Researches regarding the Behavior of CuAl10.5Ni5Fe4.8Mn1.5 at Erosion Generated by Vibratory Cavitation

PhD. Student eng. **Iosif LAZAR**[1], Prof. PhD.eng. **Ilare BORDEASU**[2], Prof. PhD.eng. **Mircea O. POPOVICIU**[3], Lect. PhD.eng. **Lavinia Madalina MICU**[4]

[1] Politechnica University of Timisoara, Mihai Viteazul St. No.1, 300222, Timisoara, Romania, E-mail: office@ducodan.ro,

[2] Politechnica University of Timisoara, Mihai Viteazul St. No.1, 300222, Timisoara, Romania, E-mail: ilarica59@gmail.com,

[3] Academy of Romanian Scientists, Mihai Viteazul St. No. 1, 300222, Timisoara, Romania, E-mail: mpopoviciu@gmail.com

[4] "Mihai I King of Romania" University of Agricultural Sciences and Veterinary Medicine of Banat in Timisoara, Route of Arad no.119, 300645 Timisoara, Romania, E-mail: lavimicu@yahoo.com

Abstract: *The paper presents research results regarding the behavior at cavitation erosion of the CuAl10.5Ni5Fe4.8Mn1.5 bronze used in manufacturing ship propelers. For the experimental research it was used the Standard Vibratory Apparatus with piezoelectric crystals, of the Timisoara Polytechnic University Cavitation Laboratory. The analyze is realized by using the curves and parameters recommended in the ASTM G32-2010 Standard, the photographic images and the profiles of the surface subjected to cavitation. The resistance evaluation was obtained by comparisons with the behavior of the stainless steel OH12NDL for which we have numerous laboratory researches as well as detailed informations about the behavior in field running. The final conclusion is that the researched bronze has a very good cavitation erosion and can be used for manufacturing ship propellers.*

Keywords*: Bronze, cavitation resistance, roughness, characteristic curves, microstructure*

1. Introduction

The cavitation effect upon ship propellers has been notified in the year 1848, when the first modern metallic passenger ship with mechanical propulsion constructed in Great Britain, was subjected to technical verification. The ship was designed by Isambard Kingdom Brunel and launched to the water in 1843 [12]. The negative effects such as important erosion and the reduction of the propulsion velocity were identified only in 1893 by Parsons [4, 7], after studies effected in a hydrodynamic tunnel. The aspect of the cavitation phenomenon and the effects upon the blades, both presented in Fig. 1, show that the most affected zones are blades tips [12].

a) b) c)

Fig. 1. Ship propellers running in cavitation and a blade eroded by cavitation [11]
a) cavitational vortex at the propeller blade peak; b) blade with cavitation erosion;
c) detail of the eroded zone

As a result of those inconveniences, from them on until now, there are effected multiple researches to find materials having increased resistance both to cavitation and corrosion. Simultaneously are made studies regarding various procedures for increasing the cavitation erosion resistance of the areas subjected to cavitation [1, 2, 3, 6]. The results of the present researches are in line with those trends [5, 7, 8].

2. Researched material

For researches was used the bronze CuAl10.5Ni5Fe4.8Mn1.5 [11]**.** The chemical composition and the mechanical characteristics with relevance to cavitation erosion, determined in the Timisoara Polytechnic University Laboratory for the Material Sciences and Engineering are: 10.46 % Al, 4.85% Ni, 4.72 %Fe, 1.41 % Mn, the rest being Cu; fracture strength R_m = 980 MPa, yield strength $R_{p0.5}$ = 789 MPa, Brinell hardness = 283 HB30, elongation A_5= 8 %, resilience KCU= 7 J.

