Modification of Cavitation Erosion Resistance of Aluminum Alloy 7075 by Maintaining of Artificial Aging Heat Treatment at 180°C

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Abstract: *The use of volume heat treatments aims to change the microstructure and the values of the mechanical properties, with homogeneous distribution in the volume of the part, so as to confer resistance to various stresses. From the point of view of the hydrodynamic stresses of the microjets generated by the cavitation mechanism, these treatments ensure an increase in the life of the required surface. In the case of aluminum-based alloys, volume thermal treatments do not produce important changes in the structural phase, but they cause important changes in the values of the mechanical properties. As these alloys have small specific masses and good mechanical properties, research is currently being resumed aimed at extending their use to parts that work in cavitation such as: propellers of motor boats and pleasure boats, pump rotors in the cooling system of thermal engines and aircraft wings. In this sense, the vibratory cavitation tests are carried out on aluminum alloy 7075 subjected to volumetric thermal treatment of artificial aging at 180^{0}C with a holding time of 24 hours. The comparison with the results previously obtained on the delivered state and the regime with the same temperature and duration of one hour shows that the effect of increasing the duration of the heat treatment leads to a significant increase compared to the state of delivery and slightly different from that obtained by the one with a duration of one hour.*

Keywords: *Aluminum alloy, microstructure, mechanical properties, cavitation, cavitation erosion, strength, average depth of erosion, erosion speed*

1. Introduction

Usually, aluminum alloys, developed in the form of laminated semi-finished products, such as alloy 7075 state T651, are used in the manufacture of parts without going through volumetric or surface heat treatments. Use in this form is dictated by ease of machining and high mechanical property values comparable to low alloy steels [1-5]. As a result, they are mainly used in the strength structures of aircraft and river and marine vessels (sailboats, motor boats). However, industrial development in naval, aeronautical and automotive systems aims to extend the use of this alloy to parts that operate in hydrodynamic conditions, such as pump rotors and boat propellers, dangerous through the effects of cavitational erosion and/or hydroabrasion [6, 7, 8, 9]. In order to increase their lifetime to the cyclical stresses of cavitational microjets, the effects of traditional technologies (volumetric and surface thermal treatments [10, 11]) and new technologies (use of laser [7, 12] are being researched to lead to the modification of the mechanical resistance characteristics of the required surface structure, which provides increased resistance to such demands. As volumetric heat treatment furnaces have become more and more efficient, through the rigorous control of regime parameters (temperature and duration), the paper studies the effect of the cavitation erosion behavior of the alloy 7075 state T651 structure obtained by thermal aging at 180^{0}C for a duration of 24 hours.

2. The material studied

Alloy 7075 state T651, in semi-finished state (laminated sheet), is characterized by the chemical composition and mechanical property values shown in table 1 and by the microstructure shown in fig.1.
Through the heat treatment of artificial aging at 180^{0}C, with a holding time of 24 hours, the values of the mechanical properties have been changed, as can be seen in table 1 (notation TT180/24). Through this treatment modification, the microstructure also suffered, fig.2, but not one of phase, but only of the size and degree of dispersion of the chemical/intermetallic compounds, which, along with the mechanical properties, change the behavior and resistance to the fatigue stresses of cavitation.

Table 1: Chemical composition and values of mechanical properties

State	Chemical composition, [%] Wt									
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
Semi-finished (SF)*	0.68	0.107	1.58	0.076	2.05	0.19	5.76	0.2	0.23	rest

Mechanical properties				
Stare	R_m MPa	$R_{p0.2}$ MPa	HB daN/cm^2	KCU J
Semi-finished (SF)*	531.841	424.82	140	12.8
TT 180/1h*	549.549	410.55	157	14.1
TT180/24h*	570.921	417.51	140	12.7

* Values determined in the Laboratory of the Special Materials Research and Expertise Center - Polytechnic University of Bucharest.

From table 1 it can be seen that through the thermal treatment of artificial aging, the values of the mechanical properties, compared to the state of the semi-finished product, suffer increases (R_m), decreases (R_{p02}) or insignificant modification (KCU) and the identical hardness (HB). Compared to the one-hour treatment, it shows a decrease in hardness (HB) and resilience (KCU) and an increase in mechanical strength (R_m) and yield strength (R_{p02}).

