CAVITATION EROSION RESISTANCE OF AMPCO 45 BRONZE WITH HEAT TREATMENTS

Prof.univ.dr.ing. Ilare BORDEASU[1], Prof.univ.dr.ing. Mircea Octavian POPOVICIU[2], Prof.univ.dr.ing. Ion MITELEA[3], Asist.dr.ing. Lavinia Madalina MICU[4], Dr.ing. Octavian Victor OANCA[5], Ing. C-tin BORDEASU[6], Drd.ing.Laura Cornelia SALCIANU[7], Drd.ing. Cristian GHERA[8]

[1] "Politehnica" University of Timisoara, ilarica59@gmail.com
[2] Academy of Romanian Scientists, Timisoara Branch, mpopoviciu@gmail.com
[3] "Politehnica" University of Timisoara, ion.mitelea@upt.ro
[4] "Politehnica" University of Timisoara, lavimicu@yahoo.com
[5] "Politehnica" University of Timisoara, Octavian.oanca@yahoo.com
[6] "Politehnica" University of Timisoara, blondutzu_wild@yahoo.com
[7] "Politehnica" University of Timisoara, salcianu.laura@yahoo.com
[8] "Politehnica" University of Timisoara, cghera2000@yahoo.com

Abstract: *Cavitation erosion of ship propellers is a great inconvenient for maritime transportation. The use of proper alloys and heat treatments can increase the life of these pieces. In the paper is analyzed the effect of such a heat treatment upon the bronze AMPCO 45, used in the past especially for aircraft bearings, valve spindles and wear rings. Paper analyzes if it can be also applied for ship propellers, a field in which outside corrosion it appear also cavitation. In order to increase the hardness of this material a special heat treatment was applied. AMPCO 45 with and without heat treatment was subjected to vibratory cavitation erosion in the T2 device in the Cavitation Laboratory of Timisoara Polytechnic University. The final evaluation was realized through comparisons with the bronze CuNiAl- III RNR, used on a large scale for manufacturing ship propellers. Finally, it was demonstrated that AMPCO 45 has excellent properties from the cavitation erosion point of view.*

Keywords*: cavitation erosion, bronze, volume heat treatment, hardness, cavitation mean depth erosion, cavitation mean depth erosion rate*

1. Introduction (Arial, 11pt, Bold)

For increasing the cavitation erosion resistance frequently is used heat treatment, for the entire mass of the machine detail. This procedure increases all the mechanical characteristics and especially the hardness. On the other hand, Garcia and Hammitt [4] established that the increase of hardness is a key factor for fighting with cavitation erosion. Consequently the present paper analyzes the case of the bronze AMPCO 45. Using an appropriate heat treatment the HV3 hardness of this material was increased with 20.64%. Afterwards this material was carefully examined in the laboratory station T2 form the point of view of the resistance to cavitation and the results were compared with those of the bronze CuNiAl – III RNR a material frequently used for manufacturing ship propellers. Comparing the curves MDER(t) in the stable zone of erosions resulted that untreated AMPCO 45 is 1.8 times weaker than CuNiAl- III RNR but after the heat treatment the resistance to cavitation erosion of AMPCO 45 became 1.2 times better than CuNiAl – III RNR.

2. Researched material and applied heat treatment

The tested material is a bronze with CuNiAlFeMn with the commercial name AMPCO 45. The detailed chemical composition is [13]: Al 10%, Ni 5%, Fe 2,5 %, Mn 1,0 %, others 0.5%, balance Cu and the following mechanical properties [13]: tensile strength R_m=814 MPa, yield point 517

MPa; Rockwell hardness HRB30= 98; Fatigue limit (100,000,000 cycles) 262 MPa, Density ρ = 7,53 g/cm^3.
The detailed heat treatment is given in Fig. 1 and consists in heating at 890°C followed by cooling in water and a second heating at 520° C followed by cooling in air

