ISSN 1453 – 7303 **"HIDRAULICA" (No. 2/2024)**
Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*

Modification of the Cavitation Erosion Resistance of Aluminum Alloy 2017 A by 12 Hours Duration of the Artificial Ageing Heat Treatment at 140°C

Prof. PhD Eng. **Ilare BORDEAȘU[1,2,*]**, Prof. PhD Eng. **Brândușa GHIBAN[3]**,
Assist. Prof. PhD Eng. **Alexandru Nicolae LUCA[1]**,
Lect. PhD Eng. **Dorin BORDEAȘU[1]**,
Lect. PhD Eng. **Cristian GHERA[1]**, Lect. PhD Eng. **Cornelia Laura SĂLCIANU[1]**,
Assoc. Prof. PhD Eng. **Daniel Cătălin STROIȚĂ[1]**

[1] Politehnica University of Timisoara, Mechanical Machines, Equipment and Transportation Department, Mihai Viteazul str., no.1, Timisoara, Romania

[2] Romania Academy of Scientists, Timisoara Branch, Mihai Viteazul str. no.1, Timisoara, Romania

[3] Politehnica University of Bucharest, Metallic Materials Science and Metallurgy Department, Splaiul Independentei 313, sector 6, 060042, Bucharest. Romania

* ilare.bordeasu@upt.ro

Abstract: *Aluminum-based alloys are known for their applications in most fields, due to their physical-mechanical properties and their technological capability to lend themselves to the realization of various parts, with geometrical configurations ranging from simple to complex.*
These parts include those working in hydrodynamic flow fields, characterised by certain degrees of destruction by erosion created by microjets and shock waves. Such parts are the propellers of motor boats, the impellers of household pumps, radiators and pumps in the cooling system of motor vehicles. As erosion causes the surface of the part to change, causing it to fail, research is currently being developed to increase service life by increasing the resistance of the structure to cavitation erosion. This is the direction of the present work, the results of which show the effect of artificial ageing treatment at 140 °C, with a holding time of 12 hours, of aluminium alloy 2017 A. Comparison with similar results obtained previously on the delivery condition and on artificial ageing at the same temperature, with holding times of one hour and 24 hours, shows that the structure obtained by the analysed heat treatment regime is a variant for increasing the service life to cavitational stresses.

Keywords: *Aluminum alloy, characteristic curves, microstructure, average erosion depth, erosion speed*

1. Introduction

Aluminum-based alloys have experienced a real development due to their properties, replacing in some cases structures and components made of cast iron or steel. Thanks to the new material processing technologies, with the help of numerical control machines, complex parts can be made with high precision [1,2,3].

Fig. 1. Components made of aluminum alloys [6,7]

Aluminum alloy 2017A has Cu, Mg, Mn as the main alloying elements. It has good fatigue resistance, high tensile strength, is ductile and can be easily welded. Due to its high strength, low specific mass, and corrosion resistance, it is easily applicable in the structure of aviation equipment, but also in the construction of equipment that works in cavitation conditions [4,5], such as pump casings, cooling pumps for motor vehicles, boat propellers (fig. 1).

2. Researched material

The researched material is aluminum alloy 2017 A (symbolized AlCu4MgSi (A)- according to EN-AW-2017) [4,5]. It is taken from sheet metal with a thickness of 50 mm. The chemical composition and mechanical properties were determined in the specialized laboratories of the Special Materials Expertise Center, Polytechnic University and are presented in tables 1 and 2. The aluminum alloy was subjected to artificial aging heat treatment at 140°C, with three holding times, 1 hour, 12 hours and 24 hours, followed by cooling in the oven. The microstructural images, taken after the thermal treatment of artificial aging, did not reveal substantial changes [16] compared to the delivery state, instead the mechanical tests, as seen in table 2, show changes, depending on the duration of maintenance.

