HEAT TREATMENT PARAMETERS INFLUENCE ON THE CAVITATION RESISTANCE OF AN ALUMINUM ALLOY

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The aluminum based alloy are widely used in different applications. The type 2017 A is characterized by high values of mechanical properties, which is why it is used for parts subjected to various mechanical stresses, in the fields of automotive, aviation and also in hydraulic equipment. Lately, as a result of the evolution of machines and mechanical processing processes, its application to high-speed propeller blades and rotors of heat engine cooling pumps has been sought. As these parts work in cavitation mode, in order to increase the resistance to erosion created by micro-jets and shock waves, specialists are investigating the effect of various techniques applied for this purpose. The results of the research on the behavior and strength of the 2017A alloy, heat treated by three aging regimes (180 °C, 140 °C and 120 °C), with the same maintenance duration (24 hours), to the erosion produced by the cavitation generated by vibration are also included in this direction. The analysis of surface degradation, performed based on photographic images from various times and microscopic ones at the end of the cavitation attack, as well as based on the evolution of characteristic curves and parameter values recommended by ASTM G32-2016, it is found that the most appropriate treatment is from 120 °C.

Keywords: aging heat treatments, aluminum alloys, cavitation erosion

1. Introduction

Due to the low weight of aluminum approx. one third of that of steel [1], but also of good mechanical properties, especially at low temperatures, the alloys

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of this material have been widely used in almost all fields. One of the most adaptable metals, aluminum is used in a variety of compounds that are continuously being researched. Due to their combination of simultaneous characteristics—low density, high specific strength, and excellent corrosion resistance—alloys in the 5xxx series are used in the shipbuilding, automotive, aerospace, and transportation industries as well as in the production of some hydraulic system components [1 - 9]. On the other hand, some components, during operation, such as radiators and rotors of vehicle cooling pumps, as well as propellers of fishing and pleasure boats are affected by the corrosive, abrasive, chemical and cavitational action of water [9, 18- 20]. At certain hydrodynamic flow regimes, cavitational corrosion becomes the most dangerous. Operation in such regimes inevitably leads to structural damage due to cyclic microjet stresses and shock waves produced by imploding cavitational bubbles. Although the chemical constitution and alloying with other chemical elements improves the mechanical properties, the lifetime is still limited when operating in high intensity cavitational flows.

The material researched in the paper is the 2017 rolled aluminum alloy, which is part of the Al-Cu-Mg alloy group. The material is characterized by good workability and weldability, good mechanical properties, high fatigue strength, good corrosion resistance through the use of spray treatments or other corrosion protection.

Due to these properties, this material is mainly used in the aeronautical and aerospace industry, various resistant structures, metal constructions, military equipment, rivets [2, 3].

a b

Fig. 1. Fields of use of aluminum alloy 2017 [2]

In these applications, the material is subjected to a combination of mechanical stresses, chemical and electrochemical erosion, thermal shocks, cavitational erosion, etc.

A destructive effect often encountered in equipment working in the hydrodynamic field is the cavitation phenomenon [4-10].

Research on samples made of such material has shown that by applying thermal, thermochemical or mechanical treatments to them, some mechanical properties can be improved without significantly affecting the other characteristics, such as the structural constitution [11-20].

2. Materials and Experimental Procedures

The material under investigation is the aluminum alloy EN-AW 2017 ISO: AlCu4MgSi (A) in rolled state [3]. In the delivery state, the material has the chemical composition shown in Table 2 and the mechanical properties shown in Table 1.

Table 1

Mechanical characteristics of the material in the delivery state [3]

Mechanical characteristics					
Alloy EN AW-2017	Material condition	Tensile strength, Rm (MPa)	Yielding Strength, (MPa)	Elongation at Break (%)	Brinell Hardness, (HB)
	laminated	Min. 290	Min. 221	Min. 10	Min .110
experimental		291.16	225.01	12	121

Table 2

Chemical composition of the material in the delivery state [3]

alloy	Chemical composition (% wt.)								
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Altele	Al
EN AW-2017	0.2÷0.8	≤ 0.7	3.5-4.5	0.4÷1.0	0.4÷1.0	≤ 0.10	≤ 0.25	≤ 0.25	≤ 0.05	Rest
experimental	0.75	0.65	3.75	0.85	0.95	0.09	0.15	0.18	-	rest

From this material 12 cylindrical samples were taken, from which were made three samples for each heat treatment condition.