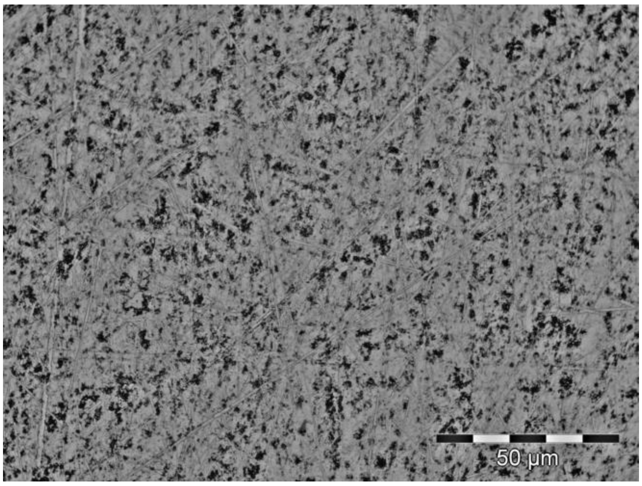


Fig. 1. Microstructure of aluminum alloy 7075 state T651
(semi-finished state)

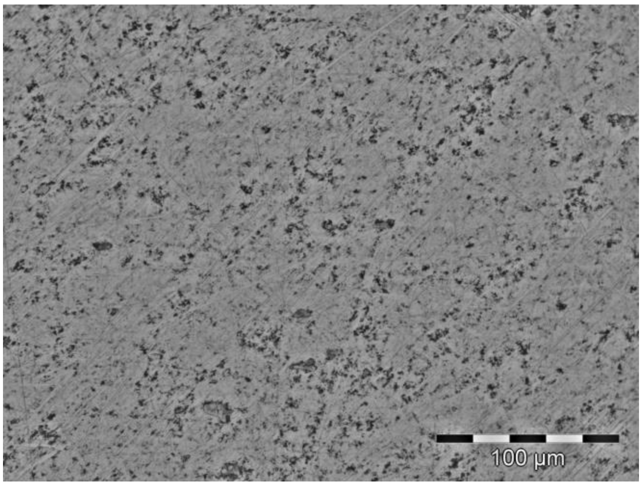


Fig. 2. Microstructure of aluminum alloy 7075 state T651
(after artificial aging at 180^{0}C, maintaining 24 hours)

Fig.1 and Fig. 2 show the effect of heat treatment, compared to the semi-finished state, by reducing the size and density of the intermetallic compounds.

3. Experimental research

a) Devices and method used for the cavitation test

The behavior and resistance tests of the heat-treated structure to cavitation erosion were carried out in potable water from the network, using the standard vibrating device of the Cavitation Erosion Research Laboratory, from the Politehnica University of Timișoara [6, 13]. The total request/test duration (165 minutes), divided into intermediate periods (of 5, 10 and 15 minutes), the water temperature during cavitation (22 ± 1^0C) as well as the way of processing and interpreting the results are in accordance with the laboratory's custom [6], which complies with the requirements of ASTM G32-2016 [14]. The stages completed in the experimental program can be seen in detail in [6].

b) Specific curves and parameters. Discussions

In fig. 3 shows the diagram showing the accuracy of the research, through the dispersion band of the experimental values, obtained on the three tested samples, against the analytical curve of MDE(t) mediation and the value of the standard deviation σ. The upper S96(t) and lower I96(t) limits of the dispersion band, corresponding to the tolerance interval (96 %) and the value of σ of 0.306 certify the accuracy of the experiment.

The diagrams of fig. 4 and fig. 5 contain the elements necessary to characterize the behavior and resistance to the vibratory cavitation stress of the structure obtained by thermal aging at 180^0C, with a holding time of 24 hours.