3. Cavitation tests

The cavitation erosion tests were realized in the vibratory device T2, with piezoelectric crystals, in conformity with the rules of the Timisoara Polytechnic University Cavitation Laboratory [9], [2], [6], [7] in the same time respecting all the requirements of the ASTM G32-2010 Standard [11].
All tests were realized in double distilled water. The liquid temperature during the researches was maintained at 22±1ºC. In conformity with the requirements, there were subjected to the tests 3 identical samples.
Before beginning the tests the active surface of the samples were polished with abrasive paper and with the paste PROFILINE SONAX FS 05-04**.** The mean roughness of the active surface, before the begining of tests (Fig. 2 present one of the three tested samples) was obtained with the portable roughness measuring device TR 110. The measuring was done in 6 points. The values for Ra are:
- for sample 1: Ra = 0.167 µm,
- for sample 2: Ra = 0.171 µm,
- for sample 3: Ra = 0.179 µm

Fig. 2. The **s**ample surface before cavitation exposure

The exposure time for each sample, in conformity with the Laboratory rules [1], [2], [3], [8], [6] was 165 minutes, at the begining with two short periods of 5 and 10 minutes, afterwards wit 15 minutes periods. At the end of each individual period it was measured the mass Δm_ilost as the result of the cavitation exposure. With these results there were computed:

- The cumulative mass losses M:

$$M_i = \sum_{i=1}^{12} \Delta m_i \qquad (1)$$

- The mean erosion rate:

$$v_i = \Delta m_i / \Delta t_i \qquad (2)$$

The meanining of the notations used above i :
i – testing period (i = 1, 2,...,12)
Δm_i – the lost mass in the period i, measured in grammes,
Δt_i – the time of the exposure in period "i„ (5, 10 or 15 minutes).
The mediation of the experimental values was realized through analitical curves obtained with the following relations [7]:

- for the mass losses:

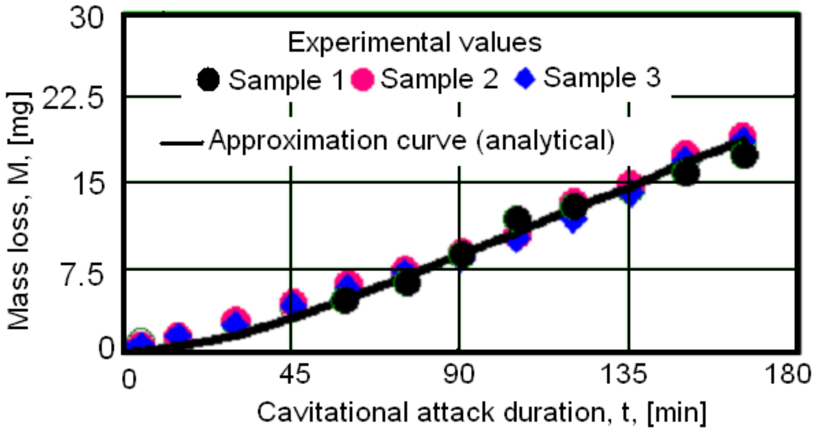
$$M\,(t) = A \cdot t \cdot (1-e^{-B \cdot t}) \qquad (4)$$

- for the erosion velocity:

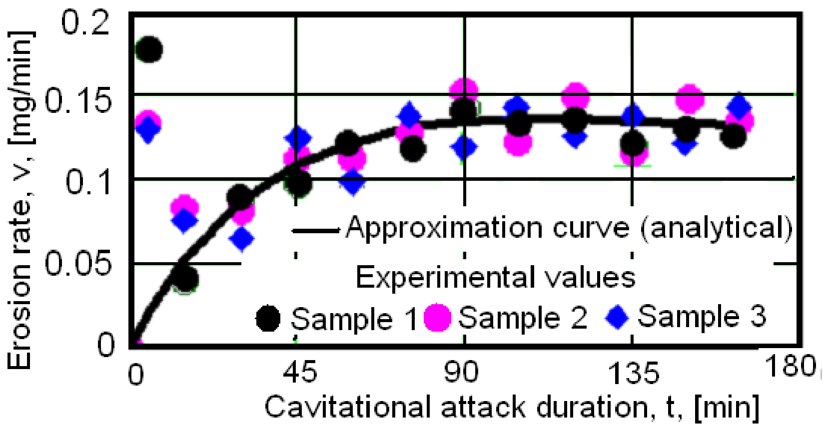
$$v(t) = A \cdot (1-e^{-B \cdot t}) + A \cdot B \cdot t \cdot e^{-B \cdot t} \qquad (5)$$

where:
A **–** is the scale parameter, statisticaly established, from the condition of minimum scatter of the experimentally obtaind points, with regard to the obtained curve.
B - is the form parameter of the curve.

