erosion by cavitation.

2. Researched material and applied thermal treatment

The test material is a bronze CuNiAlFeMn commercially known as AMPCO45 having the chemical composition Al – 10%, Ni – 5%, Fe – 2.5%, Mn – 1%, others – 0.5% and the rest Copper and main mechanical properties of mechanical strength Rm 814 MPa, Yield strength $Rp_{0.5}$ 517 MPa, elongation A 515%, Rockwell hardness of 98 HRC, compressive strength 303 MPa, resilience 11.3 J and elasticity module E 117 GPa [11,12].

Specimens for cavitation erosion testing program, according to the standard procedure for each state (supplied and HT) were three in number. Heat treatment was carried out according to the diagram in Figure 1.

In first stage the heat treated specimens for the experimental program were investigated in terms of hardness HV3, resulting in an average of 298 HV3 respectively increased hardness compared to the delivery state, 247 HV3 with about 20.64%.

3. Ultrasound cavitation experiment results

Ultrasonic cavitation experiments were conducted with the piezo-ceramic crystal vibrating device [9], using the standard method of Cavitation Laboratory, subject to the requirements of ASTM G32-2010.

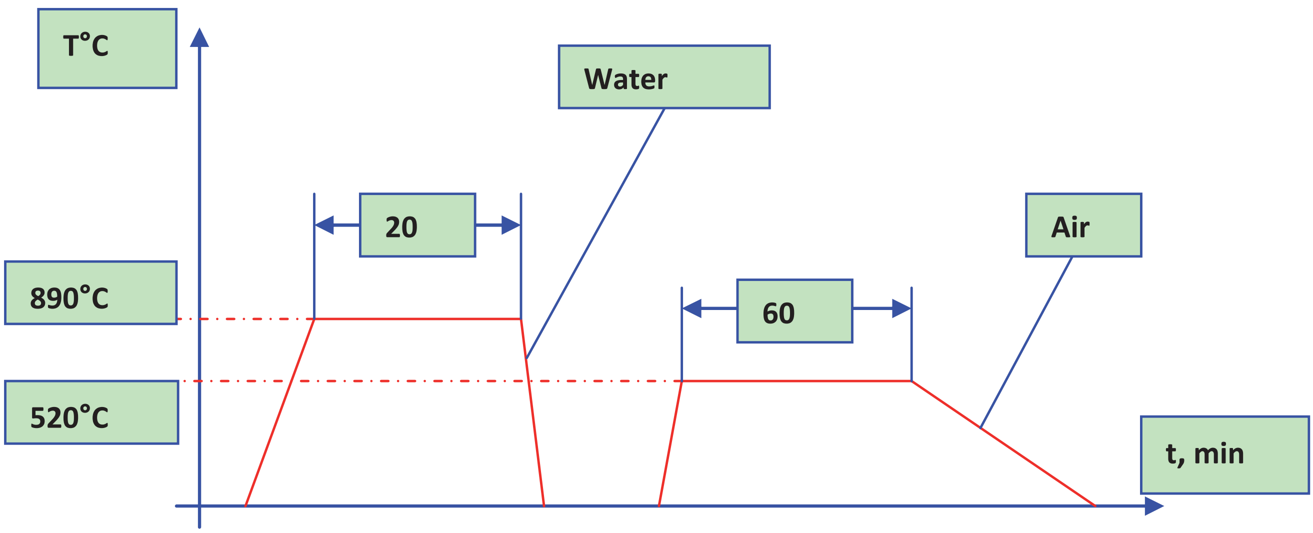


Fig. 1. AMPCO 45 thermal treatment diagram

The experiments were analysed statistically to highlight the repeatability of the results and the cavitation erosion mode [1,2]. Therefore the dispersion bands were built the maximum values were determined for the cumulative depth of erosion at test completion, data regression curves and standard error (s_{xy}). These are presented in Table 1 in comparison to fresh material and AMPCIO 45 material with heat treatment.

The low standard deviation, Table 1, below 0.4 shows that by this heat treatment structural and properties homogeneity was obtained in all exposed surface to cavitation; the erosion produced in heat treated bronze AMPCO 45 is made evenly.

From Table 1, it is observed that the heat treatment shows a very good behaviour to cavitation attack for material AMPCO 45with an average penetration depth of erosion after 165 minutes of attack of 6.208 µm, being about two times smaller than the fresh material delivered which was 12.694 µm.

3.1. Cavitation erosion characteristic parameters. Specific curves

Based on the mass loss Δm_i recorded at the end of each intermediate test period, "i", the mass losses cumulated were determined mass m, which were used to determine the average penetration depth of erosion (MDE), and its speed (MDTR) [1,2].