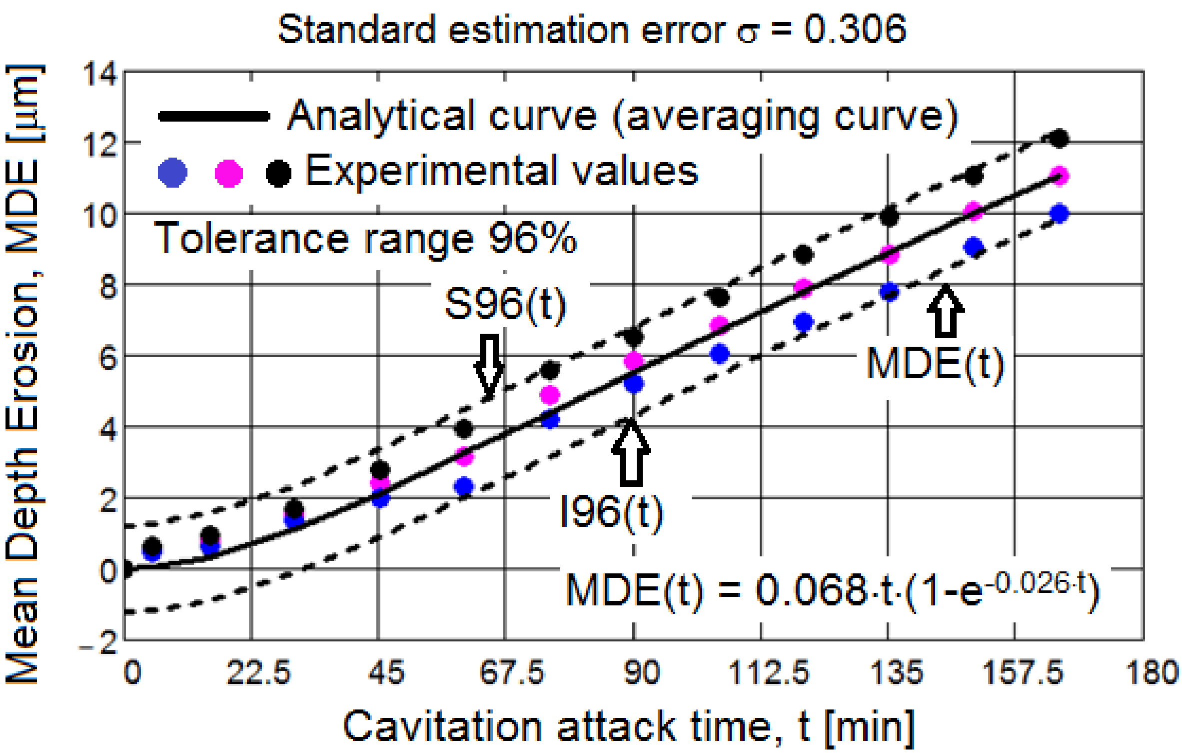


Fig. 3. The dispersion range of the experimental values.
Statistical reference parameters of the dispersion band