2.1 The aging heat treatments

The sets of samples were subjected to aging heat treatments, which consisted of heating the samples to different temperatures of 180° C, 140°C and 120°C and maintenance for 24 hours, folowed by cooling in air, according to the diagram shown in fig. 2. For the heat treatment experiments a NABERTHERM muffle furnace was used type L5/1.51L, 1100°C.

2.2 Structural analysis

Structural characteristic of the samples in different state, both delivery state, or ageing state were determined quantitative and qualitative by analyzing at

stereomacroscope type OLIMPUS SZX, equipped with QuickMicroPhoto4.4 soft and OLYMPUS metallographic microscope type CX23T7S2 LED.
To identify the samples, they were marketed with the following symbols:

Z – material in delivery state;
Z180 – age hardening at 180°C with holding time 24h;
Z140 – age hardening at 140°C with holding time 24h;
Z120 – age hardening at 120°C with holding time 24h;

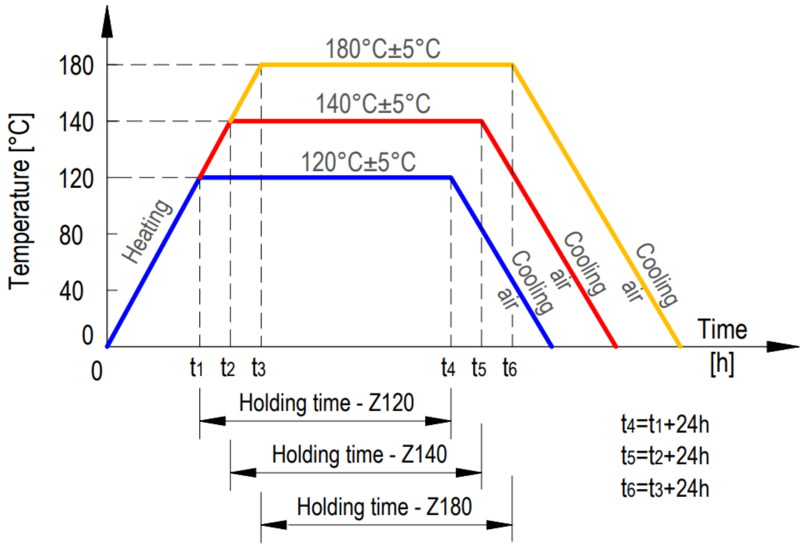


Fig. 2. Ciclogram of age hardening treatment

2.3 Cavitation erosion tests

The samples of material in delivery condition, as well as the treated samples were subjected to the cavitational erosion tests, according to the procedures of the Cavitation Erosion Research Laboratory within the Politechnica University of Timişoara, on the vibrating device with piezoceramic crystals presented in fig. 3, in compliance with the requirements of international standards ASTM G32-2010 [11].

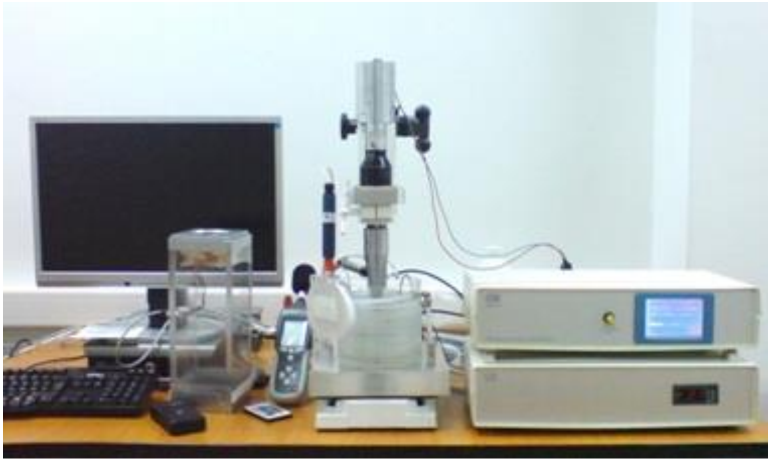


Fig. 3. Vibrating device with piezoceramic crystals

The functional parameters of the device, kept constant throughout the research, are: power - 500 W, vibration frequency - 20000 ± 2% Hz, vibration amplitude - 50 µm, sample diameter - 15.9 ± 0.05 mm, supply voltage - 220 V/50 Hz, working fluid - drinking water, working fluid temperature - 22 ± 1ºC.

3. Results and discussions

3.1 Analysis based on mechanical properties and structural analysis

Results concerning mass los and mechanical properties values are given in table 3. After cavitation tests it was observed different mass loss under different state. So, for ageing 180°C/24h, or 140°C/24h a considerable increase of mass loss take place in comparison with delivery state, instead the best behaviour is observed for applying an ageing at 120°C/24h, where it takes place a decreasing of mass loss, aproximately with 40% lower than delivery state.