In Figure 2, the two curves are given specific to behaviour of AMPCO bronze 45 at erosion produced by cavitation compared to fresh material supplied curve 1, and heat treatment volume curve 2. From Figure 2a we see that the approximation is very well done the last 30 minutes of cavitation exposure. From Figure 2b there is a very good mediation made by the approximation curve in the interval 90-165 minute, similar to the approximation of Figure 2a.

The arrangement of experimental points under the approximation curve, Figure 2a, within 45-135 minutes interval shows the resistance created by the treatment applied to the surface exposed to impact and shock waves generated by cavitation bubble implosion.

The difference between the analytical curve and the experimental points of MDER parameter, in the range 15 to 175 minutes, shows the resistance acquired by the bronze and the beneficial effect of the treatment applied.

Both for the untreated alloy and as well as for the heat-treated material the evolution of approximation curve suggests a specific behaviour of materials with excellent resistance to cavitation erosion.

3.2. Phenomenological analysis of eroded microstructure

Cavitation erosion specimens were investigated with the means specific to the laboratory, optical microscopy, scanning electron microscopy SEM and EDAX spectroscopy.

The alloy investigated AMCO 45, is part of the binary Cu-Al alloys with up to 9.4% Al, having a single-phase structure, consisting of a solid solution of Al dissolved in Cu [7,8].

In industrial cooling conditions, there is an eutectic formation in the structure of bronzes with 6-8% Al. Additional alloying with Ni, Fe, Mn, etc. causes the maximum solubility of Al in Cu to decrease thus the eutectoid transformation line will be shifted to lower concentrations of Al and at lower temperatures. The existence of eutectic transformation makes this alloy to be susceptible to heat treatment hardening followed by aging by dispersion (Figure 1). During the heating phase, eutectoid $\alpha + \gamma$ phase transforms into β, and by sudden cooling transformation without diffusion is triggered to form a martensitic structure. Final operation of heating, which is annealing, causes dispersion hardening under the influence of partial decomposition of martensitic and precipitation of finely dispersed chemical combinations (Figure 3).

Table 1.
Statistical parameters values

	APCO 45 with thermal treatment	APCO 45 fresh material
Average penetration depth of erosion after exposure of 165 minutes, µm	6.208	12.694
Maximum value according to the regression curve, µm	7.366	13.966
Minimum value according to the regression curve, µm	5.05	11.422
Standard estimation error (s_{xy}), µm	0.386	0.424

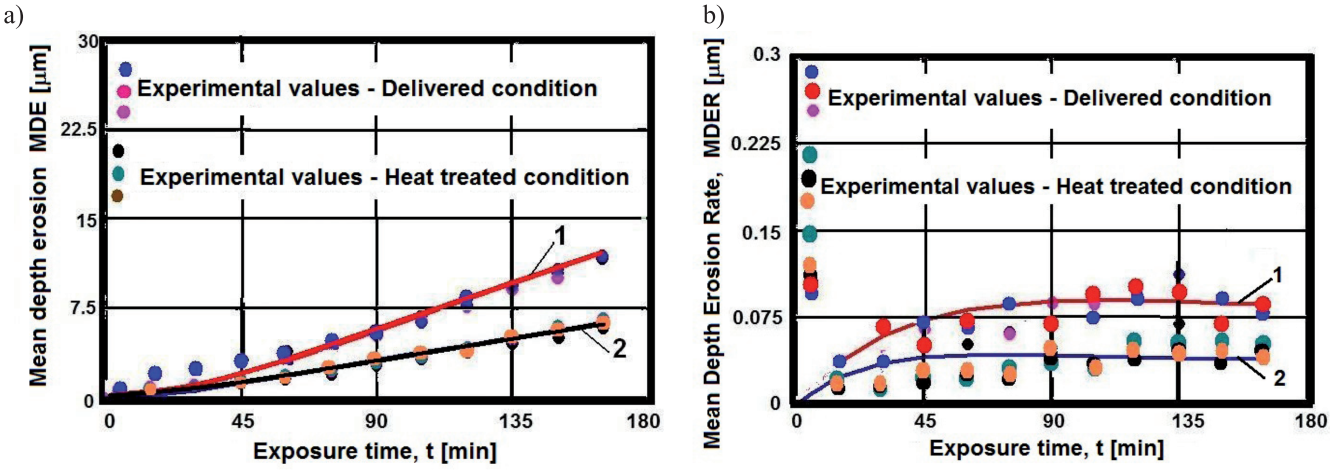


Fig. 2. Specific curves of behaviour evolution and cavitation erosion resistance: a) evolution of average erosion depth with MDE exposure duration, b) evolution of average penetration speed of erosion during MDER exposure