Table 1: The chemical composition of 2017A alloy, state T451

Alloy	Chemical composition, [% wt]									
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
Determined values	0.61	0.3	4.25	0.5	0.97	0.1	0.078	0.08	0.021	rest

Table 2: The physical and mechanical properties of 2017A alloy, state T451

State	State	R_m [MPa]	$R_{p0.2}$ [MPa]	HB [daN/cm^2]	KCU [J]
Delivery status (semi-finished)	T451*	291.16	225.01	121	29.1
Heat treated by aging	140 ºC-1h	239.409	142.87	88	19.5
	140 ºC -12h	282.075	156.07	109	10.1
	140 ºC -24h	298.114	148.36	87	22

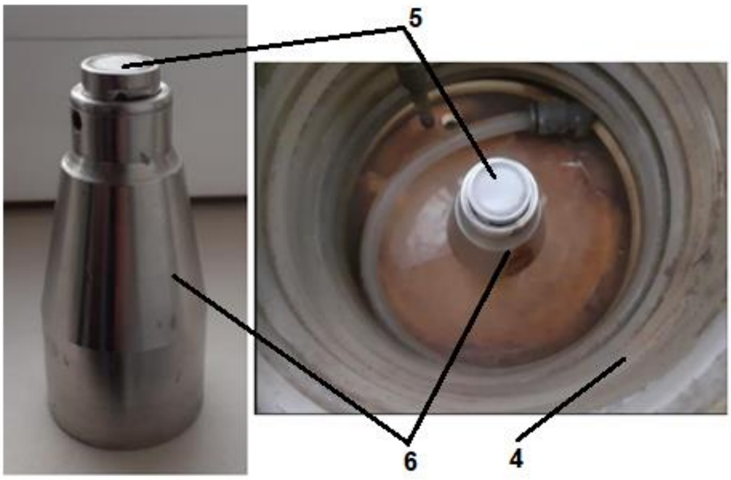
* T451: 4 shows that the condition is obtained by solution placing and natural aging, and 51 indicates stress relief during controlled stretching, applied to blanks, which are subjected to stretching to remove internal stresses after solution placing and quenching in plates.

The presentation of the mechanical properties for the delivery states and those obtained by the treatment with durations of one and 24 hours is done for the reason that these will serve at the end of the work to evaluate the resistance to cavitation of the structure obtained by the treatment with 12 hours.
The data in table 2 show that, compared to the delivery state, only the aging heat treatment at 140 ºC-24h shows a slight increase of 2.33% in the mechanical tensile strength, the rest of the mechanical properties, regardless of the holding time, have significantly lower values.
In order to be able to analyse the results more easily, in the following, the following abbreviations will be used. **T0**, will be used for samples in the semi-finished state; **T1** will be used for samples subjected to the thermal treatment of artificial aging at 140 ºC, with a holding time of one hour; **T12** are the samples subjected to the thermal treatment of artificial aging at 140 ºC, with a holding time of 12 hours; **T24** samples subjected to the thermal treatment of artificial aging at 140 ºC, with a holding time of 24 hours.

3. Experimental methodology

The experimental research was carried out on 3 samples of each material, on the vibrating device with piezoceramic crystals (fig. 2a) within the Cavitation Erosion Research Laboratory of the Polytechnic University of Timișoara [9].
The experiments were carried out by the indirect method on a stationary sample, which determined the construction of a fixing device fig. 2b, and the procedure followed the steps described by the ASTM G32-2016 norms. The attack time is 165 minutes, divided into 12 intermediate periods [8,9,10,11]: one of 5 minutes, one of 10 minutes and 10 of 15 minutes each.
The entire control system, which allows the functional parameters to be kept constant (the double vibration amplitude of 50 μm, the oscillation frequency of 20 ± 0.1 KHz, the power of the electronic ultrasound generator of 500 W and the temperature of the distilled water of 22 ± 1 ºC) it is done through a special software made for this purpose.
Before starting the cavitation tests, the samples subjected to the impact with the microjets produced by the vibrator were polished to Ra = 0.2 ÷ 0.8 μm.
The experimental procedure includes a series of actions and procedures specific to laboratory customs [9]. Initially, the samples are degreased in alcohol (acetone) and dried with a jet of hot air. At the beginning and end of each intermediate period the samples are photographed, weighed on the analytical balance Zaklady Mechaniki Precyzyjnej Gdańsk W11, with an accuracy of 10^{-5} grams, to determine the mass lost by cavitation erosion. To allow the realization of the impact forces created by the microjets and shock waves, produced by the implosion of the bubbles in the cavitational cloud, the distance between the surface of the vibrating sample and the surface of the experimental sample was 1 mm.

a)



b)