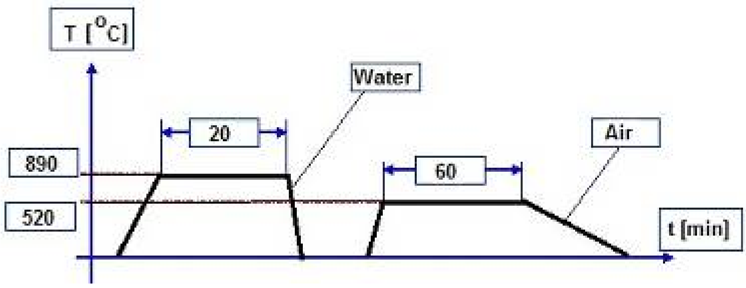


Fig.1 Heat treatment diagram

The hardness measurements after the heat treatment are presented in Table1 and show important increases in comparison with the untreated material.

Table 1 Hardness HV3

AMPCO 45 heat treated			AMPCO M45 original state		
Depth [μm]	HV3	Mean HV3	Depth [μm]	HV3	Mean HV3
161	294	298	145	265	247
159	301		148	254	
159	301		149	251	
159	301		148	254	
159	300		155	232	
158,5	300		152	241	
1161	293		152	241	
165	293		143	238	
			152	241	
			146	261	

Taking into account the mean of the measured values it results an increase of the hardness HV3 with 20.64%.

3. Cavitation erosion tests

The tests were obtained in the T2 vibratory device with piezoelectric crystal [10], [11], respecting the prescriptions of the Standard ASTM G32-2010 [8]. There were subjected to cavitation three specimens and for the characteristic curves it is used the mean value of these three specimens [1]. In Figure 2 are presented the measured values for the three tested specimens, the curve for mean values computed with the exponential equation [2], [5], [12] and its tolerance interval for a probability of 0.99. As can be seen the scatter is very small which means that the heat treated material is very homogenized. Table 2 give some numerical data.

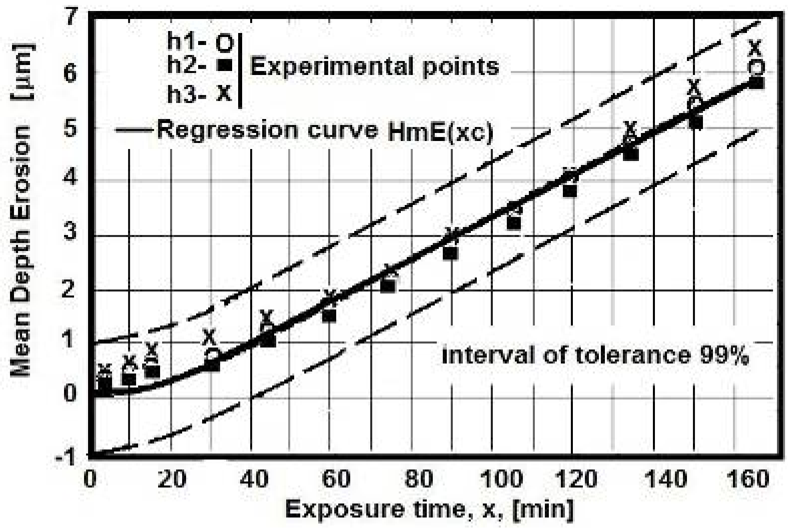


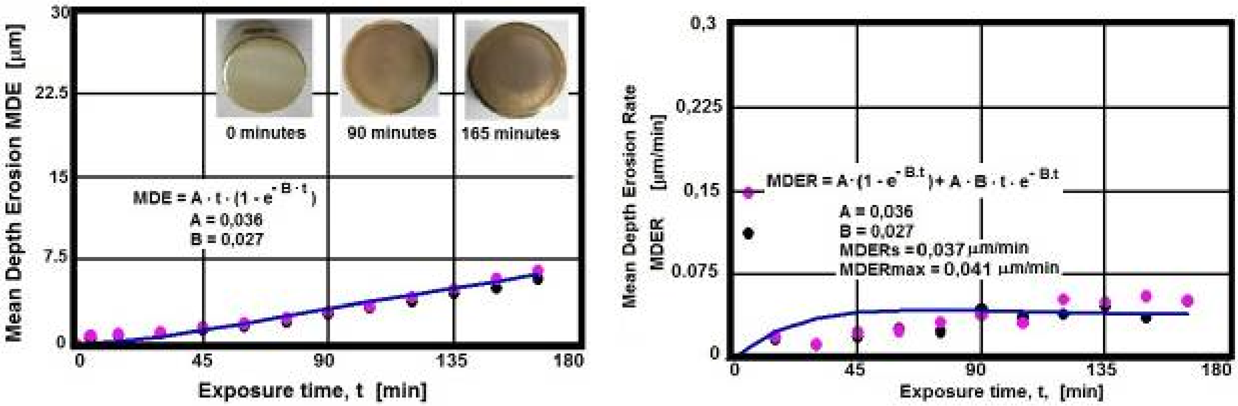
Fig. 2 Measured values, mean curve and its tolerance interval for 0.99 probability