Table 3

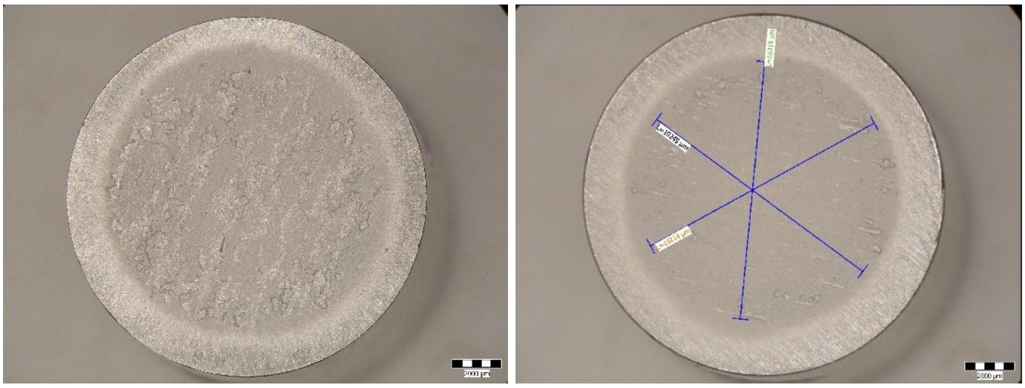
Mass loss and mechanical characteristics of the experimental samples

Properties	Materials state			
	delivery	Ageing 180°C/24h	Ageing 140°C/24h	Ageing 120°C/24h
Mass loss [mg]	7.97	13.41	10.57	5.89
HB [daN/mm^2]	117	87.0	74.9	121
KCU [J/cm^2]	14.5	22.0	9.7	29.1
Rm [MPa]	291.16	298.11	281.10	316.08
$Rp_{0.5}$ [MPa]	143.38	148.36	140.09	225.01

As one may see, by applying different ageing treatments hardness values may decrease in case of applying ageing at 180°/24h and 140°/24h, and have a slight increase at 120°/24h, in comparison with the value for delivery state. Considering the value of resilience, the best behavior is for the ageing at 120°/24 h, with is considered accepted, over 25 [J/cm^2]. Considering the values of the mechanical characteristic (respective yielding strenght and fracture strength), these remain aproximately at the same values for ageing at 180°C/24h, or 140°C/24h. Instead, by applying the ageing at 120°C/24h one may remark a slight increase, both to yielding strengh ant fracture strength in comparison with the values of the delivery state.

Following the cavitation destruction tests (with a total duration of 165 minutes), the surfaces of the samples were eroded differently, as shown in the fig. 4, fig.5, fig. 6 and fig. 7. The macroscopic analysis made on stereomicroscope reveals the following remarks. The material in the delivery state (fig. 4) shows eroded areas developed more on the surface, and less in depth. This mode of degradation is due to the hardness and good mechanical properties of material [10, 12-20].

The samples subjected to the aging treatment at 180 °C with maintenance for 24 hours (fig. 5) show the highest mass losses, extended both in surface and in depth. As a result of maintaining the samples for a long time at a high temperature, Si forms with Mg the Mg_2Si phase, which dissolves in aluminum and contributed to reduce the values of mechanical properties [1], [8], [9]. This fact contributes substantially to decrease the resistance to cavitation erosion.



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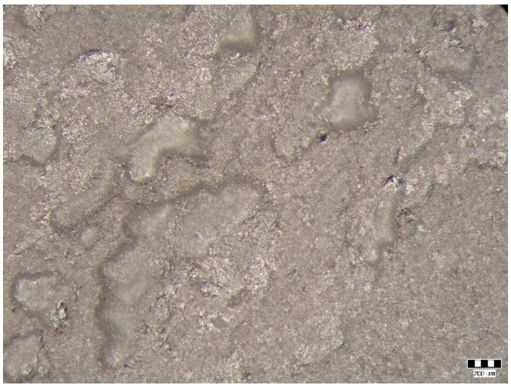

