Heat Treatment Influence of Alloy 5083 on Cavitational Erosion Resistance

PhD.Eng. **Dionisie ISTRATE[1],** Lecturer PhD.Eng. **Cristian GHERA[2],**
Univ. assist.PhD.Eng. **Laura SĂLCIANU[3],** Prof.PhD.Eng**. Ilare BORDEAȘU[4],**
Prof.PhD.Eng**. Brândușa GHIBAN[5],** PhD.Eng. **Dumitru Viorel BĂZĂVAN[6],**
Assoc. prof. PhD.Eng. **Lavinia Mădălina MICU[7],** Lecturer PhD.Eng. **Daniel-Cătălin STROIȚĂ[8],**
Assoc. prof. PhD.Eng**. Daniel OSTOIA[9]**

[1] Politehnica University of Bucharest, dionisieistrate@yahoo.com

[2] Politehnica University of Timisoara, cghera2000@yahoo.com

[3] Politehnica University of Timisoara, salcianu.laura@yahoo.com

[4] Politehnica University of Timisoara, ilarica59@gmail.com

[5] Politehnica University of Bucharest, ghibanbrandusa@yahoo.com

[6] Politehnica University of Timisoara, bazavanvio303@yahoo.com

[7] University of Agricultural Sciences and Veterinary Medicine of Banat "King Mihai I of Romania", lavimicu@yahoo.com

[8] Politehnica University of Timisoara, daniel.stroita@upt.ro

[9] Politehnica University of Timisoara, dostoia@yahoo.com

Abstract: *Aluminum based alloy type 5083 have a large applicability in the area of automobile and naval constructions (such as: Shipbuilding, Rail cars, Vehicle corps, Type truck body, Mine skips and cages, Pressure vessel). The components of these parts are sometimes required for high aggressiveness factors. Thus, during operation, both the pump rotors and the propellers are subjected to hydrodynamic stresses of the cavity, which, by erosion, leads to their removing, completely or until repair. At the same time, to increase the service life, chemical corrosion of the liquid environment, these others contain various alloying elements, which change the structure and improve the chemical, physical and mechanical properties. In order to increase the resistance to erosion and mechanical stresses of the cavitational current, heat treatments are applied which also modify the microstructure and the values of the mechanical properties. The study presents the results of research on its vibrating cavity of another 5083 cast, subjected to the heat treatment of the solution at 350°C followed by artificial aging at 180°C with different maintenance times (one hour, 12 hours, 24 hours). The analysis of the results, based on the specific curves used in the Cavitation Erosion Research Laboratory in Timișoara, recommended by ASTM G32-2016, as well as macro images of eroded surfaces for 165 minutes, shows the dependence of cavitation erosion resistance of the microstructure type results from heat treatment and not of durable value, respectively of resilience, properties with great influence on the resistance to cavitation stresses, as happens, most often, in the case of steels.*

Keywords: *Alloy 5083 aluminum, erosion of cavitation, mass loss, erosion rate, microstructure, tearing, hardness, resilience*

1. Introduction

The use of aluminum-based alloys is known for its thermal and electrical properties, but its use in the shipbuilding industry, automobiles, aviation, etc. is due to the advantage offered, in particular, by its low specific mass [1-4]. Depending on the application and the operating conditions, the choice of the alloy is made according to the chemical composition, structure and mechanical properties. Some of these components, such as the warhead and wings of aircraft, the propellers of motorboats and boats and the water cooling pumps of motor vehicles are subjected to mechanical, destructive stresses, through the hydrodynamic mechanism of the cavity [5 - 10]. The parts affected by these stresses have pitting erosion surfaces, sometimes with very large caverns, which require the operation to be stopped and the eroded surface to be repaired, or even the part to be replaced. To increase the resistance to these stresses, researchers use various technologies