Fig. 2. Cavitation test device
a) equipment image; b) sample fixing device for cavitation testing
1- sonotrode; 2- the piezoceramic transducer 3- electronic ultrasound generator; 4- the vessel with liquid and the cooling coil; 5- test for cavitation testing (d = 15.8 mm, length = 16 mm); 6- sample fixing device for performing the experimental test

4. Experimental results

The construction of the specific cavitation curves, of each state of heat treatment, which are the basis of the evaluation of the behaviour of the surface to the cavitational stresses of the microjets, [12.13,14] was made on the basis of a calculation program developed within the Cavitation Erosion Research laboratory. The characteristic curves of the variation of the average erosion depth (MDE(t)) and of the variation curve of the average erosion speed (MDER(t)), are built based on mathematical relationships starting from the mass losses determined with the Zatklady type analytical balance [8,9,10,11].
The analysis of the evolution of the behaviour and resistance to cavitation of the alloy with thermal treatment of artificial aging at 140 ºC and duration of 12 hours is carried out based on the experimental values and the curve evolutions in figs. 3 and 4.
Clarification: the experimental values (points) are algebraic averages of those obtained on the three tested samples.

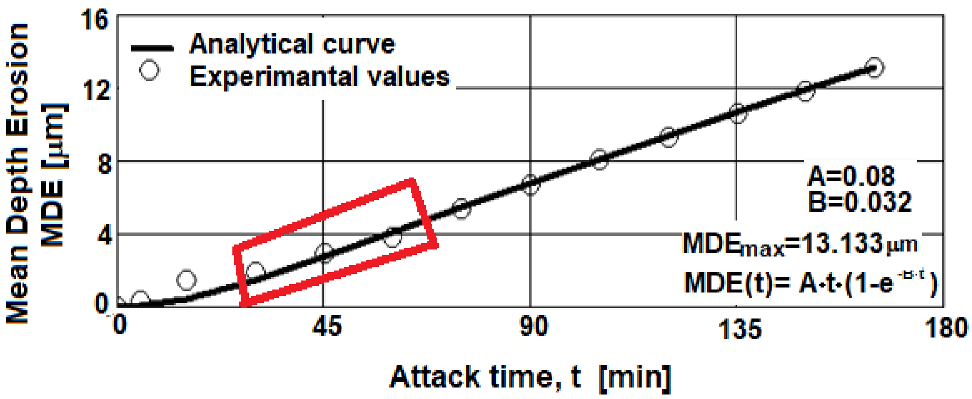


Fig. 3. Variation of cumulative mean depth of erosion with duration of cavitation

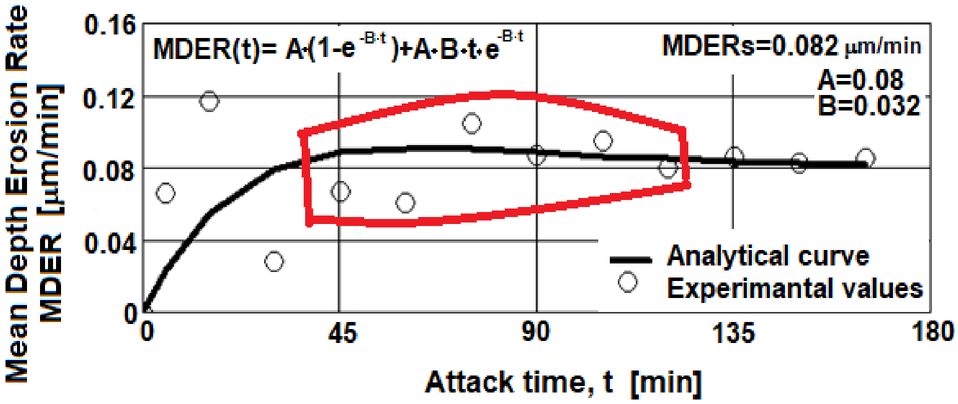
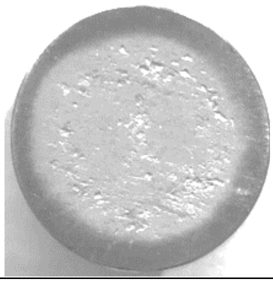