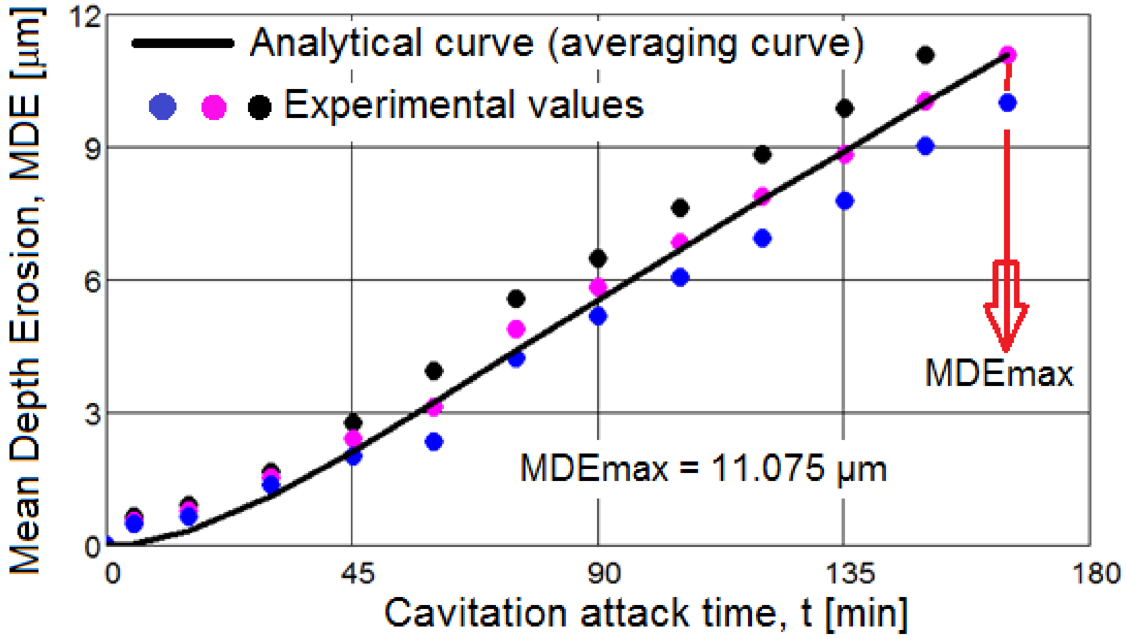


Fig. 4. Variation of cumulative mean depth of erosion with duration of cavitation stress

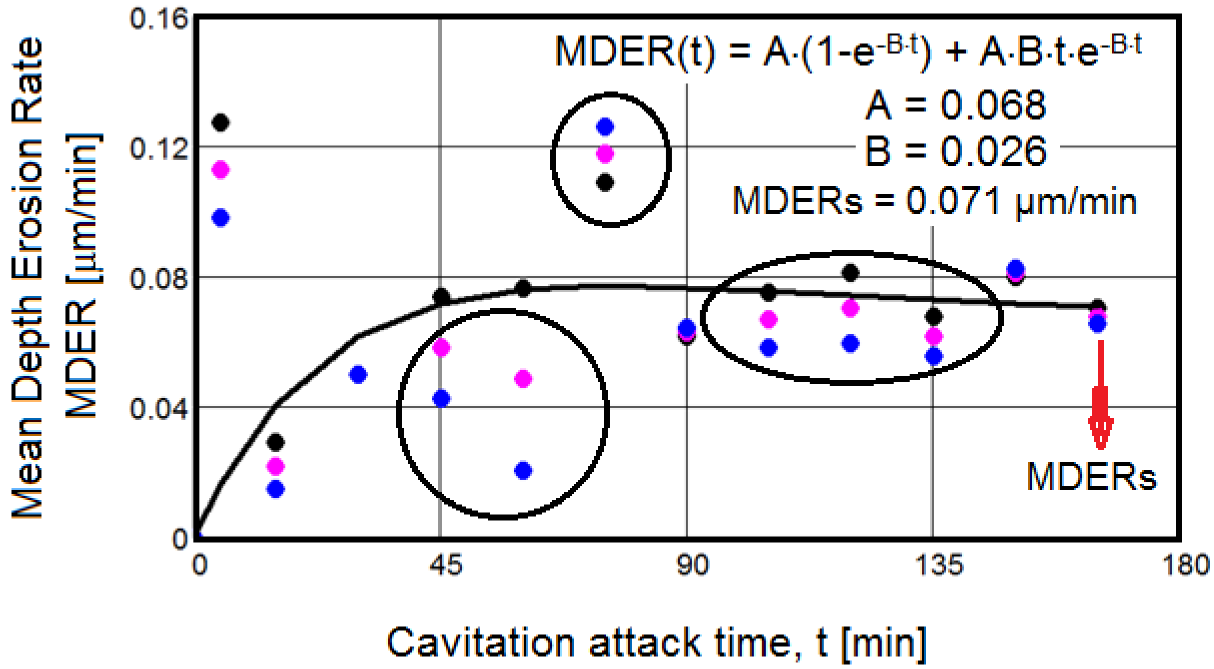


Fig. 5. Variation of average erosion penetration rate with duration of cavitation stress

