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Evaluation of the brass CuZn39Pb3 resistance at vibratory cavitation erosion

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Abstract. The CuZnPb brasses are used on a large scale in manufacturing component details for hydraulic driving or regulation devices, as well as for small and huge vanes. Partially the material is used for manufacturing the bodies and partially for sealing seats. During normal operation those pieces are subjected to cavitation erosion. The present paper analyzes the cavitation erosion behavior and the resistance of the brass CuZn39Pb3 used for manufacturing the mentioned details. For the experimental researches was used the standard vibration device realized in the Timisoara Polytechnic University Cavitation Laboratory. The evaluations are made on the basis of the characteristic curves but also by analyzing the eroded areas with great performance microscopes. The behavior of the tested brasses is also compared with those of some etalon materials. The conclusions show that the researched brass can be used only for details working in condition of poor cavitation erosion. At normal or intense cavitation erosion it is necessary at least to use methods to increase the resistance of this materials.

1. Introduction

The brasses with lead content having biphasic structure (α of type CFC and β’ of type CVC) are not used for details working in heavy corrosive environments or if can appear high mechanical stresses, but are used on a large scale for details subjected to friction wear [1], [2]. Although this material is used for casting valve bodies, which under certain working regimes are subjected to cavitation erosion, the literature give no data upon their behavior in those conditions. Being components of the systems transporting real liquids, some of having solid particles in suspension, such details can receive, in some parts, rapid detours as the result of the cumulative effect of the abrasive and cavitation erosions. Common, for details used in shipbuilding industry the brasses are under 0.5 % of lead [3]), even if their mechanical properties do not have greater values in comparison with the brasses with 2.5…3.5 % content of lead. Also, because of their good behavior during mechanical processing, the brasses with lead content are frequently used in manufacturing the seating for pressure valves or even for the whole valves of hydraulic control devices [4-7], details which at some working regimes are subjected to low intensity cavitation erosion. As a consequence we believe that the behavior to cavitation erosion must be well known, especially because the repair works by welding (common for cavitation eroded parts) is relatively difficult and is not recommended [8], [9].

2. Researched material. Laboratory devices

The researched material is brass with lead content, having the symbol CuZn39Pb3**,** in conformity with EN 10204:2004.
The specimens used in the research program were taken out from a cylindrical rod, with a diameter 20 mm and the active surfaces (subjected to vibratory cavitation erosion) were polished at a roughness of Ra = 0.02 μm.
In advance, there have been realized in the Timisoara Polytechnic University chemical and mechanical tests upon the material and have been obtained the following results:

- Chemical composition: 57.7 % Cu, 38.49 % Zn, 3.3 % Pb, 0.2 % Fe, 0.1 % Ni, 0.2 % Sn, 0.01 % Al.
- Mechanical and physical properties: fracture strength = 502 MPa, yield point $R_{p0.2}$ = 365 MPa, Brinell hardness =115 daN/mm^2, strength elongation A5 = 18 %, longitudinal elastic modulus E = 97 GPa, density ρ = 8.47 g/cm^3.
- Biphasic structure formed from the solid solutions α and β', Figure 1, [1].