The approximation curves were used for analyzing the erosion evolution during the exposure time, taking into account both the shape and the scatter of experimental points. In order to evaluate the mass losses, were used the mean mass losses obtained on the three samples, for each intermediary testing period, the cumulative mass loss as well as the loss velocity. In order to assess the cavitation erosion resistance, the obtained curves were compared with those obtained for the OH12NDL stainless steel, material with good behavior both in laboratory tests and in the field in the operation of hydraulic turbines. Supplementary, there were made comparisons between the stable velocities for final erosion exposure times. In Fig. 3 are presented the experimental obtained values together with the cavitation erosion characteristic curves.
The dispersion of the experimental points with regard to the mediation curves show that cavitation erosion is a statistic event. Thousands of tiny and patchy bubbles impacts very tiny sample areas, each with his one resistance. That is why three samples obtained from the same rod presents cavitation erosion resistance with small differences. The evolution of curve M(t) in Fig. 3a show that, beginning approximately with the minute 45, its shape is almost linear, it means that from this moment the behavior of the bronze remain approximately the same till the final exposure time. The curve v(t) gives more exactly values for the beginning of the stabilization curve, namely the minute 90 but the difference between the maximum velocity and the final value is very small (0.126 mg/min).
The differences between the experimental values of the three tested samples, whether we mean the cumulative mass loss M_i or the erosion velocity v_i are very small. It prove that the structure and the mechanical characteristics are very uniform distributed on the exposed area.
From the experience of 70 year [1], [7], such a dispersion mode is specific for the materials with very good cavitation erosion resistance, Also the evolution of the curves v(t) from the maximum value towards the stabilization one show that the researched bronzes are materials with very good cavitation erosion resistance and can be used for manufacturing details subjected to a very strong cavitation erosion and can be used for manufacturing navy propellers.
The differences between the experimental values and the approximation curves, till the minute 15 (see Fig. 3b) are given by the metallic dust and the sharp roughness expelled in this period. Normal this beginning period is not taken into account in the material behavior analyze, because it depends in great measure on the sample polishing and cleaning before the beginning of tests [1], [7].



a)



b)

