Modification of the Cavitation Resistance by Hardening Heat Treatment at 450 °C Followed by Artificial Aging at 180 °C of the Aluminum Alloy 5083 Compared to the State of Cast Semi-Finished Product

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Abstract: *The paper presents the results of the experiment of behavior and resistance to vibration cavity erosion, carried out on cast aluminum alloy 5083 heat treated by hardening at 450 ˚C and maintained for 12 hours at the artificial aging temperature of 180 ˚C. Following the experiment carried out in the Cavitation Erosion Research Laboratory of the Politehnica University of Timișoara, it is found that the duration of 12 hours is insufficient to increase the resistance to cavitation erosion, as evidenced by the destruction of caves in the shape of pits.*

Keywords: *Alloy 5083 aluminum, erosion of cavitation, mean depth erosion, erosion rate, microstructure, mechanical properties*

1. Introduction

Aluminum-based alloys have a very high industrial application due to their low weight and acceptable mechanical property values [1-3]. Among these applications, for our study, is of interest in the field of vehicles and river vessels [1], where there are demands of hydrodynamic currents with erosion by cavitation [4, 5]. Such parts are the rotors of the pumps for cooling the car engines and the propellers of the boats and engines for the propulsion of pleasure boats [6, 7, 8, 9], which after a number of hours of operation have surfaces with pitting erosion, sometimes with very large caverns, which requires the repair of the eroded area, or even the replacement of the part.

2. Researched material

The experimental program was carried out on samples taken from 5083 cast aluminum alloy and heat treated by volumetric hardening at 450 ˚C followed by artificial aging at 180 ˚C (see the cyclogram of the heat treatment, in fig. 1). Data on the chemical composition and mechanical properties of the researched semi-finished alloy can be found in [1, 3, 6, 7].

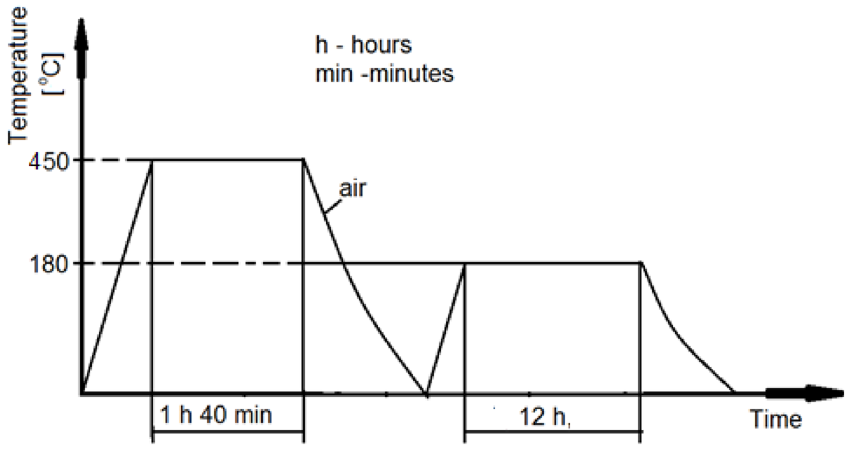

Fig. 1. Cyclogram of volume heat treatment

For the analysis of the data obtained in the detailed experiment, this paper preserves the symbolism given in the bibliographic references and mentioned in the web pages [1], (Witness (H)) for the sample taken from the semi-finished product and HNL for the heat treated sample.

3. Research equipment and method

The experimental research program was carried out in the Cavitation Erosion Research Laboratory on the vibrating device with piezoceramic crystals [4], fig. 2, within the Politehnica University of Timișoara, using the stationary sample method (fig. 2b) [4, 10].