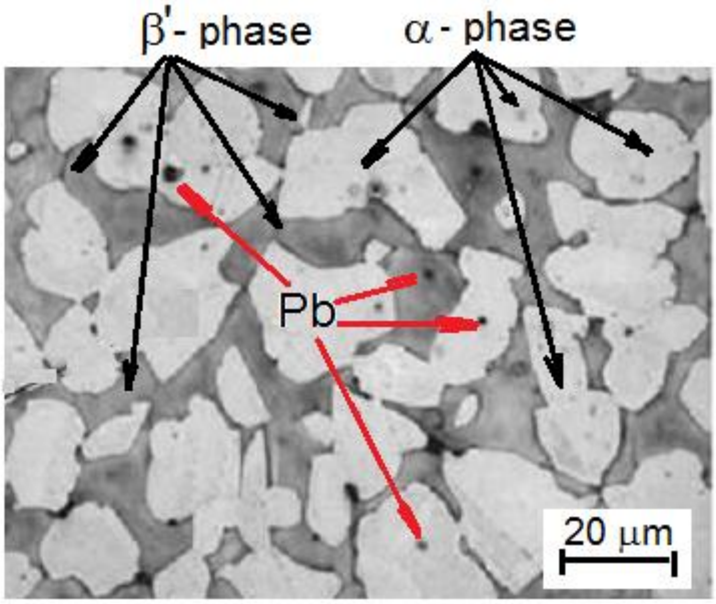
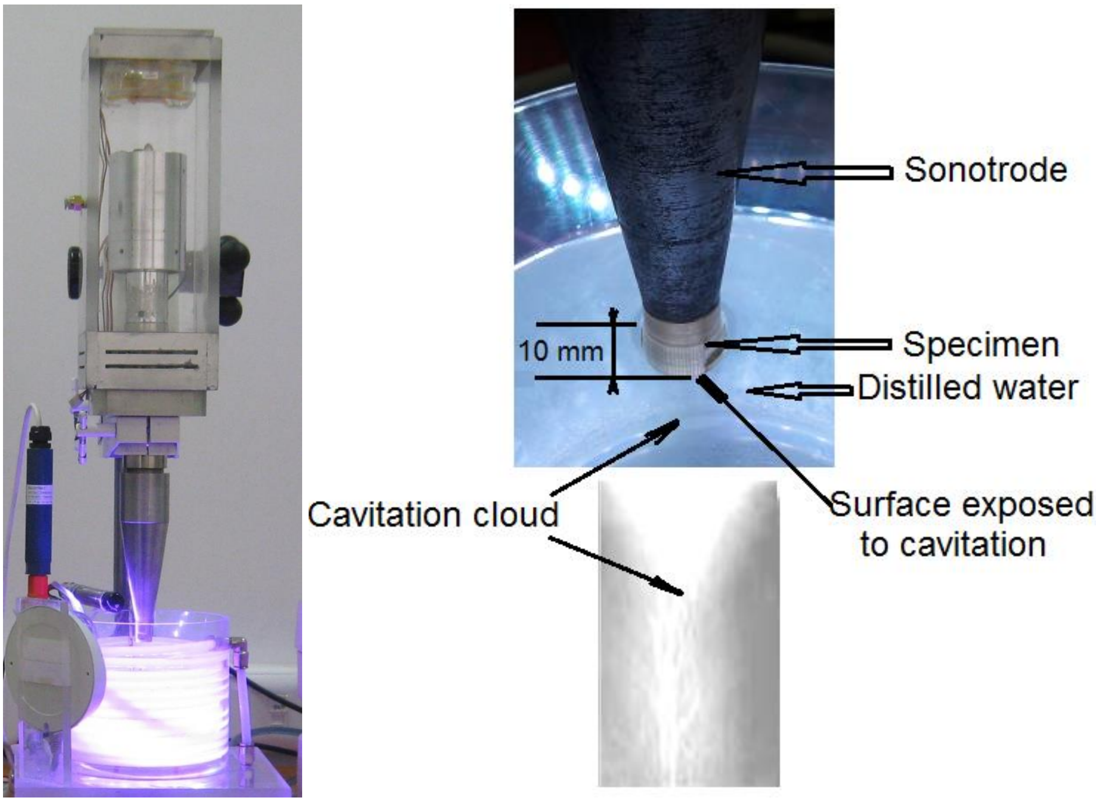


Figure 1. Structure of Brass CuZn39Pb3 (image taken from [1])

The cavitation erosion tests were carried out on the Standard Vibratory Device, with piezoelectric crystals, in the Timisoara Polytechnic University Laboratory of Cavitation [6], [7], [10]. The procedures regarding the specimen preparation before the beginning of the tests, the total exposure, and the intermediary measuring time, the registration of the mass losses and the maintenance of the specimens are in conformity with the Standard ASTM G32-2010 [11] and the laboratory customs [12-15].
The functional parameters of the device, having great influence upon the cavitation erosion intensity, were controlled by a special soft in order to maintain the prescribed values. These parameters are:

Double amplitude of the vibrations = 50 μm
Oscillation frequency = 20 ± 0.02 kHz
Power of the electronic ultrasonic generator = 500 W
Testing liquid: double distilled water
Liquid temperature = 22 ±1^0 C

In order to realize the cavitation erosion the used specimens, with cylindrical shape and a diameter of D = 15,8 mm, are fixed in the sonotrode of the vibratory system and immersed in double distilled water on a depth of 10 mm, Figure 2.



a) **b)**

Figure 2. Images taken during the exposure to vibrating cavitation
a) Ensemble image of the standard cavitation erosion device
b) Detail with the specimen fixed in sonotrode and immersed in water

The morphologic analyze of the eroded structure was realized using images obtained with the scanning electronic microscope Vega 3 Tescan.