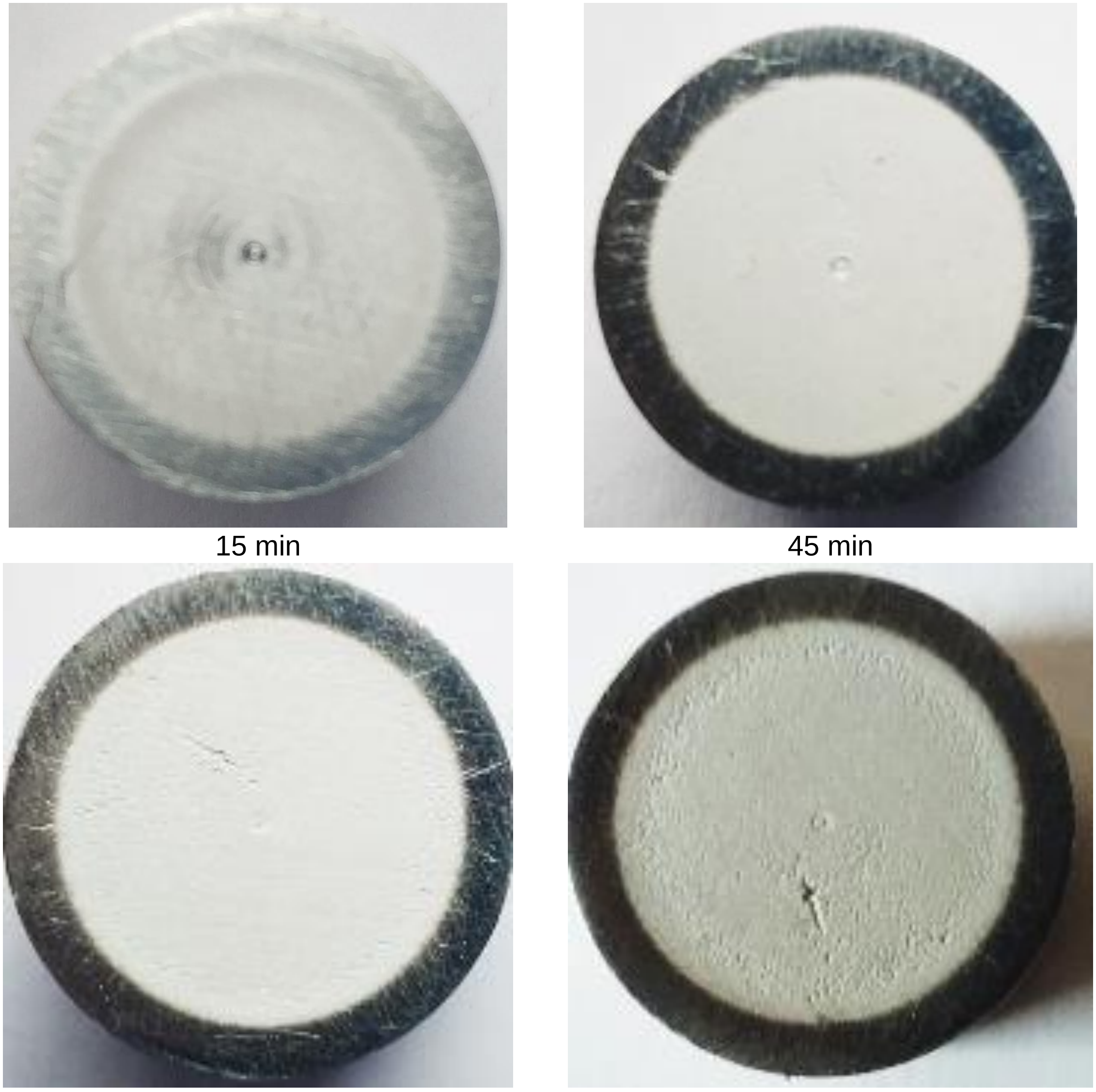
Findings resulting from the data contained in the diagrams in fig. 4 and fig. 5:

1. the experimental values of the cumulative average depths of penetration, fig. 4, continuously increase, which shows that the mechanical properties, according to experience and data from the literature [9, 15, 16] are correlated and homogeneously distributed in the structure of the required surface;
2. according to the MDE value, during the first 30 minutes of cavitation, the three samples behave almost identically, the differences being insignificant. After the 30 minutes and until the end (165 minutes) the behavior is different, explained by the microstructures that cannot be perfectly identical. Even the hardness in table 1, which is the algebraic mean of at least 10 measured values, may show differences between the three samples;