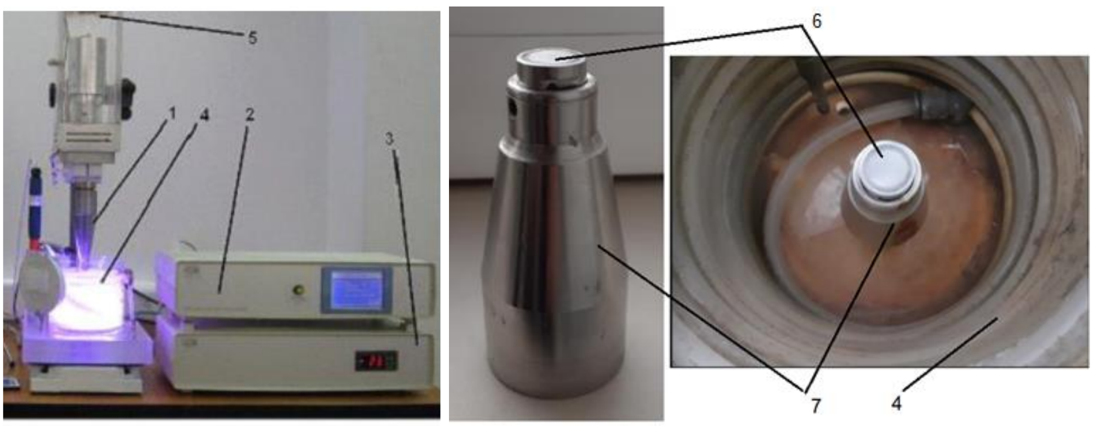

Fig. 2. Standard vibrating device
1- sonotrode; 2- electronic ultrasound generator; 3- electronic device for regulating the water temperature; 4- the vessel with liquid and the cooling coil; 5- piezoceramic transducer 20 KHz and 500 W; 6- computer for parameter control; 7- test for cavitation testing (d = 15.8 mm, length = 16 mm); 8- sample fixing device for performing the experimental test

The total duration of a test, the intermediate periods, the liquid environment, the processing and interpretation of the recorded data are in accordance with the custom of the laboratory [4, 10, 11, 12] and those prescribed in the international standard ASTM G32-2016 [13].
For the purpose, three samples were tested in double distilled water, according to the requirements imposed by ASTM G32-2016.
According to the rigors related to the appearance of the surfaces at the beginning of the cavitation test, they were polished to a roughness, Rz = 0.2 ÷ 0.8 µm.
Throughout the cavitation test, the functional parameters of the device (double vibration amplitude of 50 µm, oscillation frequency of 20 ± 0.1 KHz, electric power supply of the electronic ultrasonic generator of 500 W) and distilled water temperature of 22 ± 1 ˚C, which determines the hydrodynamic regime of the cavitation, respectively the intensity of destruction by micro-jets and

shock waves produced by the implosion of cavitation bubbles, were kept at constant values, due to the fact that the whole operation program is computer controlled and controlled specially built for this purpose [12].

4. Experimental results

4.1 Specific curves and parameters

Construction of specific cavitation curves (analytical curves), which serve to determine the values of the cumulative average depth (MDE_{max}) achieved by eroding the vibrating cavity in the surface structure, as well as the final bearing speed $MDER_s$ (known as stabilization rate of surface erosion [4, 10, 13]), was made starting from the algebraic mean values of the mass losses (Δmi) determined at the end of the intermediate periods Δt_i (5, 10 and 15 minutes) with the analytical balance type Zatklady which has an accuracy of 10^{-5} grams.
The analytical relations of the curves, detailed as a way of constructing in [14], have the form:

- for the variation of the cumulative average depth

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

- for average erosion rate (erosion rate)

$$MDER(t) = A \cdot (1 - e^{-B \cdot t}) + A \cdot B \cdot t \cdot e^{-B \cdot t} \tag{2}$$

where:
A - is the scale parameter, statistically established for the construction of the approximation/mediation curve, provided that the deviations of the experimental points (values) from it are minimal;
B - is the shape parameter of the curve.

The values of these coefficients can be seen in the diagrams in fig. 3 and 4 containing the curves MDE (t) and MDER (t).
The areas delimited by the dark red curves define the time interval in which the mass loss or destruction of the structure is pronounced. These variations are very well highlighted by the photographic images (macro) and SEM in fig. 5 and 6.