3. Experimental results

The evaluation of the behaviour and resistance of the brass to vibratory cavitation respect the Standard ASTM G32 – 2010 and the experimental customs of the Timisoara Polytechnic University Cavitation Laboratory and is made using the specific curves for the mean depth erosion (MDE) and mean depth erosion rate (MDER). For eliminating aleatory differences there were tested three similar specimens and the curves are traced for the mean values of the results. Specification: *the total time exposure of a specimen is 165 minutes and there were made 12 mass loss measurements. The first two for smaller testing times (after 5 and 10 minutes) and the following 10 were made for 15 minutes of exposure. There were taken special measures to eliminate as much as possible the effect of corrosion.* The mass of the eroded material was measured by the use of an analytic balance type Zatklady with a precision of 10^{-5} g.

The parameters MDE and MDER were computed for each intermediate period with the relations:

- mean depth erosion penetration for a single interval

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

- cumulative mean depth penetration

$$MDE_i = \sum_{i=1}^{12} \Delta MDE_i \tag{2}$$

- mean depth penetration rate for an interval:

$$MDER_i = \Delta MDE_i / \Delta t_i \tag{3}$$

The used symbols are:
i = 1…12 – testing period
Δm_i –is the erosion lost mass in the period "i", in grams,
ρ = 8.47 grams/mm^3- brass density,
Δt_i – cavitation exposure time for the period "i" (5 minutes, 10 minutes or 15 minutes)
d_p – diameter of the specimen (d_p= 15,8 mm),
To characteristic curves approximating the experimental results were obtained using the following analytical relations [16]:

- for mean depth erosion

$$MDE\ (t) = A \cdot t \cdot (1 - e^{-B \cdot t}) \tag{4}$$

- for mean depth erosion rate

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

The parameters A and B were established statistically, in conformity with previous researches [5], [16].

In Figures 3 and 4 are presented the experimental obtained values and the analytical approximation for MDE and MDER, which allow to examine the brass behavior during the exposure to vibratory cavitation. For the same purpose are given the images in Figure 5 which show the extension of the eroded surfaces.