3. the variation of the experimental values compared to the MDER(t) averaging curve - the intervals enclosed by the dark, colored, black curves - fig. 5, shows that at certain periods the stress of the microjets leads to large expulsions of grains, as a result of the type of microstructures;
4. fig. 5 shows that in the interval 60-90 minutes there is a jump in the penetration speed. It is characterized by an important expulsion of material, characterized by the base metal, but especially by the intermetallic compound. This plot also shows that the samples with red and blue have close and slightly different behaviors than the one with black. This observation confirms the accuracy of volumetric heat treatment of artificial aging;
5. the shape of the averaging curves of the experimental values, MDE(t) and MDER(t), according to the literature [6, 17, 18], is specific to surfaces with good mechanical properties and homogeneously distributed in the volume of the material (see table 1) which strengthen the bonding forces of the grains (see photo images in fig.6 and 7) and ensure good resistance to cavitation erosion.

c) The morphology of destruction by cavitation erosion

Fig. 6 shows 4 photographic images, taken with the Canon Power Shot A 480 camera, at the most significant durations of exposure to vibrating cavitation.



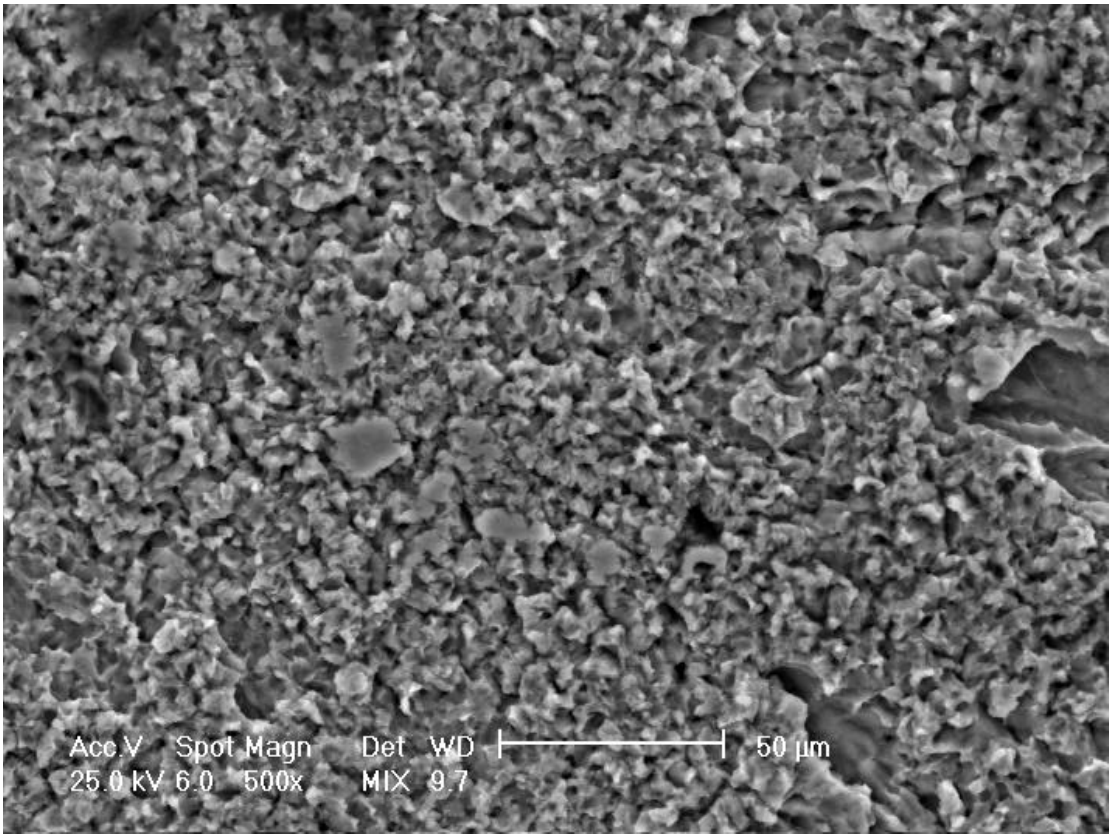
15 min 45 min

105 min 165 min

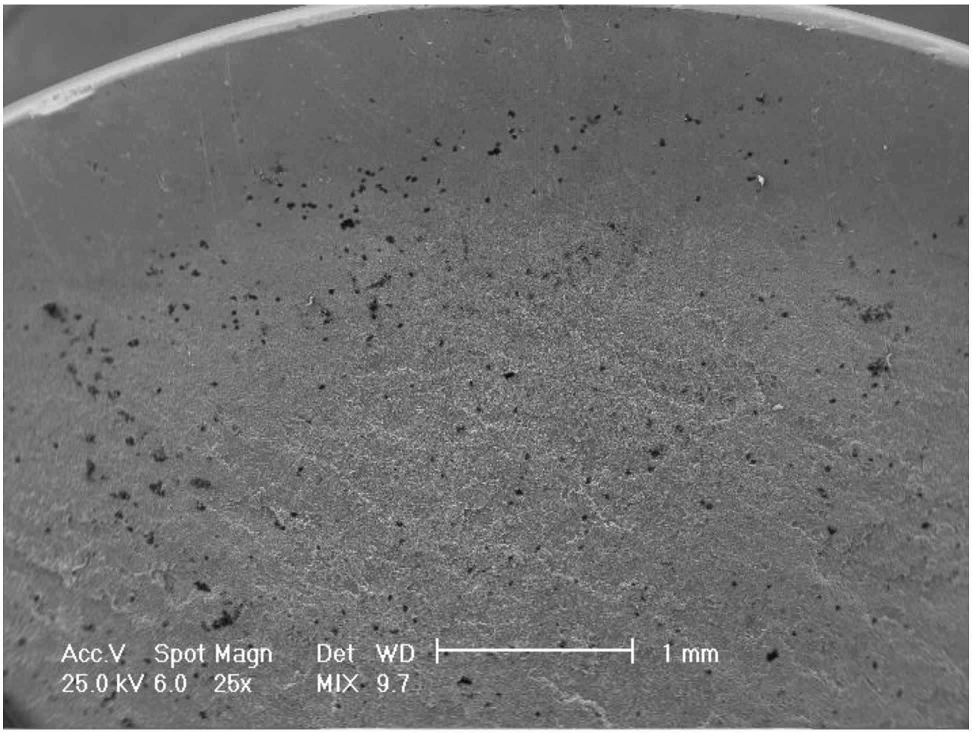
Fig. 6. The evolution of erosion in the area of the attacked surface