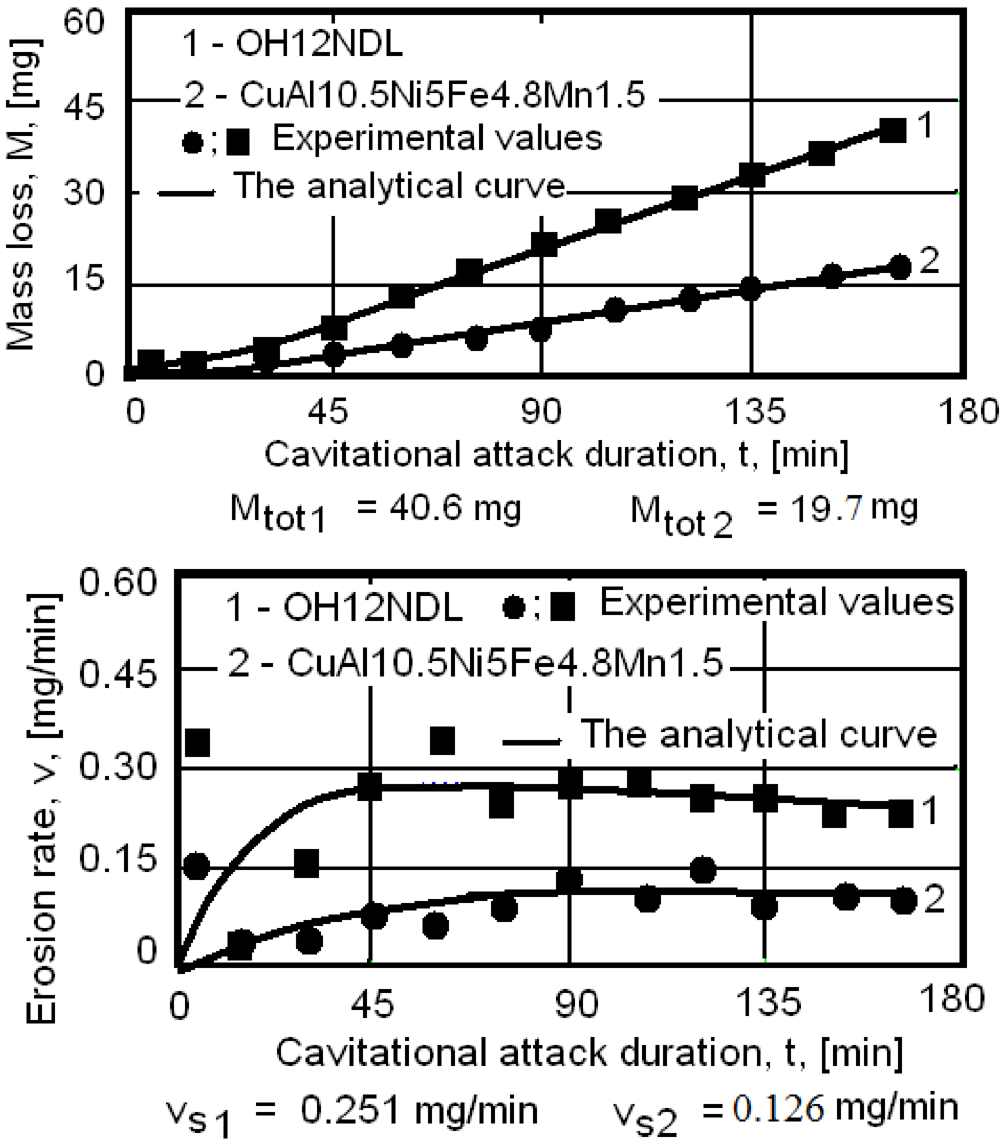
Fig. 3. Specific curves of behavior evolution and cavitation resistance
a) mass loss against the exposure to cavitation attack
b) erosion rate against exposure to cavitation attack

The evolution of the sample surface erosion is presented in the images of Table 1, realized for two specific intervals. The photographic images show clearly the increase of the cavitation erosion intensity upon the whole area and the penetration in the depth of sample.

Table 1: Erosion evoution of the exposed area

Attack duration	Sample		
	1	**2**	**3**
75 minutes			
165 minutes			

To put into evidence the cavitation erosion behavior, as well as the resistance to the mechanical fatigue stresses generated by the impacts of the surface with the microjets and the shock vawes generated by the implosion of the cavitation bubbles, in Fig. 4 there are made comparisons between the obtained experimental curves and values and those for the martensitic stainless steel OH12NDL for which we have both laboratory experimental results and field results in hydraulic turbines. In the same time there were made discussions regarding the comparisons between spefic parameters (M_{tot} and v_s).



a) b)

Fig. 4. Comparison with OH12NDL etalon steel:
a) mass loss comparison; b) erosion rate comparison

Taking into acount the values of both parameters the rezistance of the researched bronze is about two times greater than the resistance of the martensitic stainless steel OH12NDL. In conculusion the bronze CuAl10.5Ni5Fe4.8Mn1.5 has excellent behavior to cavitation erosion.

4. Phenomenological investigation of the eroded microstructure

The investigation of the eroded structure was done on the scanning electronic microscope Philips XL 30 ESEM in the Laboratories for Materials Science and Engineering.