Table 2 Values of statistic parameters after 165 minutes of exposure

Measured mean depth erosion [µm]	6,208
Maximum value from the tolerance interval [µm]	7,366
Minimum value from the tolerance interval [µm]	5,05
Standard error of estimation (s_{yx}) [µm]	±0,386

3.1. Cavitation erosion specific curves and parameters

Figure 3 present the experimental results both for mean depth erosion (MDE) and for mean depth erosion rate (MDER). The curves for the mean values are traced with the exponential equation shown in the diagrams.



a) b)

Fig.3 Cavitation erosion characteristic curves:
a) Mean depths erosion against time
b) Mean depth erosion rate against time

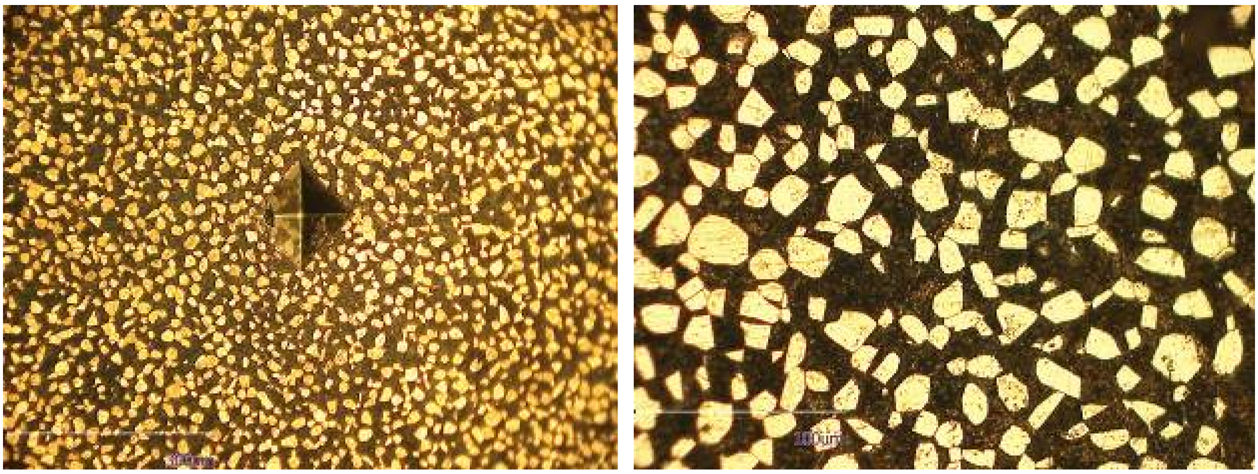
Figure 3a show a very good estimation for all measured points. From figure 3b result a good estimation only for the interval 90-165 minutes, especially the initial points show outstanding values of the erosion rate. This situation can be explained from the definition of the derivative. In the upper part of Fig. 3a there are presented also photographs of the specimen surfaces subjected to cavitation.

3.2. Experimental results analyze

The measured points scatter in Fig. 3 can be explained as follows: in the initial period, less than 10 minutes the sharp roughness crests, which are weak points, are easy eliminated and the erosion rate is very great. In the interval 45-90 minutes the destructive cavitation energy is consumed mostly to create cracks and dislocations of the material and the erosion rate is not very great [1], [3], [7]. After 90 minutes of exposure the situation is somehow stabilized the crack formation and the expelling of particles are approximate equal, the difference between the maximum erosion rate (0,041 μm/min) and the final erosion rate (0,037 μm/min) is not significant.