and methods to increase the resistance of surfaces exposed to impact by micro-jets and shock waves, produced by the hydrodynamic mechanism of the cavitation. They aim to change the structure and mechanical properties such as hardness, mechanical strength, yield strength, resilience, which, according to extensive experimental studies, over 100 years, made of various metals, such as those made in the Erosion Research Laboratory by Cavitation of the Politechnica University of Timișoara [6-10], by Hobbs, Garcia and Hammitt [9], Franc and collaborators [8], Steller [11], Xiao-ya Li a.o. [12], contribute to increasing the resistance to erosion caused by cavitation.
The paper presents the research results concerning the vibrating cavity of the cast 5083 alloy, subjected to the heat treatment hardening solution at 350°C followed by artificial aging at 180°C with different maintenance times (one hour, 12 hours, 24 hours). The most used techniques are the volumetric heat treatments that also ensure mechanical resistance to vibrations during operation (in the case of aircraft wings, boat propeller blades). As aluminum alloys, through heat treatments, undergo some changes that do not align with the mechanisms of transformation suffered by steels, the results of the paper show substantial differences between the destruction of the structure of surfaces attacked by cavitation, resulting after heat treatments, despite mechanical properties known to be favorable for increasing the resistance of the structure to cavity erosion.

2. The researched material. Experimental procedure

For the research, initially, a piece of material was taken from a boat propeller that sailed on the Danube in the area of Romania, Figure 1, whose chemical composition, presented in Table 1, was determined in the specialized laboratory of the Politechnica University of Timișoara.

Table 1: Chemical composition of the experimental propeller alloy

Alloy	Chemical composition, [%] mass									
	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Other**	**Al**
Experimental propeller	0.389	0.378	0.102	0.83	4.71	0.19	0.246	0.141	-	Rest
5083	0.4	0.4	0.15	0.4-1.0	4-4.9	0.05-0.25	0.25	0.15	0.05	Rest

Fig. 1. Boat propeller that sailed on the Danube
(purchased from the Drobeta Turnu-Severin Shipyard)

Compared with the data provided by the literature [4], it was found that the material is other aluminum 5083, cast state (see the standard chemical composition in Table 1), obtained by continuous casting, most often in the form of plates, characterized by: semi-hardness, very good corrosion resistance (especially in the marine environment), very good behavior at low temperatures, very good machinability, good and uniform mechanical properties in the mass of others, low internal stress, homogeneous microstructure, Figure 2.

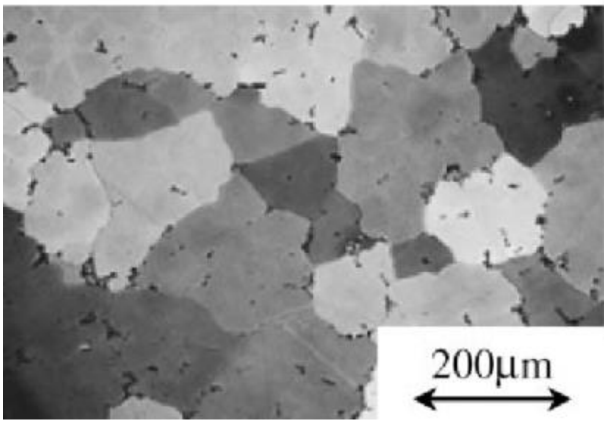


Fig. 2. Microstructure of cast 5083 alloy [4]

The used applications of this alloy are [1-3]: for airplanes, automobiles, pressure vessels, sailboats, dinghies and boats.
Because it was not possible to cut pieces from the propeller to allow the specimens to be made to the dimensions necessary to perform cavitation tests, the Special Materials Expertise Center of the Politechnica University of Bucharest was used, which provided a set of 12 cubes with a side of 30 mm, 5083 aluminum alloy, taken from a cast plate, purchased from Color Metal.
Table 2 gives the main mechanical properties, according to [4] and those determined in the Laboratory.