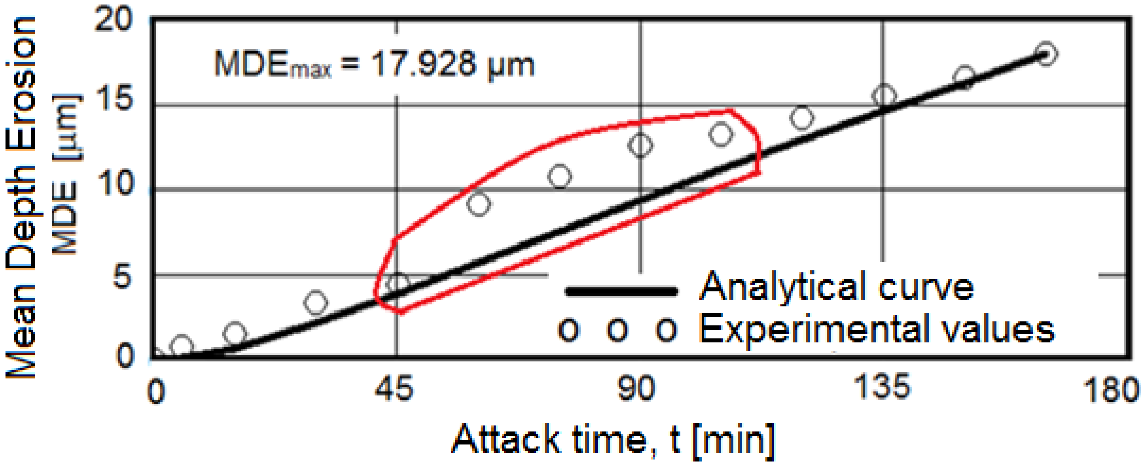

Fig. 3. Variation of the average erosion depth with the duration of exposure to cavitation ((A = 0.109, B = 0.035)

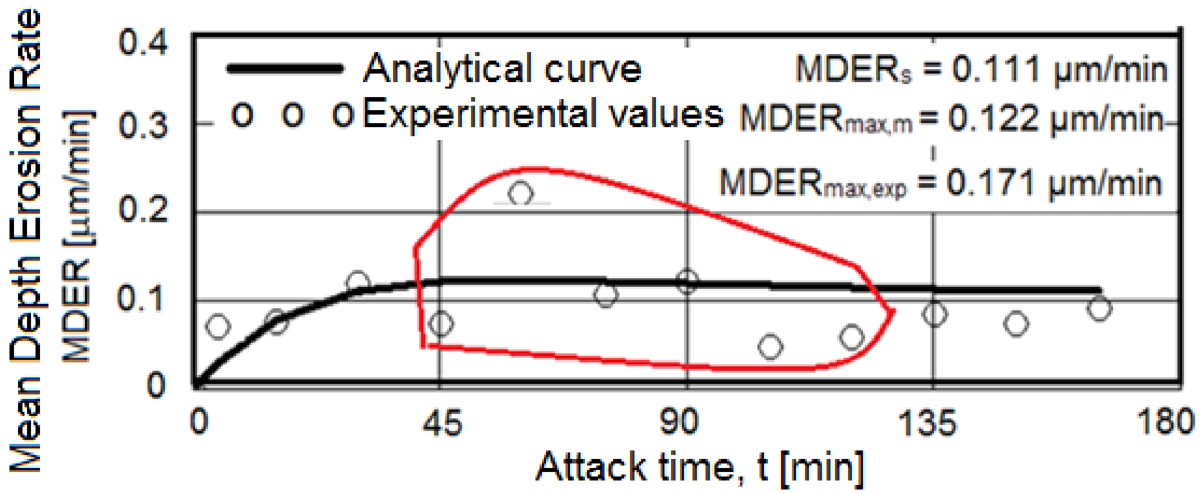

Fig. 4. Variation of the average erosion rate with the duration of exposure to cavitation ((A = 0.109, B = 0.035)

The data in Fig. 3 and 4 show:

1- The most significant mass losses, with important differences between the values of the speeds between two successive measurements, are recorded in the range 45-120. These speed jumps are in accordance with the macro-photographic images in fig. 5 and SEM (profilogram) in fig. 6;

2- The erosive mechanism of the first 30 minutes is observed, in which the mass losses are caused by the elimination of the roughness tips and the abrasive dust. The actual material losses are reduced, in the structure developing elasto-plastic deformations and crack networks [5, 7, 9, 10, 13, 14];

3- The shape of the approximation / mediation curve of the experimental values, with a difference of 11 µm / min between the maximum value ($MDER_{max,m}$= 0.122 µm/min) and the one towards which it tends to stabilize ($MDER_s$= 0.111 µm/min), is specific to surfaces with average mechanical properties in value (Brinell Hardness = 80.7 HB and Resilience = 18 J, $R_{p0.2}$ = 144.5 MPa, R_m = 311.21 MPa), which gives this condition a behavior specific to materials with low resistance to cavitation [5, 10, 15, 16];