3.3. Investigations of the eroded microstructure

It is well known that binary Cu-Al alloy under 9.4% of Al have a single-phase structure, constituted by the solid solution α of Al dissolved in Cu. When the stability limit is exceeded, in conformity with equilibrium diagram Cu-Al [6], in the structure appear the phase β, which is a solid solution of Cu_3Al. If the aluminum content of the alloy increase it will be e constituted, at room temperature, by the phase α and the eutectoid α + γ´ (γ´ is the compound $Cu_{32}Al_{19}$).
In industrial cooling conditions, the eutectoid is formed also for bronzes with 6-8 % Al. The supplementary alloying with Ni, Fe, Mn, etc. reduce the maximum solubility of aluminum in copper and the eutectoid line will be translated to smaller concentrations in Al and to more reduced temperatures. The existence of the eutectoid transformation makes this alloy susceptible to hardening through quenching heat treatment followed by ageing through dispersion (Fig. 1). During the heating faze, the eutectoid α + γ´ is transformed in faze β, and through sudden cooling is released a transformation, without diffusion, forming a martensite structure. The final heat treatment operation, which is an ageing, determines a hardening through dispersion by the effect of partial martensite decomposition and by precipitating minute chemical combination (fig. 4). The reduced roughness (fig.5) together with a uniform and minute erosion of the area exposed to cavitation (Table 3 and Fig. 9) demonstrates the high efficiency of the applied heat treatment.
The EDX analyzes (Fig. 10-12) show that only in the central zone of the specimen occur a small reduction of the concentration in aluminum, explainable through the pronounced expelling of phases of compounds with copper and iron.
Figures 8-10 show the excavation process of the bronze structure, with caverns of various dimensions, depending on the position of eroded area.



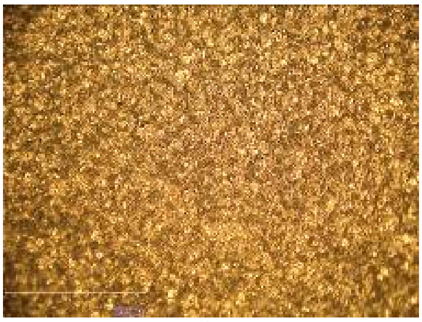
a) 350x b)1050x

Fig.4 Microscopic images of the heat treated bronze structure

Table 3 Microscopic images after different cavitation exposure (x150)

0 minutes

30 minutes



90 minutes

165 minutes

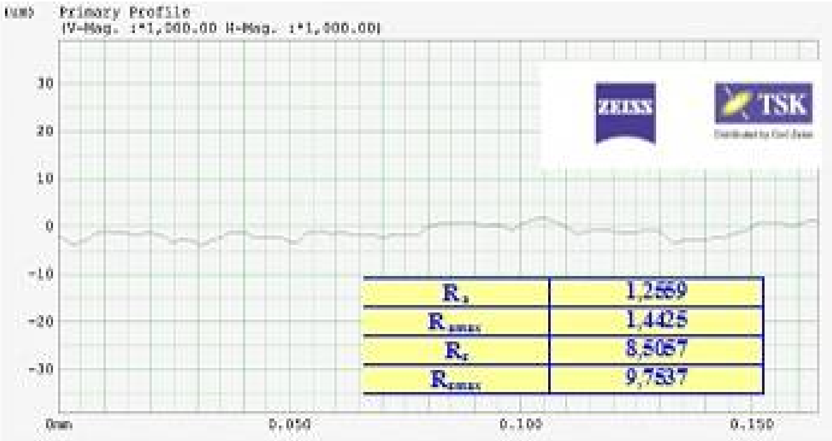


Fig.5 Measured roughness after 165 minutes of cavitation exposure - ZEISS SURF COM 2000 SD3