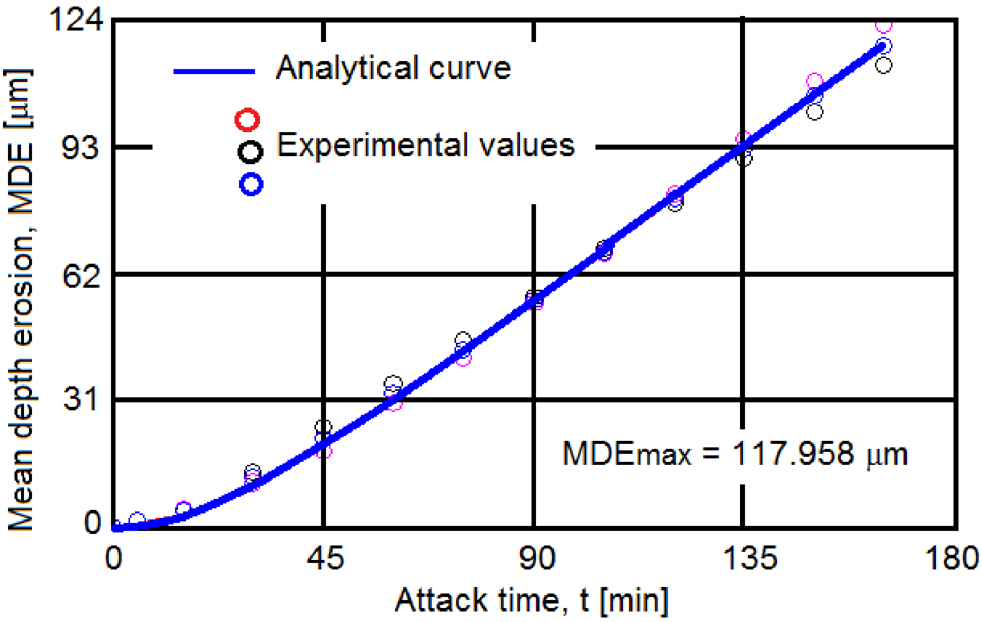


Figure 3. Evolution of mean depth erosion against cavitation exposure time

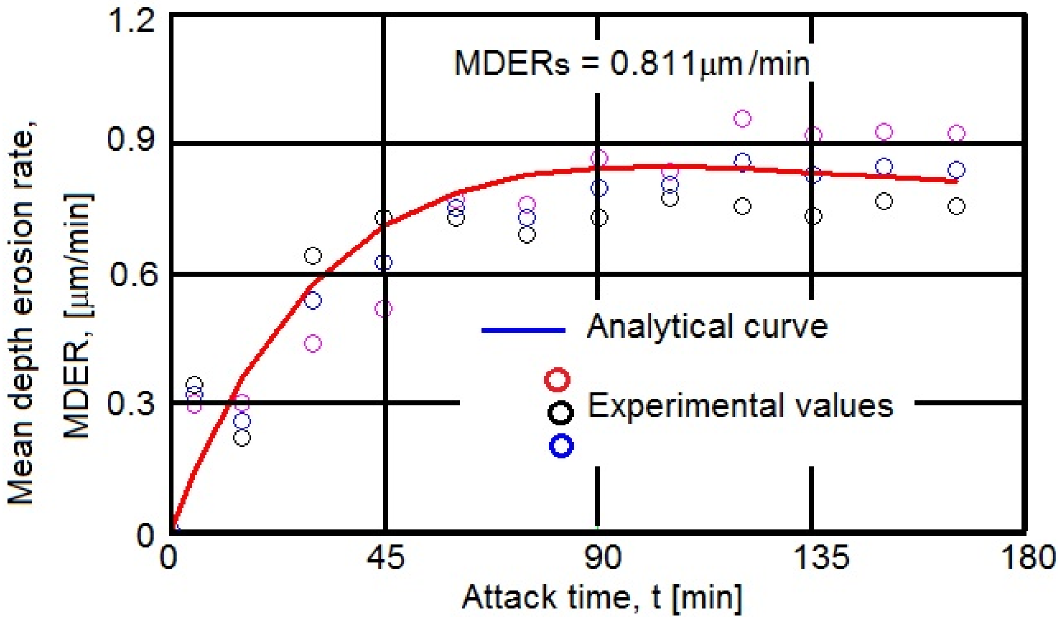


Figure 4. Evolution of mean depth erosion rate against cavitation exposure time

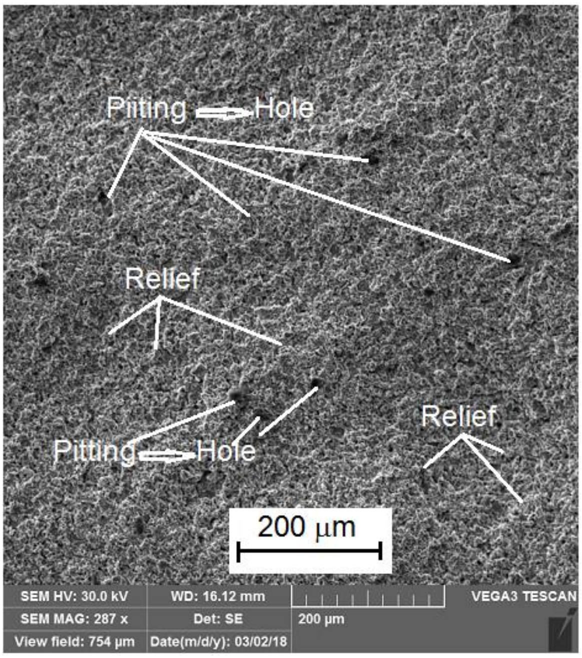
Min 0 Min 15 Min 90 Min 135 Min 165

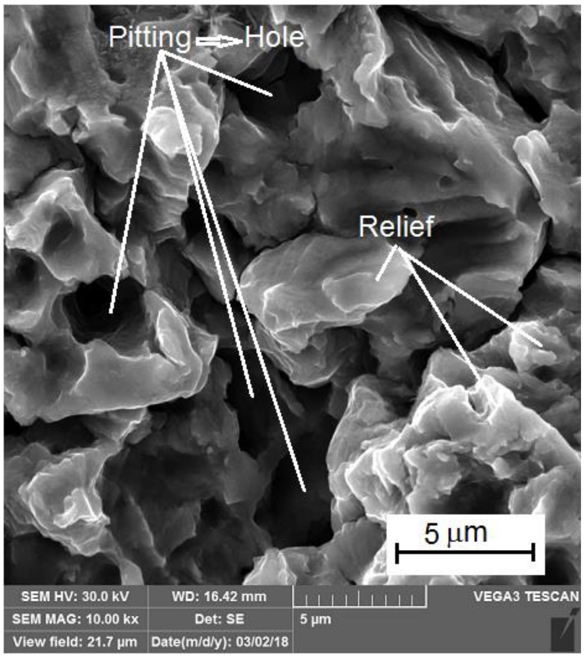
Figure 5. Images of specimen surface at different cavitation exposure time