The images presented in Fig. 5 (before the cavitation exposure, on separate specimens designed only for this purpose) and in Fig 6 (specimens subjected to the maximum exposure time) show that the microstructure of the material is constituted in principal from a solid solution α and a small proportion of the eutectoid α + γ´.
The images of figures 5...7 reveal the peculiarities of the eroded surface degraded by cracks at the grain boundaries but also by realizing caverns and pitting as the result of the expelled grains. Because the solid solution α gives a good plasticity and the eutectoid enhances the mechanical characteristics, the initiation of the cavitation erosion take place at the interface of these two structural constituents and only afterwards continues with expelling of the whole grain. This behavior results from the images presented in Fig. 6. Supplementary, the electronic scanning microscopy put into evidence the formation of annealing mackles and the priority expelling of the solid solution grains.

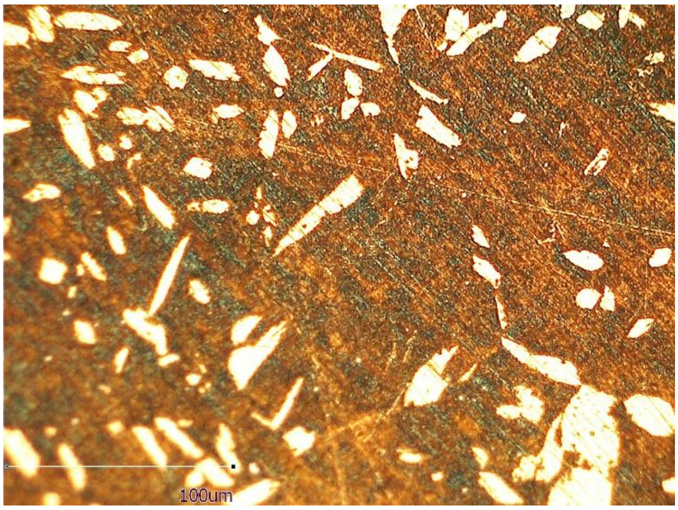


Fig. 5. Microstructure of the bronze CuAl10.5Ni5Fe4.8Mn1.5
(1750 x)