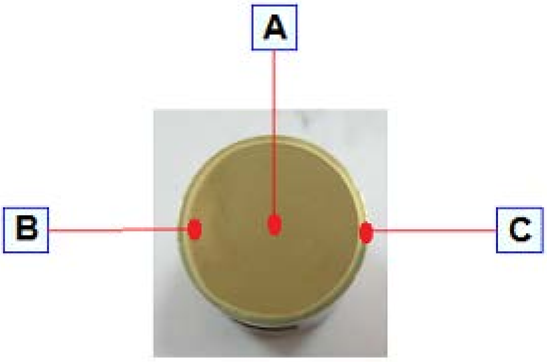
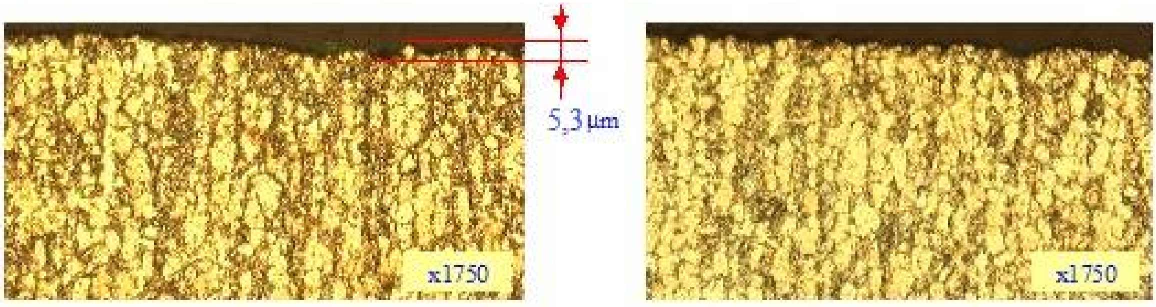


Fig. 6 The zones microscopic analyzed

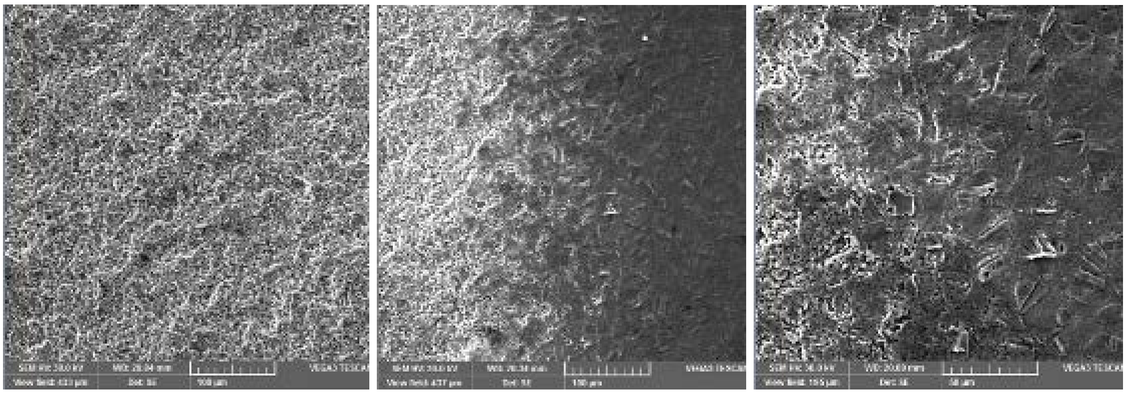


A C

Fig. 7 The cavitation eroded surface (165 minutes) - digital microscopy
A- Central zone; C – External limit of the eroded zone