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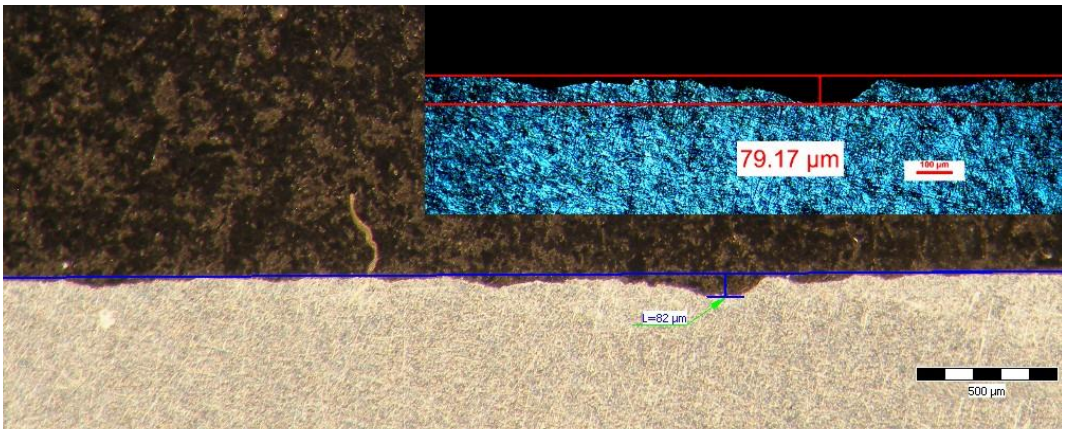

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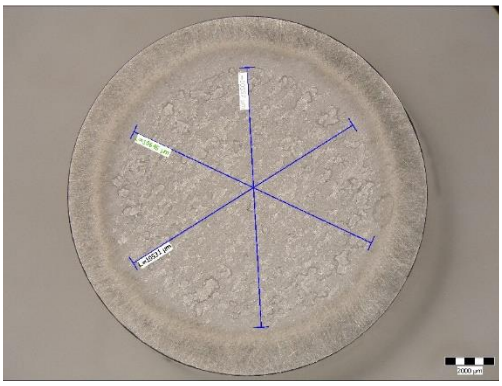
Fig. 4- Stereomacroscopic aspects of cavitational surfaces for sample in delivery state (a,b,c) and microstructural aspect (d) of eroded surfaces of samples in delivery state revealed by stereomicroscopic analysis (base image) and metallographic analysis (right top image)

a



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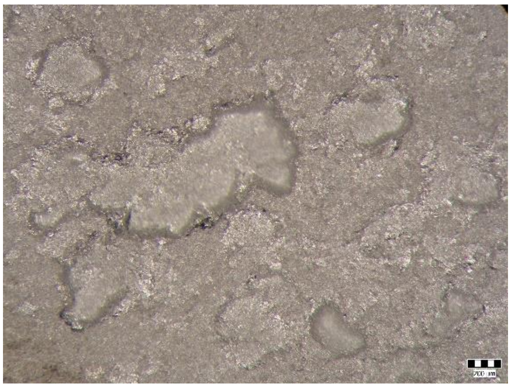

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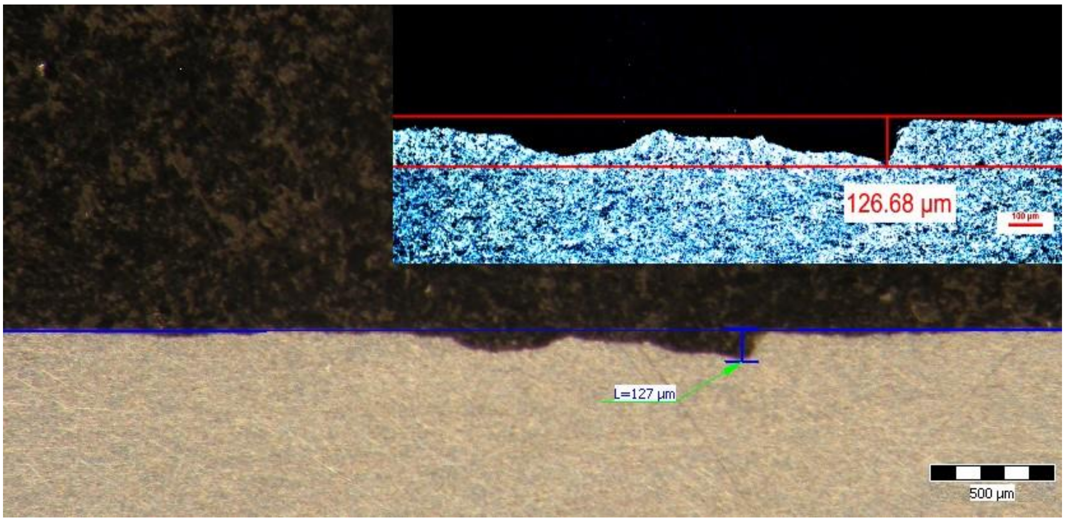