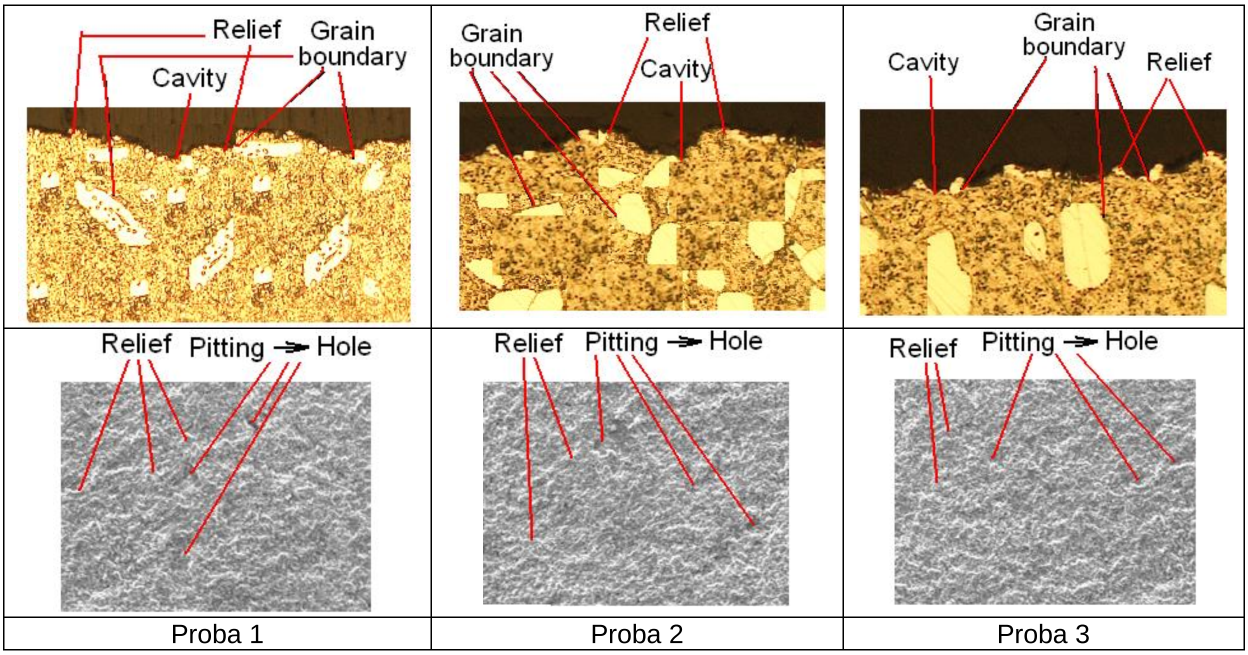


Fig. 6. Images of structure degradation (pitting, hole, deformations)
Final exposure time, 165 minutes (1750x)

The images in Fig. 8 presents the profiles of the eroded surface, obtained in the central zone, in conformity with Fig 7, on a 4 mm length, using the roughness device Mitutoyo.

Fig. 7. Recording zone of cavitated area roughness, with the Mitutoyo apparatus

In comparison with the images in Fig. 6 it can be seen a very good concordance between the profiles and the erosion mechanism. Taking into account the bronze density, computed upon the chemical composition (7.45 grams/mm^3) it results that the maxim penetration depth computed with the relation:

$$MDE_i = \sum_{i=1}^{12} \Delta MDE_i = \sum_{i=1}^{12} \frac{4 \cdot \Delta m_i}{\rho \cdot \pi \cdot d_p^2} \quad (6)$$

are:

for the sample 1: MDE ≅ 13.584 µm
for the sample 2: MDE ≅ 12.997 µm
for the sample 3: MDE ≅ 13.871 µm

This observation confirm the idea that cavitation resistance evaluation can be done, with a good approximation, also using the parameters of roughness, especially R_z.