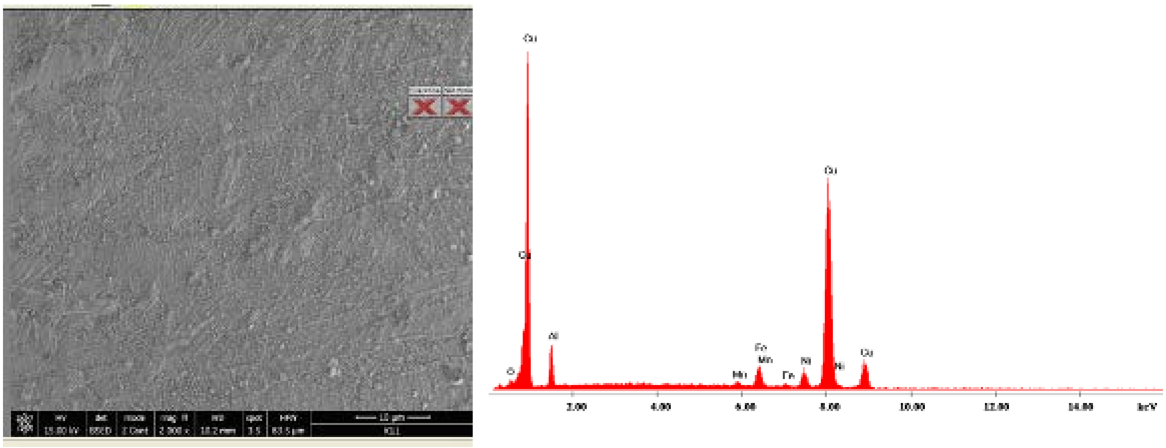
A B C

Fig. 8 Cross section through the eroded area at the end of cavitation exposure (165 minutes)
Digital Microscopy - HIROX 1300 apparatus
A- Central zone; B- Limit of eroded zone; C- External ring, without erosions



A B C

Fig. 9 Images of the zones specified in figure 6



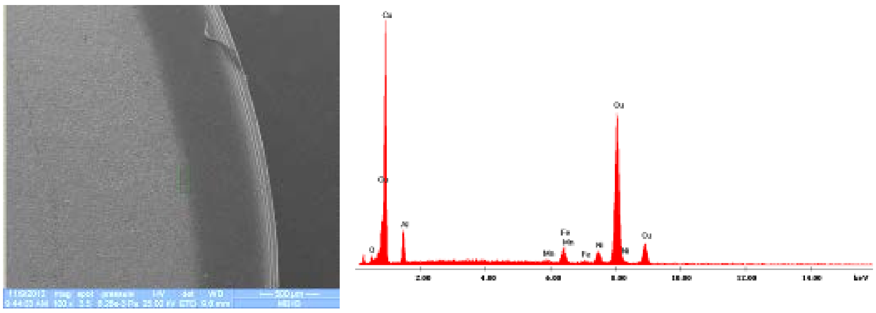
a) b)

EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Elem	Wt %	At %	K-Ratio	Z	A	F
O K	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
Total	100.00	100.00				

c)

Fig. 10 SEM microscopy and EDX spectroscopy, Central zone A

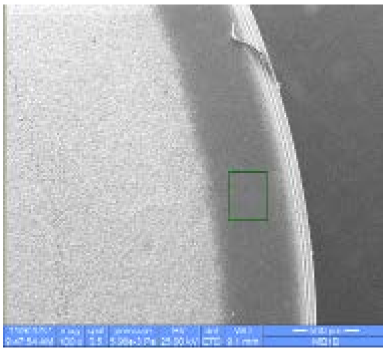


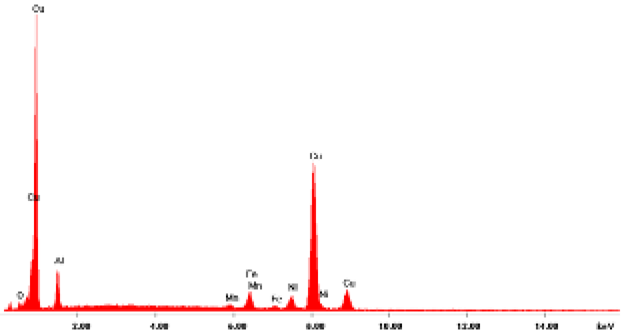
a) b)

EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

Elem	Wt %	At %	K-Ratio	Z	A	F
O K	2.74	8.94	0.0086	1.1607	0.2700	1.0026
AlK	9.19	17.80	0.0200	1.0829	0.2008	1.0000
MnK	0.72	0.68	0.0080	0.9854	0.9727	1.1601
FeK	3.70	3.46	0.0453	1.0057	0.9839	1.2389
NiK	5.02	4.47	0.0509	1.0251	0.9882	1.0000
CuK	78.63	64.65	0.7646	0.9784	0.9938	1.0000
Total	100.00	100.00				

c)
Fig. 11 –passing over zone B


a)


b)

EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : Default

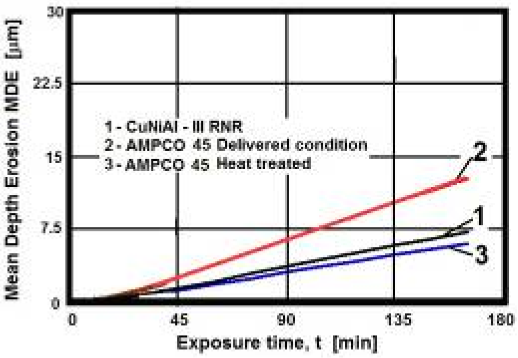
Elem	Wt %	At %	K-Ratio	Z	A	F
O K	1.69	5.51	0.0052	1.1597	0.2657	1.0026
AlK	11.79	22.75	0.0259	1.0819	0.2029	1.0000
MnK	0.72	0.68	0.0079	0.9843	0.9717	1.1551
FeK	3.85	3.59	0.0469	1.0046	0.9832	1.2314
NiK	5.22	4.63	0.0528	1.0240	0.9874	1.0000
CuK	76.72	62.84	0.7447	0.9773	0.9932	1.0000
Total	100.00	100.00				

c)

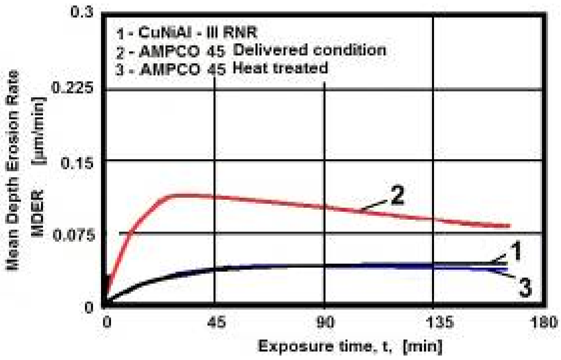
Fig. 12 SEM microscopy and EDX spectroscopy, -external zone C

4. Comparisons with reference materials

A reliable evaluation of the heat treated AMPCO 45 bronze can be obtained through comparisons of the characteristic curves with those of the marine bronze CuNiAl III-RNR (with excellent cavitation erosion) and recommended by the Standards RNR [9] and ICEPRONAV for manufacturing ship propellers [1].



a)



b)

Fig.13 Cavitation erosions characteristic curves
a) Mean depth erosion against time
b) Mean depth erosion rate against time

Figure 13 presents the cavitation erosion behavior of three bronzes CuNiAl III-RNR (curve 1), AMPCO 45 without treatments (curve 2) and AMPCO 45 heat treated (curve 3). The curves in Fig. 14a show the great increase of the cavitation erosion resistance for the treated AMPCO 45 which become better than CuNiAl- III RNR. The evolution of the curves MDER(t) with reduced maximum values and the tendency to stable erosions near the maximum value are characteristic with good and excellent cavitation erosion [1], [3]. Taking into account the values of the erosion rate in the stable zone (Fig. 14 b) results that untreated AMPCO 45 is 1.8 times weaker than CuNiAl – III RNR. After the heat treatment the resistance to cavitation erosion of AMPCO 45 became 1.2 times better than CuNiAl- III RNR.

5. CONCLUSIONS

The applied heat treatment for the bronze AMPCO 45 conducted to an exceptional increase of the cavitation erosion qualities. The resistance becomes better that that of the bronze CuNiAl – III RNR and recommend this material even for manufacturing the ship propellers.
The determined tolerance interval shows that the regression equation is correct and representative. The differences between the mean depth erosions for all the three specimens are smaller than the tolerance interval. It means that the tested material is uniform in different points. This feature remains for the whole extension of the exposure time.
Measurements of the hardness for the material in the genuine state and for the heat treated show an increase of the later with 20.6%. This increase explains in great extent the excellent behavior of the heat treated AMPCO 45 to cavitation erosion.
The measured roughness of the eroded surface does not reveled sharp crests. This is also an explanation for the good behavior to cavitation erosion.

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