Table 2: Physical-mechanical properties of experimental alloy type 5083

Alloy	R_m [MPa]	$R_{p0..2}$ [MPa]	HB [daN/mm^2]	A_5 [%]	KCU J/cm^2	E [GPa]	ρ [kg/dm^3]
Experimental	260	117	72,8	11	25,2	70	2.66
Standard [4]	230-290	110-130	68-75	10-15	-	70	2.66

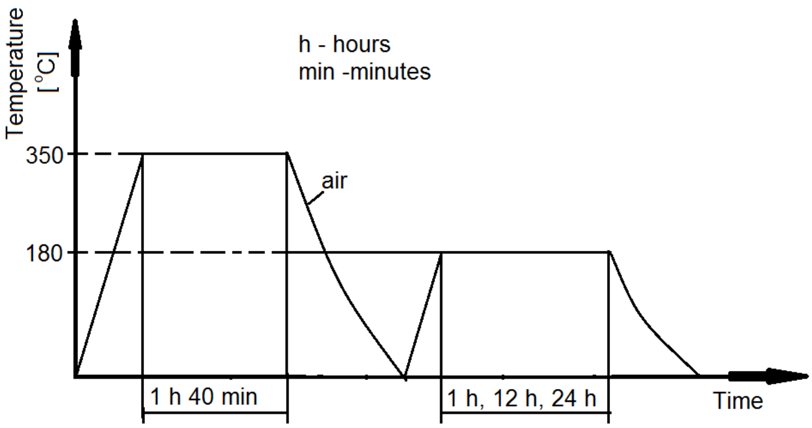


Fig. 3. Cyclorama of heat treatment

Of the 12 specimens, 9 were heat treated in the Laboratory of Metallic Materials Science, Physical Metallurgy within the Politechnica University of Bucharest. All 9 specimens were subjected to heat treatment at 350°C, with air cooling. The heat treatments were performed in a Nabertherm type oven. Then sets of three were subjected to artificial aging at 180°C, with different durations of maintenance, according to the cyclogram in Figure 3.

Table 3 shows the average values of hardness measured at 5 points on each heat-treated sample and resilience measured on three other specimens. In addition, these measurements were performed in the Laboratory of the Special Materials Research Center of the Politehnica University of Bucharest.

To simplify identification and ease of analysis, the specimens / heat treatments were symbolized as follows:

I - without heat treatment;

II - heating at 350 ℃ (holding time 1 hour and 40 min, cooling in air) followed by artificial aging at 180 ℃ (holding time 1 hour);

III - heating at 350 ℃ (holding time 1 hour and 40 min, cooling in air) followed by artificial aging at 180 ℃ (holding time 12 hours);

IV - heating at 350 ℃ (holding time 1 hour and 40 min, cooling in air) followed by artificial aging at 180 ℃ (holding time 24 hours).

Table 3: Values of mechanical properties of experimental 5083 alloy after application of various heat treatments

Property	Type of treatment		
	II	III	IV
HB, [MPa]	79	77.9	71.8
KCU, [%]	25.8	31.7	16.4

The values in Table 4 show that, by increasing the holding time, the hardness values decrease and the resilience values are not influenced by this duration. This aspect leads us to the opinion that a clear conclusion cannot be formulated regarding the influence of the maintenance duration at the artificial aging temperature, on the two mechanical properties, which according to Bordeașu's studies [5, 7, 13, 14], Franc [8], Gracia & Hammitt [9], Anton [10], influence the resistance to cavitation erosion.

As will be presented below, the resistance and cavitation behavior of the alloy in different structural states is influenced by the structure resulting from the volume heat treatment and it is difficult to highlight the dependence on hardness or resilience.

The experiment took place in the Cavitation Erosion Research Laboratory of the Polytechnic University of Timișoara, on the vibrating device with standard piezoceramic crystals, using cylindrical vibrating samples, with a diameter of 15.8 mm and 16 mm long [7]. The research conditions ,, on the total duration (165min), the intermediate periods (one of 5 and 10 minutes each and 10 of 15 minutes) on the liquid medium, the processing and interpretation of the recorded data are in accordance with the laboratory custom [5, 7, 13, 14] and those prescribed in the international standard ASTM G32-2016 [15].