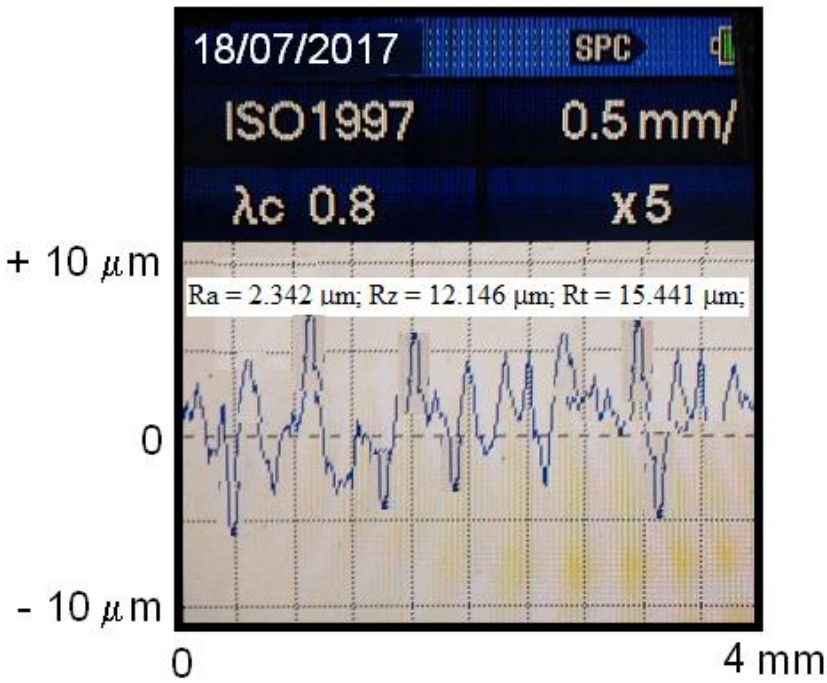


Fig. 8. - Sample 1

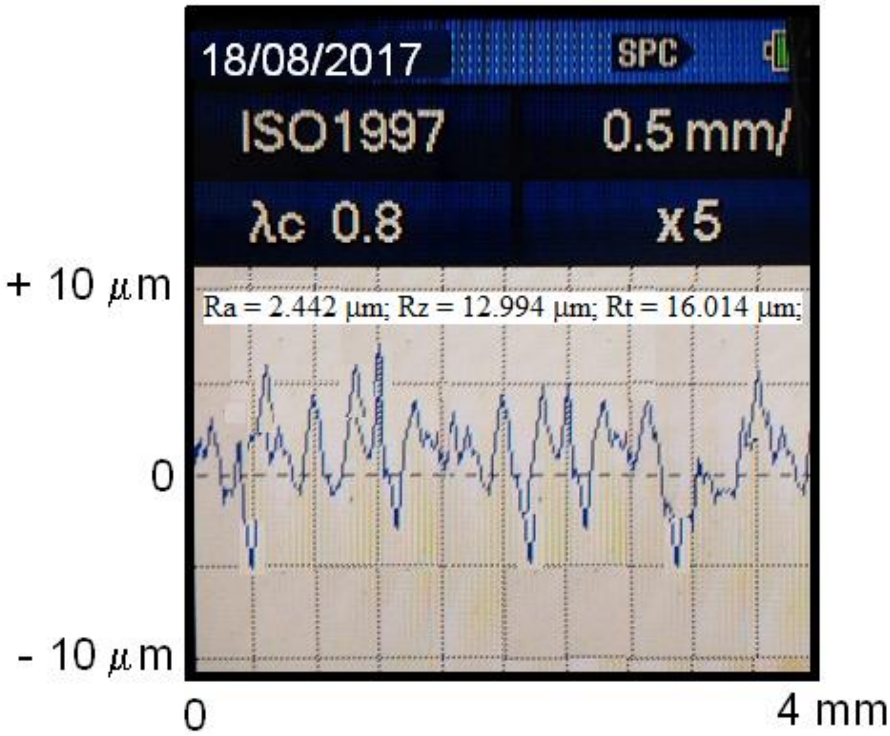


Fig. 8. - Sample 2

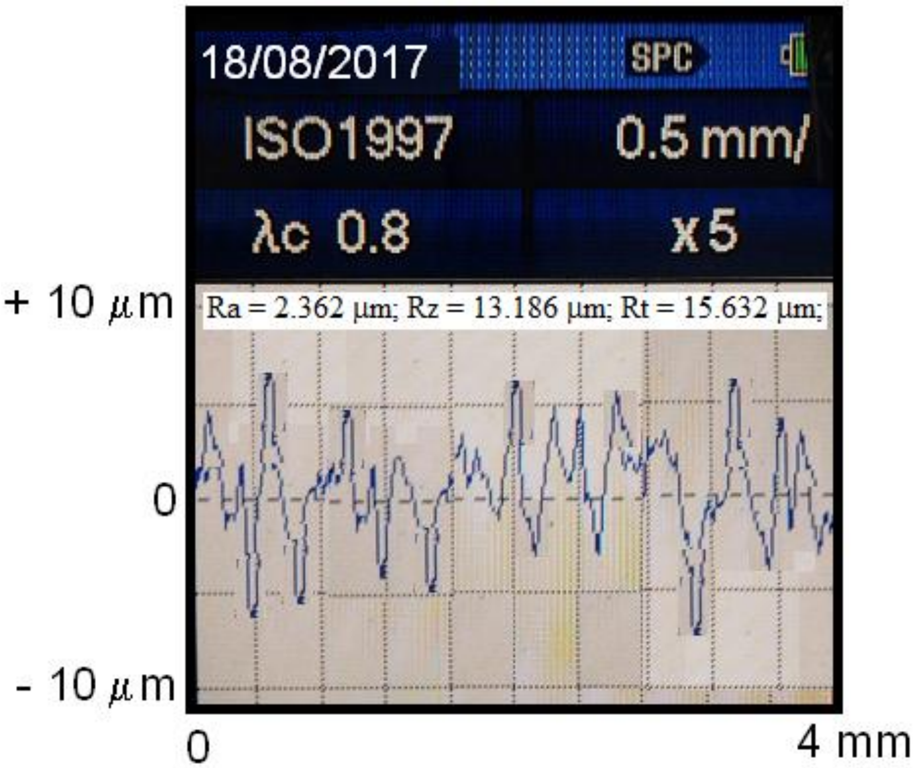


Fig. 8.- Sample 3

Fig. 8. Profile of the eroded surface, recorded in the center of the cavitated area

5. Conclusions

The evolution of cavitation characteristic curves and reduced scatter for experimental results, of the three tested samples, suggest that the bronze CuAl10.5Ni5Fe4.8Mn1.5 has a homogenous structure giving a very good resistance to cavitation erosion.

Because the solid solution α is responsible for a good plasticity and the eutectoid enhance the mechanical resistance, the cavitation erosion begin on the interface of the two constituents and only afterwards continues towards the inner part of the grains.
The roughness profile, obtained with a Mitutoyo device, confirm the uniform degradation of the cavitation exposed surface, the behavior being specific for materials with very good cavitation erosion behavior, as well as with fine structures, great homogeneity which give uniform mechanical properties.
The comparison with the stainless steel OH12NDL, with which we obtained good cavitation erosion behavior both in laboratory and in running hydraulic turbines show that the tested bronze satisfy the requested demands also for ship propellers.

References

[1] I. Bordeaşu, „Eroziunea cavitaţională a materialelor”, Editura Politehnica, Timişoara, 2006;
[2] I. Bordeasu, M.O. Popoviciu, „Contributions Regarding Cavitation Erosion Hierarhy For Stainless Steels”, *Machine Design,* Vol.5 (2013) No.4, ISSN 1821-1259, pp. 157-162;