From Figure 3 it can be seen an approximatively symmetric scatter of the experimental points with regard to the analytic mediation curve while for Figure 4 the scatter is greater and the symmetry appear only after 120 minutes of tests (this difference appear for all tested materials). The scatter differences between the experimental points and the curves is caused by the fact that MDER(t) is the derivative of MDE(t). On the other hand, evidently the tested area presents a heterogeneous structural constitution formed by the α solid solution and the electronic compound β', which is fragile [8] and also differences between the grains dimensions and their border width, the grain border being the zone in which preferentially the first material losses occur (see Figure 6.). The variation of cavitation erosion resistances in different points of the surface is an assumption confirmed by the different values of the hardness on the same surface (the mean hardness is obtained by 8 measurements conducted in different points of the exposed surface) [5], [6], [10], [12], [13], [15], [17].

After the evolution of the approximation curve MDER(t), Figure 4, for which does not appear significate reduction after 90 minutes of exposure and taking into account the previous laboratory results, confirmed by industrial practice [1-16], it can be said that the tested brass can be classified through the materials which can be used for pieces subjected to reduced cavitation requirements (as for seats of high pressure valves). We also specify that the cavitation erosion resistance can be further improved by applying adequate technologies for surface engineering.

The images of Figure 5 show that in the first 15 minute the cavitation erosion begins with the formation of a peripheral ring. The explanation consists in the imploding mode of the cavitation cloud (see Figure 2) which determines caverns and erosions only in this ring and towards the inner zone of the exposed surface are only eliminated the roughness picks and generated cracks networks without visible caverns. For 90 minutes of cavitation, on the external ring are formed star like caverns and simultaneously on the whole exposed surface are visible pittings. This is clearly seen Figure 6 where are presented photographs obtained with a SEM microscope were it can be seen how the phase β' is expelled and how the cracks are propagated. All this facts determines the increase of the mean depth erosion rate which reached a maximum (see Figure 4).





a)-300X **b)-1000 x**

Figure 6. SEM images of the eroded microstructure, after 165 minutes of cavitation exposure (the images were taken in the inner zone of exposed area)

In the 90-135 minutes testing interval, the caverns with star shape increase their size (both in plane and depth), the small holes begin more evident, but in the same time the vapors and gases remaining in these small holes have a damping effect and determine a reduction of the erosion velocity. This phenomenon give the shape of the MDER(t) which receive a stabilization shape which is maintained till the end of the tests.

To evaluate the cavitation erosion resistance there are presented the diagrams of Figures 7 and 8, in which the mean values of the tested material are compared with the cavitation erosion behavior of the stainless steel OH12NDL (with a good cavitation erosion resistance [5], [6], [10], [15], used for manufacturing the blades of the hydraulic turbines for the Iron Gates I, for both power plants in Serbia and Romania) and of the bronze CuAl10.5Ni5Fe4.8Mn1.5 (with excellent cavitation erosion resistance [5], used for manufacturing the propellers for maritime ships); both are reference materials in our laboratory.