4- After 120 minutes and until the end of the test, the erosion process takes place at approximately constant speed (the differences between the experimental, successive values of erosion rates are insignificant, within the range of deviations, specific to this hydrodynamic process), reason for which the variation of the MDE(t) curve over this time interval is approximately linear, and of the MDER(t) curve is asymptotically decreasing towards the stabilization value of the $MDER_s$. The explanation given in the literature [5, 16] is put on the hardening of the superficial layer of the cavity surface and on the attenuation of the impact forces by the air penetrated in the caverns;

5- Significant difference, of about 40%, between the maximum value obtained by experiment ($MDER_{max.\ exp}$ = 0.171 µm/min) and the one defined by the mediation curve ($MDER_{max,m}$= 0.122 µm/min), even if it is recorded at the same cavitation duration (90 minutes, fig. 4). This aspect is another proof of the complexity of the mechanism by which the structure responds to the cavitation request and by which the effect of the duration of maintenance on the heat treatment of aging on the structure and mechanical properties, as value and mode of distribution in the sample volume.

4.2 Morphology of surface degradation

The evolution of the surface structure degradation, obtained as a result of the mentioned heat treatment, is shown in the photographic images from fig. 5, made with the Canon Power Shot A 480 camera.

The erosion profile, created by the caverns in the area of the surface destroyed by the cavitation, is shown in fig. 6 by the SEM image, recorded after the end of the test (the 165 minutes of exposure of the cavitation attack).