[3] I. Bordeasu, M.O. Popoviciu, T.S. Duma, „Consideration concerning the Steels Cavitation Erosion Resistance Modification with Specific Heat Treatments”, *KOD 2012, Proceedings The 7-th international symposium about forming and design in mechanical engineering*, 24-26 mai.2012, Balatonfured, Ungaria, ISBN 978-86-7892-399-9, pp.519-522;
[4] J.P Breslin, P. Andersen, „Hydrodynamics of ship propellers”, 3, Editor Cambridge University Press: United Kingdon, 2003;
[5] J.P. Franc, et al, „La Cavitation”, Mecanismes phisiques et aspects industriels, Press Universitaires de Grenoble, 1995;
[6] L. M. Micu, I. Bordeasu, M. Popoviciu, „Cavitation erosion of HVOF metal-ceramic composite coatings deposited onto Duplex stainless steel substrate”, *Revista de Materiale Plastice*, vol.53, no.4, 2016, ISSN 0025-5289, pp.781-786;
[7] O. Oanca, „Tehnici de optimizare a rezistenţei la eroziunea prin cavitaţie a unor aliaje CuAlNiFeMn destinate execuţiei elicelor navale”, Teza de doctorat, Timișoara, 2014;
[8] M.O. Popoviciu, I. Bordeasu, „Proposed Model for Cavitation Erosion Test Results Presentation”, *Machine Design*, Vol.5(2013) No.1, ISSN 1821-1259, pp. 11-16;
[9] *** (2010). Standard method of vibratory cavitation erosion test, ASTM, Standard G32-10;
[10] *** Registrul Naval Roman, „Reguli pentru clasificarea şi construcţia navelor maritime”, Vol. V, Bucureşti, 1986;
[11] *** http://www.ampcometal.com/common/datasheets/en/AM4_EX_E.pdf;
[12]***https://www.google.ro/search?q=image+of+ship+propeller+cavitation+damage&oq=image+of++ship+propeller+cavitation&gs_l