Throughout the research, the functional parameters of the vibrating device, on which depends the intensity of the hydrodynamics of the vibrating cavity, respectively that of erosion, due to the automated control by a special software, were maintained at standard values [7, 15]: double vibration amplitude 50 µm, vibration frequency 20 ± 0.2 kHz, electronic ultrasonic generator power 500 W, distilled water temperature 22 ± 1°C.

3. Experimental results. Discussions

The evaluation of the behavior and resistance of the structure of the surfaces exposed to cavitation was made based on the variations of the mass of expelled material (Figure 5, 7, 9, 11, 13) and of the rate of material losses - erosion rate - (fig.6, 8, 10, 12, 14) with the duration of exposure to cavitation, as well as on the macro images of the eroded surface at significant times for the evolution of erosion as area and depth, Table 4.

For the analysis, the experimental values of the cumulated mass loss and of the erosion rates were approximated by curves constructed with the analytical relations, below, established by Bordeasu and collaborators [7, 16]:

$$m(t) = A \cdot t \cdot (1-e^{-B \cdot t}) \text{ – for cumulative mass losses } M_i \qquad (1)$$

$$v(t) = A \cdot (1-e^{-B \cdot t}) + A \cdot B \cdot t \cdot e^{-B \cdot t} \quad \text{- for erosion speed (speed of mass loss)}$$

where:

A - is the scale parameter, statistically established for the construction of the approximation curve, provided that the deviations of the experimental points from this curve are minimal

B - is the shape parameter of the curve

The experimental values, approximated by the two curves described by relations (1), are calculated on the basis of the mass losses Δmi, recorded at the end of each intermediate test period, "i", according to the relations below.

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

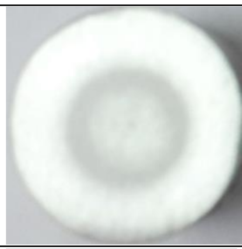
$$v_i = \frac{\Delta m_i}{\Delta t_i} \qquad (2)$$

Δti – duration of cavitation corresponding to periods "i" (5 minutes, 10 minutes or 15 minutes)

Table 4 and Figure 4 shows macro images of the eroded cavitation surface obtained by shooting with the Canon Power Shot A 480.

From these images, one can easily observe the differences in behavior and resistance to cyclic stresses of cavitation micro-jets. Thus, in samples III, surface erosion begins relatively quickly (within 15-30 minutes of cavitation) and, by the end of the experiment (165 minutes), the pits turn into large caverns, which give the shape of the detachment of metal chips. In the rest of the samples, the erosion of the cavitation is manifested by pinches, which develop completely differently from sample III, they increase in number and depth with the duration of the cavitation, in the form of caves.

Table 4: Macro images, photographed with the Canon Power Shot A 480 camera

Cavity attack duration [min]	**I**	**II**	**III**	**IV**
5				
30				

60				
90				
120				

Sample I

Sample II

Sample III

Sample IV

Fig. 4. Appearance of the eroded surface after 165 minutes of cavitation

It should be noted that all samples follow the mechanical mechanism of erosion initiation [5, 7], in the form of pinches on a peripheral ring, which then develops on the area exposed to cavitation microjets, caused by the collapse of cavitation bubbles generated by ultrasonic vibration. As can be seen, especially on the enlarged surfaces, from 165 minutes, Figure 4, of the 3 treatments, the best behavior, respectively resistance to cavitation erosion are obtained for the duration of 24 hours of maintenance of the artificial aging treatment at 180℃.
According to the aspect of the degree of erosion (cave sizes and shapes, but also the porosity created by the large number of pits), correlated with the hardness values (table 3), the impression is created that by decreasing HB hardness and KCU resilience the resistance to cavity erosion tends to increase (see sample IV characterized by the lowest values of HB = 71.8 daN / cm^2, KCU = 16.4 J / cm^2). False appearance, because the hardness negatively influences the resistance to cavitation, only when the surface becomes brittle [5, 8], and this is not the case.
The diagrams in Figure 5-12, through the experimental values and the approximation curves show the behavior of the surfaces at the cavitation demands, and those in Figures 13 and 14 serve to compare the resistance conferred by the three treatments, but also to the initial state of delivery (without treatment).
The areas marked by dark, red curves include the experimental values that express the yield of the surface material to the impact with the cavitation microjet which, in a significant duration of the cavitation (depending on the duration of maintenance to the artificial aging treatment) degrades by expanding the caverns in area and depth. At the same time, it is noticed, in all the samples, that after about 120 minutes of cavitation, until the completion (165 minutes), the mass losses and the erosion rates are approximately constant. From the experiences of the laboratory [5, 7, 13, 14] and other authors [8, 9, 11], we consider that this behavior, towards the end of the experiment, is caused by the air entering the caverns during the surface vibration, which dampens the pressure / the impact shock between the surface exposed with the shock wave and the micro-jets produced at the implosion of the cavitation bubbles, respectively.
Following the areas marked by curves and the macro images in Table 4 it can be seen that the corresponding periods correspond to those in which the surface erodes deeply.