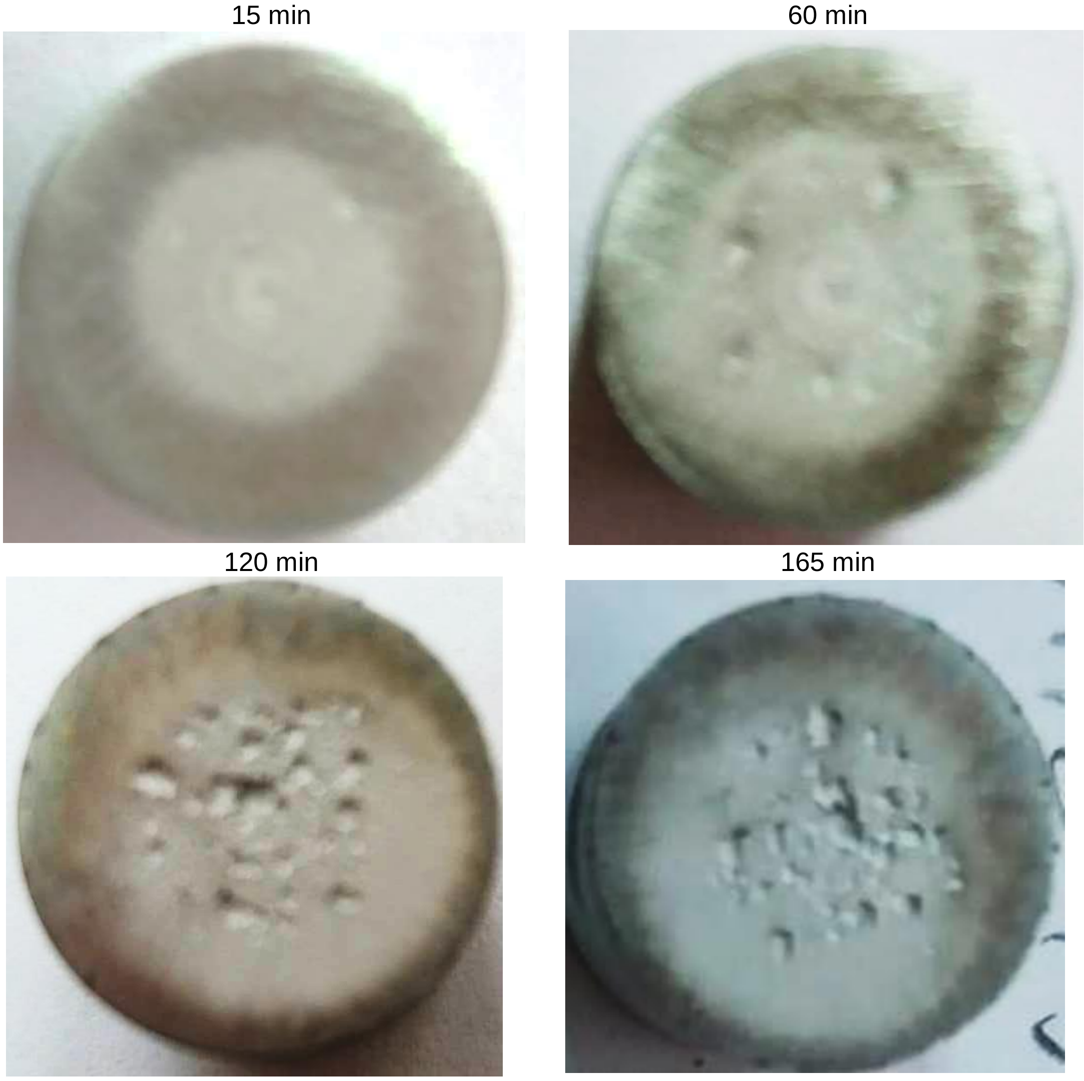

Fig. 5. Macro-photographed images after different times

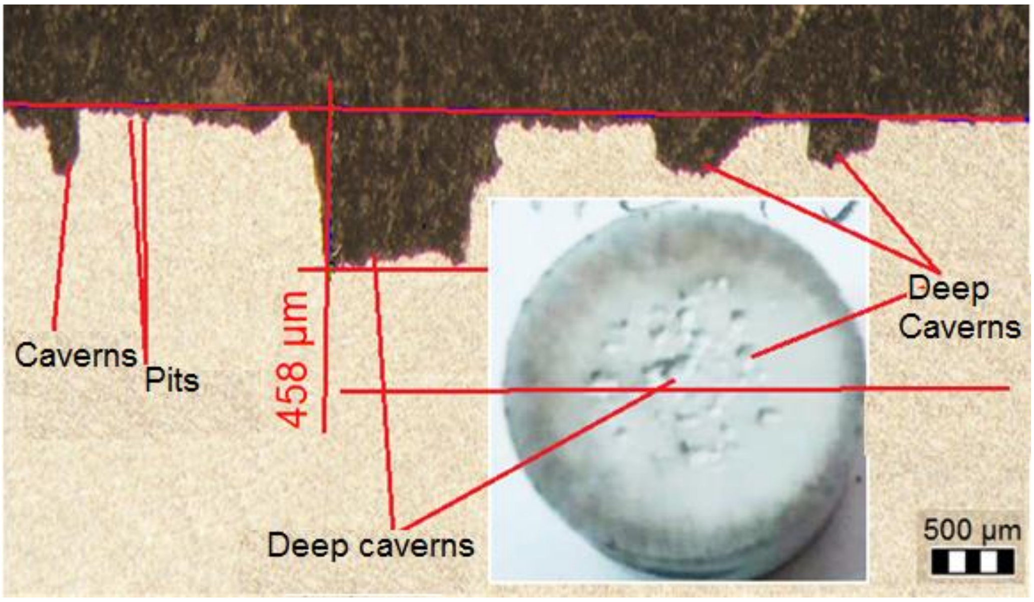

Fig. 6. Structural aspect in transversal cross-section and frontal section

The images in fig. 5 and 6 lead to the following findings:
- the photo images in fig. 5 show that the cavitational erosion of the surface starts as early as 15-30 minutes, as shown in fig. 3 and 4, but substantial, large losses, with the creation of deep caverns in depth, shape After 45 minutes of exposure to cavitation, the caverns deepen and material losses are close, causing approximately constant erosion rates. The causes have been set out above;
- from fig. 6 shows an enormous difference (over 25 times) between the value of the maximum depth of the cave caught in the section plan (451 µm, fig. 6) and the maximum average cumulated after 165 minutes (17.928 µm, fig. 3). Therefore, this difference reaffirms the conclusions of [11]; to evaluate the behavior and strength of a structure at the request of the cavity it is recommended to use the average value on the surface MDE_{max} and not the maximum of a cave, in an arbitrary area. However, it should be noted that the very high value of the pit caught in the sectioning plan raises a big question mark about the degree of fineness and the constitution of the structure resulting from this heat treatment of aging.

5. Comparison of results

The influence of the maintenance duration of 12 hours, of the heat treatment carried out at tempering temperature 450 ˚C, followed by artificial aging at 180 ˚C, on the resistance of the structure to the vibrating cavity, is presented, comparatively, in fig. 7, through the values of the parameters of the cumulative average depth of erosion MDE_{max} and of the three erosion rates.