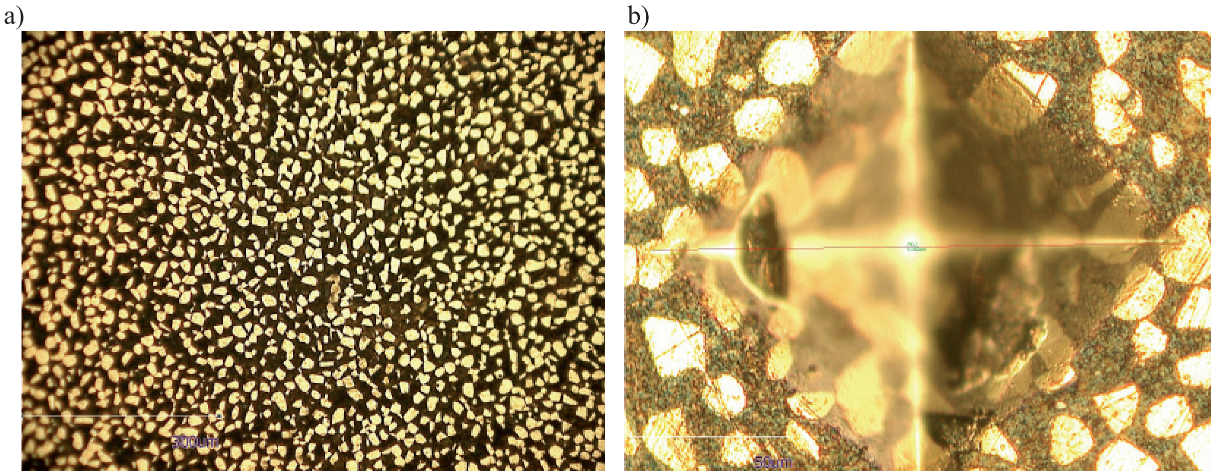


Fig. 3. Microscopic images of heat treated AMPCO 45 structure: a) X350, b) X1750

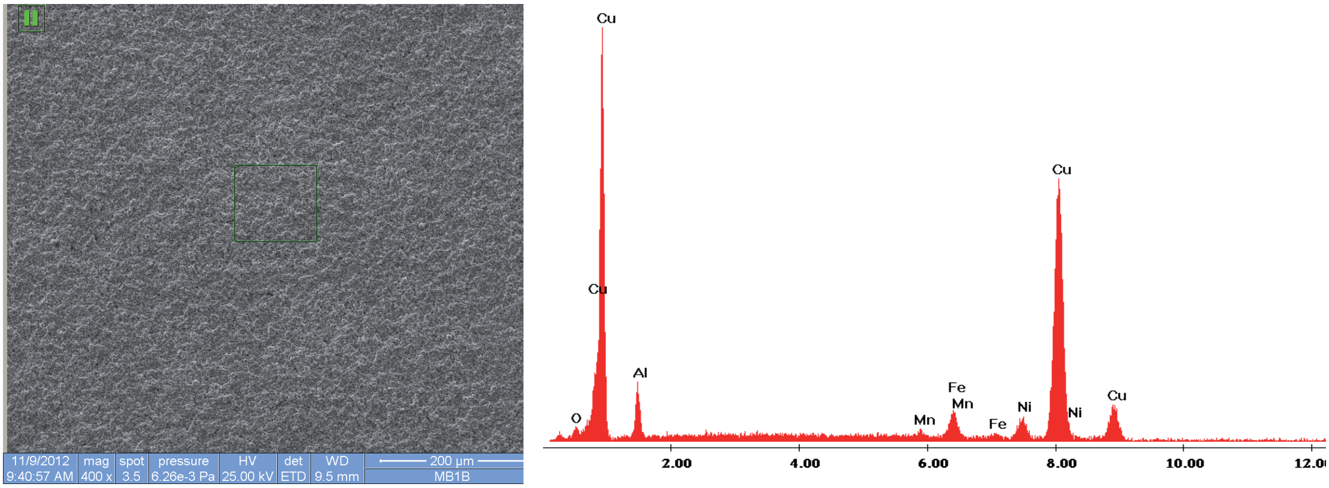
The EDAX analysis, Figure 4 reveals that only in the central area of the sample there is a slight decrease in Al concentration by 8.5%, probably explainable by pronounced expelling of its compounds phases with Cu and Fe.

4. Correlating resistance at cavitation erosion with surface roughness

The main parameter of roughness used for prescribing and evaluating surface roughness, according to SR ISO 4287 2001 is defined as average profile assessed, expressed as average absolute ordinate values Z (x) in the limits of a basic length lr, according to:

$$\int_0^{l_r} |Z(x)| \cdot dx \equiv R_a lr \quad (1)$$

where:
lr = base length in the X axis used for identifying irregularities and characterizing the roughness evaluated profile;
Z(x) = absolute value of the ordinate.