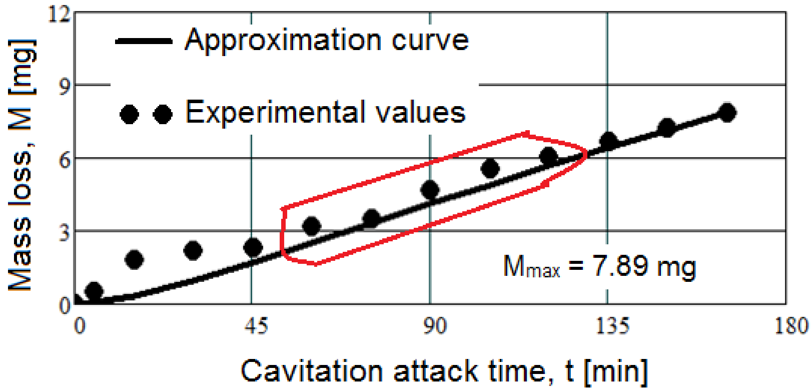


Fig. 5. Variation of eroded mass with cavitation duration (control sample)

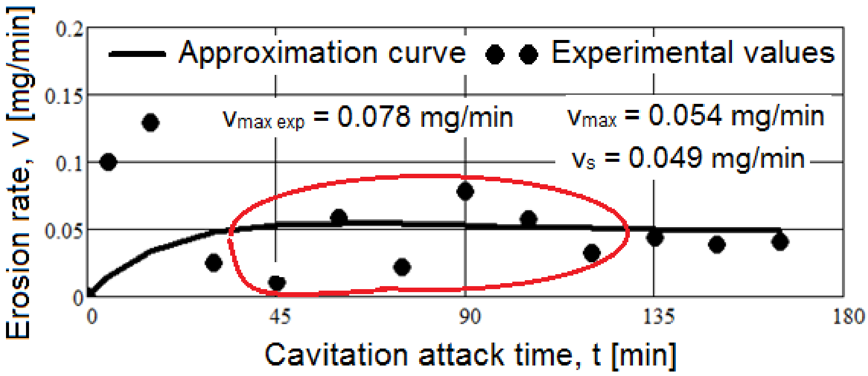


Fig. 6. Variation of erosion rate with cavitation duration (control sample)

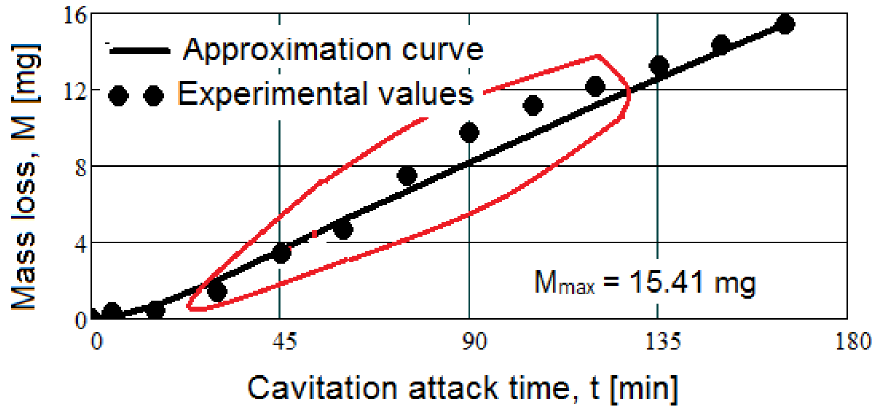


Fig. 7. Variation of eroded mass with cavitation duration (heat treatment duration 1 hour)