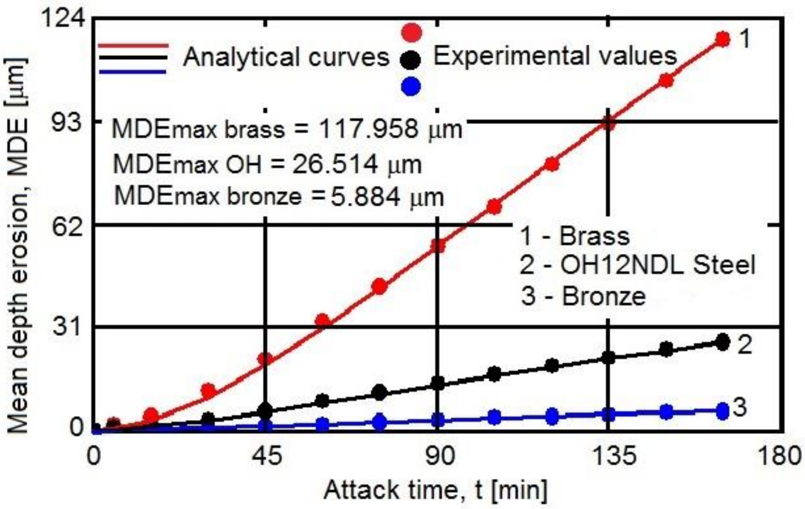


Figure 7. Comparisons of the cavitation erosion behavior taking into account the mean depth erosion

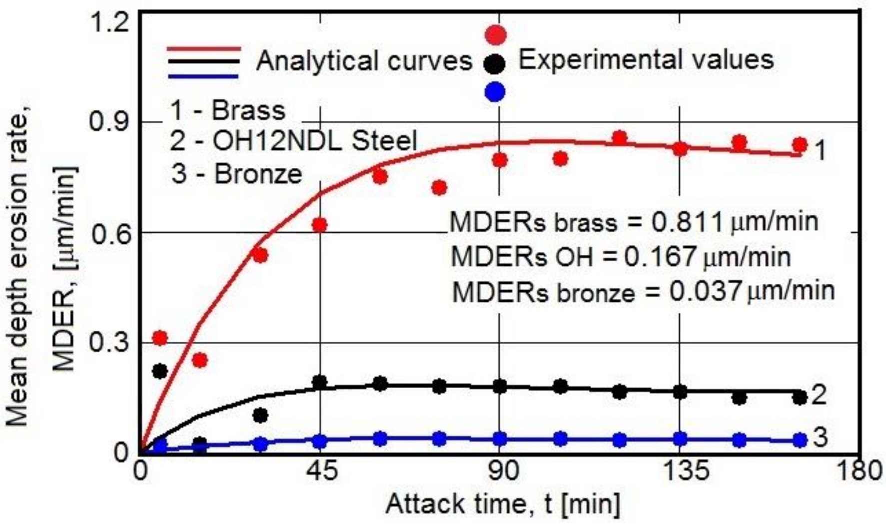


Figure 8. Comparisons of the cavitation erosion behavior taking into account the mean depth erosion rate

Comparing the curves of Figures 7 and 8 we can see that the brass CuZn39Pb3 has a much smaller resistance in comparison with the etalon materials.
This resistance is very well reflected quantitatively by the comparison of the material losses for the final exposure time (165 minutes):

- the maximum mean depth erosion MDE_{max} produced in the researched brass is approximately 4.5 times higher than that achieved in OH12NDL stainless steel and approximately 20 times greater than that achieved in CuAl10.5Ni5Fe4.8Mn1.5 bronze;
- the final mean depth erosion rate MDERs (frequently named the stabilization erosion rate [5], [11], [16]) is approximately 4.9 higher than that realized in the stainless steel OH12NDL and approximately 22 higher than that realized in the bronze CuAl10.5Ni5Fe4.8Mn1.5.

The similarity in the evolution of the curves MDE(t) and MDER(t) for the tested material and the reference ones, suggest that the cavitation erosion resistance of the brass can be improved. This can be done through the use of treatments for conferring to the surface subjected to cavitation, improved mechanical characteristics (especially for the yield point $R_{p0.2}$, the fracture strength R_m and especially for the hardness), homogenous distributed, as well as the reduction of the solid solution β' fragile component with weak resistance to the mechanical shocks produced by the bubble implosions.

4. Conclusions

The brass CuZn39Pb3 present a specific cavitation erosion behavior, for materials with uniform distributed structural constituents, but having a reduced mechanical resistance motive for which, the material researched can be used only for details working in hydrodynamic conditions with reduced cavitation intensity such as those generated in devices (pressure valves, pressure or flow controllers) working whit liquids having great viscosities (various kind of oils).
The erosion initiation and advancement take place at the boundary between the α solid solution and the electronic compound β', with the rapid destruction of the β' phase.
To can use the brass CuZn39Pb3 for details working in hydrodynamic regimes with normal intensity cavitation, such as the blades for ship propellers or hydraulic machinery runners, it is necessary to previously apply treatments for the increase of the mechanical characteristics (Rm, Rp0.2) and especially the hardness HB.

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