The 4 images justify the statements written in the analysis performed on the curves in fig.4 and fig. 5, related to the allure of the mediation cubes (MDE(t) and MDER(t)) and the dispersion of the three experimental values in relation to them. It can be seen that the erosion is continuous with small caverns, which multiply continuously with the duration of cavitation, and some deepen, confirming the expulsion of weak elements, such as intermetallic compounds.
Fig.7 shows microscopic images of the eroded surface. They show the caverns, in terms of surface area, but also in depth. It should be noted that the SEM images, regardless of the trapped area (at the periphery, fig. 7b, or inside the exposed surface, fig. 7a), as well as the depth one in fig. 7c, shows that the erosion is specific to surfaces with mechanical properties (R_m, R_{po2}, HB and KCU) with high values and well correlated with the microstructure of the surface [15, 16], determining a relatively constant behavior and with good resistance to impacts with cavitational microjets.
Note the significant difference of almost 5 times between the MDE_{max} value of 11,075 µm and the cavern caught in the section plane (53 µm). This difference confirms the importance of eliminating microstructural defects (through volumetric or surface heat treatments), such as these chemical compounds, which are unavoidable in the manufacturing phase of aluminum alloy semi-finished products.

a) Microscopic image measuring the depth of a cavern in the eroded area



b) SEM image – on an interior area (500X)



c) SEM image - at the periphery of the sample (25 x)

Fig. 7. Microscopic images (a,b) and macroscopic image (c) of the destruction produced in the surface of one of the samples

d) Comparison of results

To evaluate the resistance to the erosion of the vibrating cavitation, is made the histogram from fig. 8, in which the values of the parameters recommended by the ASTM G32-2016 norms are compared.