EDAX ZAF Quantification (Standardless)						
Elem	Wt %	At %	K-Ratio	Z	A	F
OK	2.44	8.09	0.0077	1.1621	0.2700	1.0026
AlK	8.50	16.69	0.0183	1.0842	0.1990	1.0000
MnK	0.96	0.92	0.0107	0.9866	0.9726	1.1599
FeK	3.86	3.66	0.0474	1.0070	0.9838	1.2385
NiK	5.38	4.86	0.0546	1.0264	0.9874	1.0000
CuK	78.86	65.78	0.7673	0.9797	0.9931	1.0000

Fig. 4. SEM microscopy and EDAX spectroscopy specimen AMPCO 45 heat treated

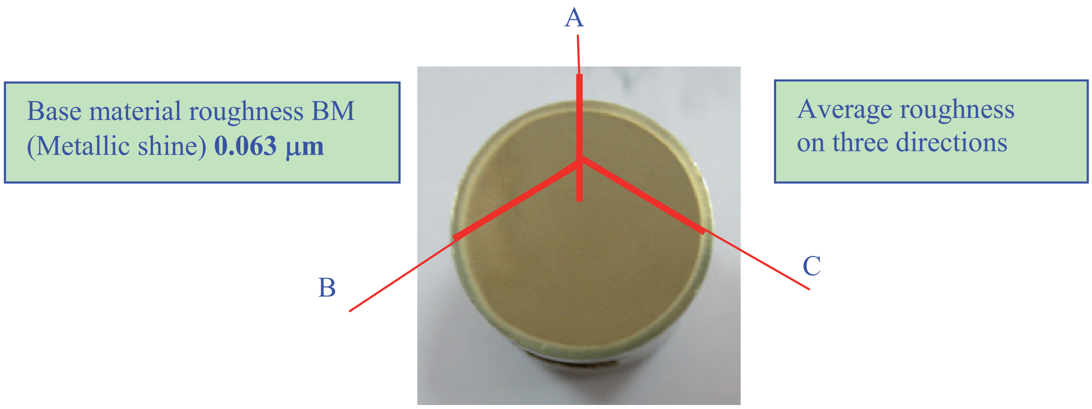


Fig. 5. Roughness measurement diagram with Mitutoyo SJ210 AMPCO45, minute 165

With the profiler device Mitutoyo SJ 210, exposed surfaces to cavitation erosion were scanned in three directions a, b, c, according to Figures 5. R_a values for investigated materials measured in three directions, based on length lr = 8 mm, and the average values are presented in Table 2.

Relation (1) expresses the arithmetic average of the absolute values of the ordinate Z(x), equivalent to the average depth of the profile scanned by the Mitutoyo SJ 210 machine, Table 2.

Using Equation 1, a correlation was made of the values obtained by measurements, of average depth sizes of cavitation erosion of materials studied (Table 2), of the average depth of erosion calculated sizes of the materials studied (Table 1) resulting from statistical analysis of the experiment.

Differences of measured values in Table 2 compared with values resulted from statistical analysis of the experiment, Table 1, are within the range of standard error of estimate (s_{xy}).

Table 2.
R_a values for investigated materials measured in three directions, based on length lr = 8 mm, and the average values

	Roughness R_a, µm Mitutoyo SJ210	MDT, µm (Table 1)
AMPCO 45 without thermal treatment $R_a lr \equiv 12.816$ µm	a 1.598	12.694
	b 1.442	
	b 1.764	
	Average R_a = 1.602	
AMPCO 45 with thermal reatment $R_a lr \equiv 6.392$ µm	a 0.908	6.208
	b 0.795	
	c 0.636	
	Average R_a = 0.779	

Low roughness values with a smooth and uniform surface degradation and lower values characterizing erosion cavitation proves the efficacy of thermal treatment applied and good correlation with the results of the experimental program.

5. Conclusions

A good correlation was made between the values obtained by measurements, the average depth of cavitation erosion of materials studied, and average depths of cavitation erosion resulting from statistical analysis of the experiment, (s_{xy}).

The heat treatment applied to the alloy AMPCO 45 causes an increase of the hardness values by approximately 20.64% that justifies the reduction of the penetration of the erosion by approximately 51%, respectively a reduction of the erosion rate by approximately 56%.

Low values of cavitation surface roughness respectively of penetration depth of the erosion and high uniformity degradation process are a consequence of the hardening by dispersion of the alloy after the heat treatment applied.

Acknowledgements

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