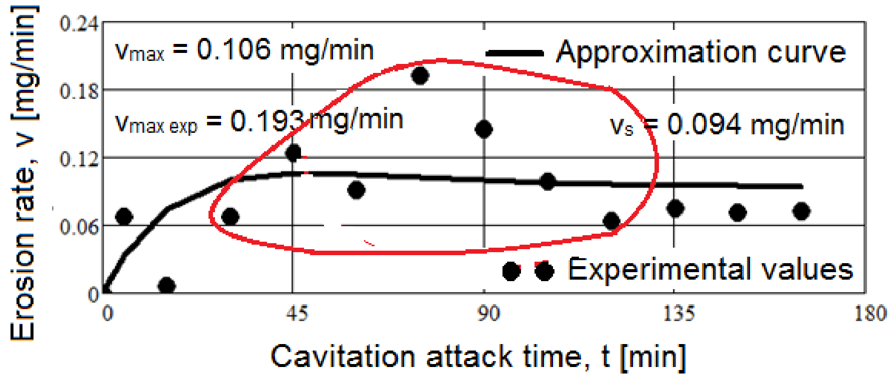


Fig. 8. Variation of erosion rate with cavitation duration (heat treatment duration 1 hour)

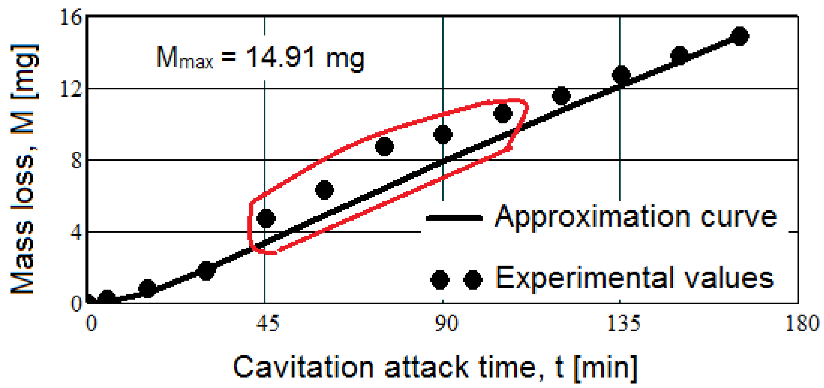


Fig. 9. Variation of eroded mass with cavitation duration (heat treatment duration 12 hours)

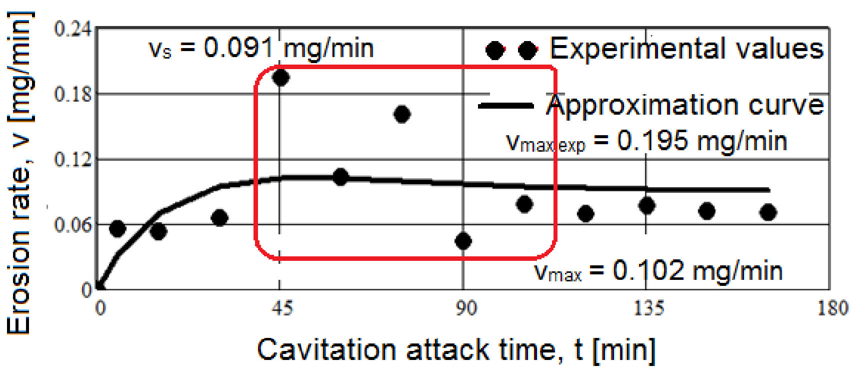


Fig. 10. Variation of erosion rate with cavitation duration (heat treatment duration 12 hours)