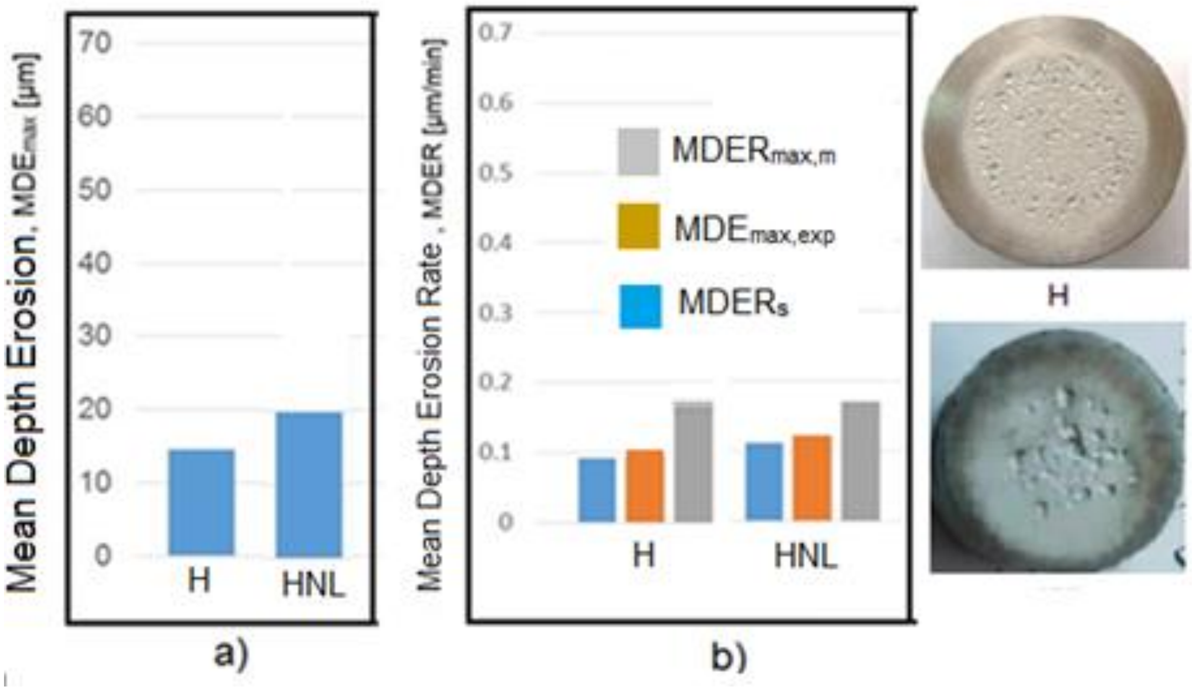

Fig. 7. Comparison between erosion parameters

The data in the two histograms, to which the photo images were attached, show:
1. according to the values of the two parameters MDE_{max} and $MDER_s$, recommended by ASTM G32 standards and used in the Cavitation Erosion Research Laboratory, the best strength is the H sample taken from the semi-finished product (MDE_{max} = 14.572 µm, $MDER_s$ = 0.092 µm/min [6, 7]);
2. Reconfirms that the maximum values of the erosion rate ($MDE_{max,exp}$), obtained from the experimental measurements and the maximum defined by the analytical curve of mediation of the experimental values ($MDER_{max,m}$) cannot be recommended to be used as comparison parameters, as due to the fact that the first does not objectively reflect the behavior and strength of the structure during the duration of exposure to cavitation (from 0 to 165 minutes), and the second does not offer the objectivity of using the speed of $MDER_s$.

6. Conclusions

1. The destruction of the structure, starting with the 135 minute of the cavitation attack and until the completion of the erosion test (165 minutes), is performed at an approximately constant speed, leading to the linear variation of the MDE(t) curve and a smooth, asymptotic decrease. MDER(t) curve to the stabilization value ($MDER_s$). The explanation is related to the hardening of the cyclically impacted layer by the cavitation microgrids and the air entering the gaps left by the expulsion of the material, which attenuates the impact force and consequently widens the cracks, breaking the bonds between the grains and expelling them.
2. The heat treatment applied determines the modification of the structure that suffers a pronounced degradation in the period 45-120 minutes, by increasing the number and geometric dimensions of the caverns.
3. The shapes of caverns, from pinching to large pits, are mainly determined by the shape of the microstructure resulting from the heat treatment regime applied.
4. The heat treatment of hardening at 450 ˚C and aging at 180 ˚C does not increase the resistance to cavity erosion, compared to the semi-finished state, but changes the way of destruction, by reducing the number of caves, increasing them in size, which requires the study continued on other regimes such as time durations and aging temperatures.

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