Fig. 4. Variation of mean depth erosion rate with cavitation duration

In the diagram from fig. 3, jumps can be observed compared to the averaging curve in the interval 30-60 minutes.
The data from the diagram in fig. 4 shows that the erosion penetration speed has oscillations compared to the MDER(t) averaging curve in the interval 45÷120 minutes. The evolution of the MDER(t) curve is one of growth, reaching a maximum at about 60 minutes of stress, after which the curve tends to decrease towards the (stabilization) value of MDERs = 0.08 µm/min. This mode of evolution is explained by the hardening of the layer in the cavitated surface, with an increase in the duration of the attack, simultaneously with the damping of the intensity of the impact forces by the air and water penetrated into the caverns.
According to the specialized literature [15, 17], the losses that occur in the first 5÷15 minutes are due to the abrasive dust from the abrasive paper.
Table 3 shows 4 significant images that show the evolution of the structure's degradation with increasing cavitation duration. It can be seen how the caverns, produced by the cyclic stresses of the vibrating cavitation, increase in number and geometric dimensions (areas and depth).

Table 3: Photos of the samples at the end of the test period

0 minutes	60 minutes	105 minutes	165 minutes
			

The mode of evolution of the caverns, after the 105th minute, justifies the decrease of the MDER(t) curve and the linearization of the MDE(t) curve, as an effect of the loss of the energy of the cavitational microjets through the damping effect of the air and water penetrated into the caverns, as well as of the hardening of the layer on the surface of the cavity.
Figure 5 shows the histogram that compares the maximum value of the cumulative average depth, after 165 minutes - symbolization T12, with that of the semi-finished states [16, 17] - symbolization T0, and obtained by artificial aging at 140 ºC with durations of an hour-symbolization T1 [16, 17] and 24 hours-symbolization T24 [16, 17].

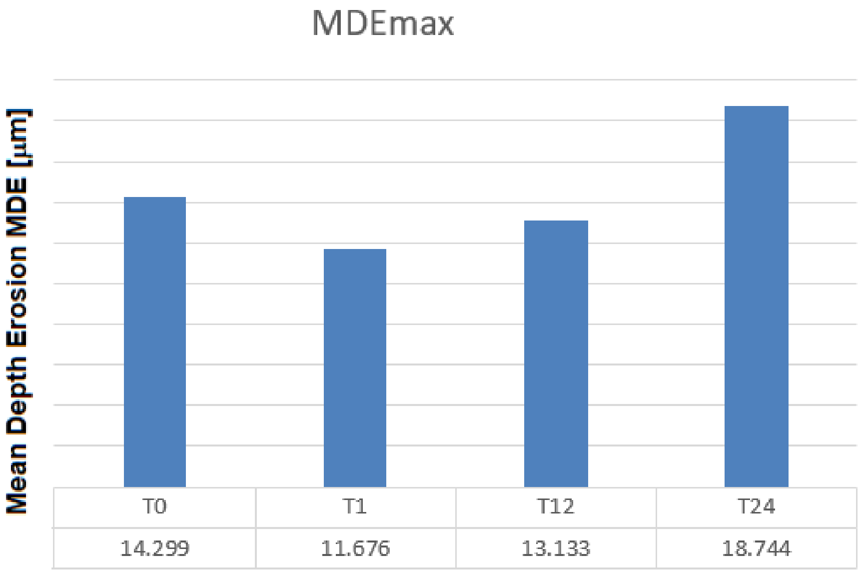


Fig. 5. Comparison of maximum cumulative depths

The data in this histogram show that through the artificial aging thermal treatment at 140 ºC for 12 hours, an increase of about 42% is obtained compared to the T24 state and about 7.2% compared to the T0 state. Compared to state T1, the resistance of the structure of state T12, to the cyclic stresses of vibrating cavitation, is about 12% lower.
These data confirm the need to correlate the temperature of the heat treatment with the holding time, in order to obtain a high resistance to cavitation stresses, which are of the local fatigue type.

5. Conclusions

The heat treatment of artificial aging at 140 ºC, with a holding time of 12 hours, shows a better resistance to cavitation compared to semi-finished steel (T0) and that obtained by the heat treatment of artificial aging at 140 ºC with a duration of 24 hours.
The mode of degradation of the investigated alloy structure under the cyclic stresses of microjets and shock waves, produced by the hydrodynamic mechanism of cavitation, is fatigue fracture, with elasto-plastic deformations and cleavage fractures.
The differences between the values of the MDE_{max} parameters, shown in the histogram in fig.5, show the need to continue research for other values of the heat treatment regime (temperature and holding time).

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