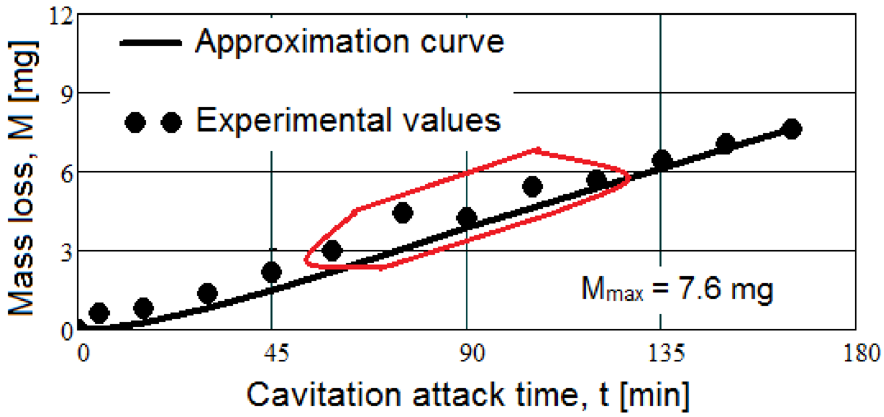


Fig. 11. Variation of eroded mass with cavitation duration (heat treatment duration 24 hours)

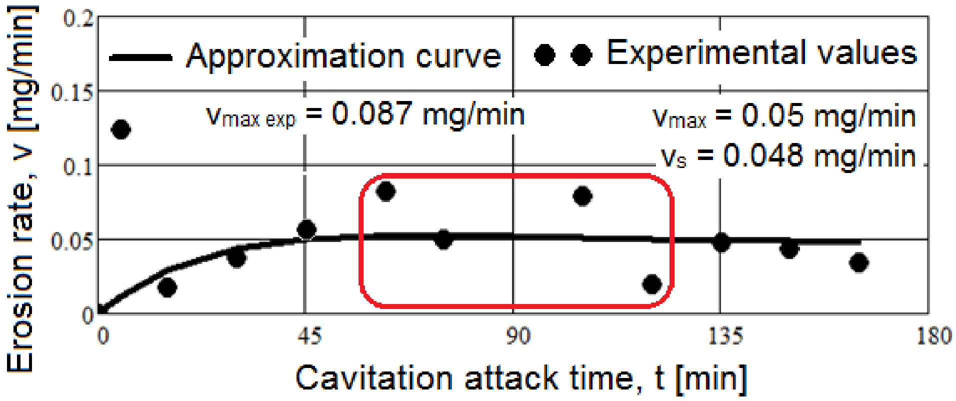


Fig. 12. Variation of erosion rate with cavitation duration (heat treatment duration 24 hours)

The comparison based on the curves of mass loss (Figure 13) and erosion rate (Figure 14) is in accordance with the appearance of the eroded surfaces, from Figure 4 and shows:
• behaviors and resistances approximately identical of the samples without treatment (I) with those of the samples with a maintenance duration of 24 hours at the temperature of artificial aging (180 °C), although they have significant differences in the mode of destruction;
• approximately identical behaviors and resistances of the samples with maintenance times of 1 hour (II) and 12 hours (III) at the temperature of artificial aging.
• Significant differences between hardness and resilience values (see Table 3) suggest that for this cast 5083 alloy not the mechanical properties have a significant influence on the resistance to cavity erosion but the microstructure resulting from the volume heat treatment.
The almost identical evolutions of the mediation curves and the differences shown by the appearance of the erosions produced in the exposed surfaces (see the images in Figure 4 and Table 4), are the proof of the complicated mechanism of destruction by cavitation, caused by the structures resulting from thermal treatments, or by retention periods (in this case). Therefore, in this aluminum alloy the evaluation/estimation of the behavior and resistance to cavity erosion, according to the values of hardness or resilience, obtained by the mentioned heat treatments, and does not align with those concluded in steels, where the duration of maintenance at the same temperature is very well reflected in the values of mechanical properties and in response to the cyclic stresses of the cavity [5, 7, 9, 10, 13, 14].