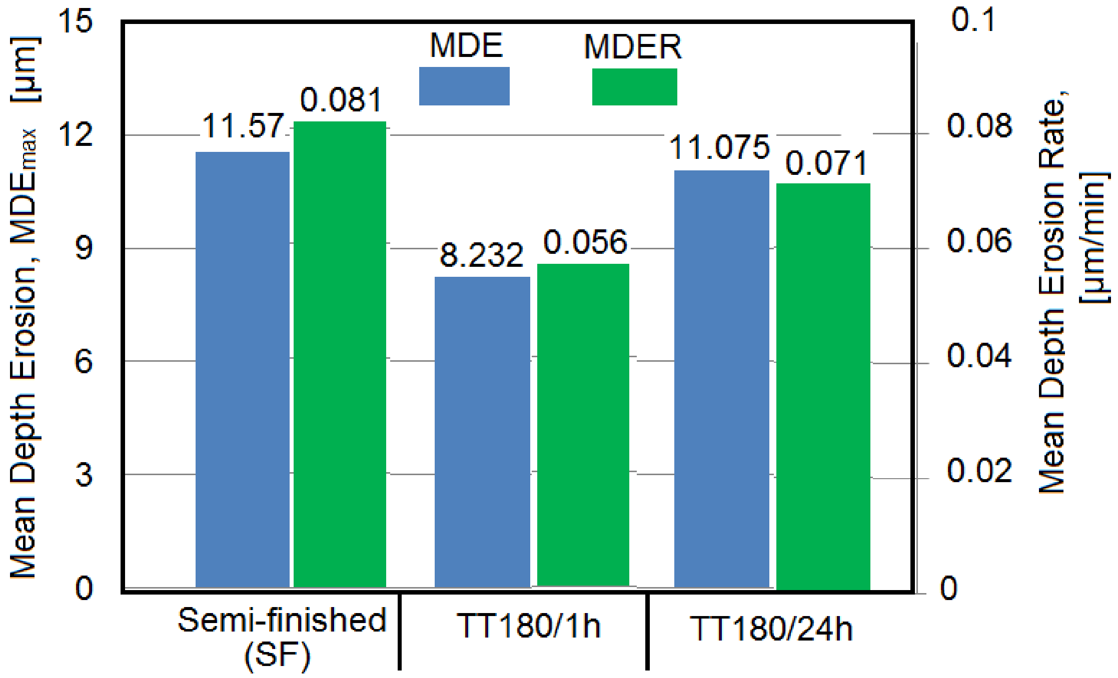


Fig. 8. Value comparison histogram

The data in the histogram shows:
1 - compared to the semi-finished state, the increase in cavitation resistance is reduced, by about 4% according to the value of MDE_{max} and by about 14% according to the value of the $MDER_s$ parameter;
2 - compared to artificial aging with a duration of one hour, is noted an important decrease in cavitation resistance; more than 34% after the value of MDE_{max} and more than 26% after the value of $MDER_s$;
3 - there is a correlation between the holding time and the aging temperature, so that through the values of the mechanical properties, especially hardness and resilience, and the resulting microstructural changes, in terms of the density and dimensions of the chemical/intermetallic compounds specific to aluminum alloys (in general), which can lead to significant increases in resistance to cyclic, destructive cavitation stresses.

4. Conclusions

1. Volumetric heat treatment, such as artificial aging at 180^0C, is a solution to increase the strength of aluminum alloy 7075 used for parts that work in cavitational currents, such as pump rotors and propeller blades of airplanes and ships.
2. The holding time at the aging temperature is a parameter with influence on the resistance of the 7075 aluminum alloy structure to the erosive stresses of cavitational microjets.
3. Not always the long holding time at a certain temperature, as is the case in this work, ensures the microstructure and the values of the mechanical properties that lead to the increase of resistance to cavitation erosion.
4. Correlating the holding time with the temperature of the aging heat treatment can lead to important increases in the resistance to cavitation through the values of the mechanical properties and the resulting microstructure.
5. The paper shows the need to study the influence of the same type of thermal treatment with other regime parameters (temperatures and holding times).

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