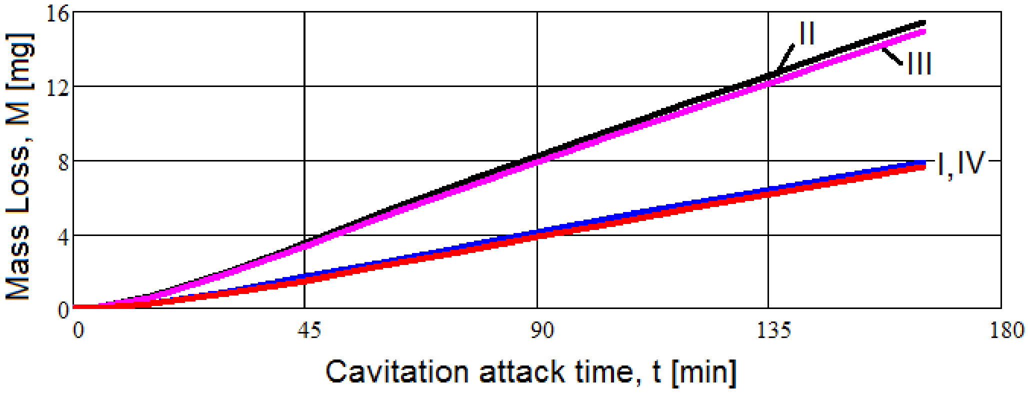


Fig. 13. Comparison of cumulative mass losses

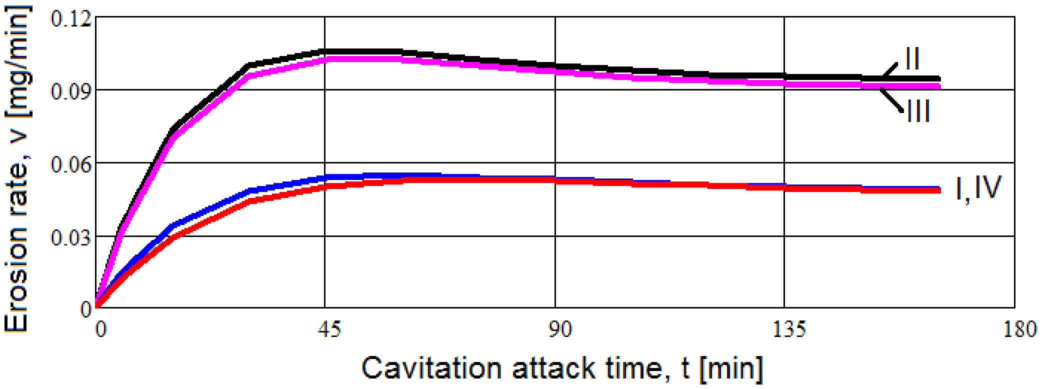


Fig. 14. Comparison of erosion speeds

4. Conclusions

1. The behavior and strength of cast 5083 aluminum alloy is strongly dependent on the microstructure resulting from the heat treatment of heating at 350 °C, followed by artificial aging at 180°C, with different maintenance times.
2. By artificial aging at 180°C / 24 hours the state of cavitation resistance is similar to the condition of non-aging test specimens, while after artificial aging at 180°C / 1 hour, or 12 hours the state of cavitation resistance is much deteriorated. A possible cause of this behavior may be due to the formation of the Guinier Preston's Zones, which by consistent precipitation achieves a decrease in mechanical properties at these intermediate heat treatments (i.e. maintenance time of one hour and 12 hours). This can be demonstrated by conducting future structural investigations.
3. No clear conclusions can be drawn about the influence of cavitation strength by hardness and resilience, as is possible on steels, due to the complicated mechanism of destruction and surface response to cyclic stresses of micro-jets and shock waves, developed by implosion cavitation bubbles,
4. It is necessary to continue the study based on analyzes by electron or optical microscopy, of very high resolution, to explain the different way of breaking the structure (chip or pinch shape).

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