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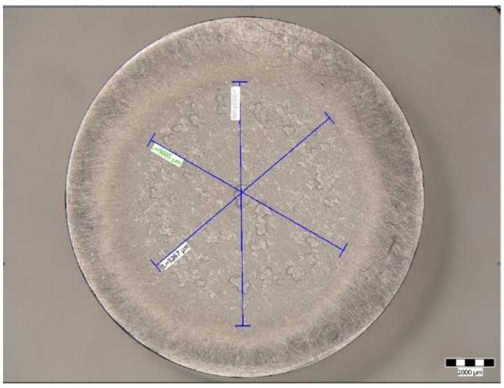
Fig. 5- Stereomacroscopic aspects (a,b,c) of cavitational surfaces for sample after ageing at 180°C/24h and microstructural aspect of eroded surfaces samples after ageing at 180°C/24h revealed by stereomicroscopic analysis (base image) and metallographic analysis (right top image)

a



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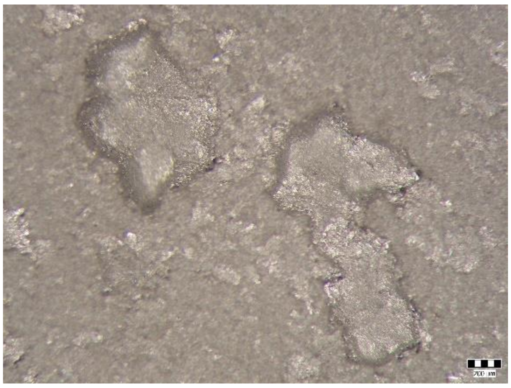

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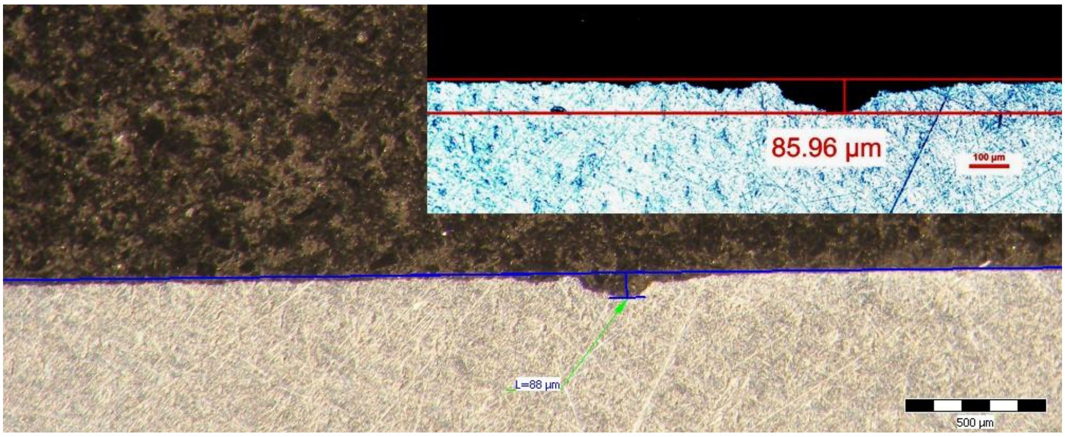

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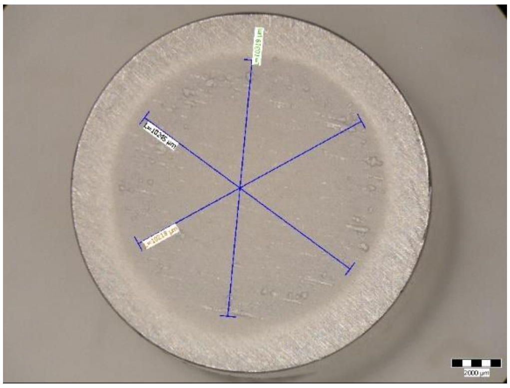
Fig. 6- Stereomacroscopic aspects (a,b,c) of cavitational surfaces for sample after ageing at 140°C/24h and microstructural aspect of eroded surfaces samples after ageing at 140°C/24h revealed by stereomicroscopic analysis (base image) and metallographic analysis (right top image)

The samples subjected to aging treatment at 140°C with maintenance for 24 hours (Fig. 6) show a behavior similar to samples treated at 180°C, with extensive eroded areas as surface, but with shallower depths.

The samples subjected to the aging treatment at 120 °C with maintenance for 24 hours (fig. 7) show the best cavitational behavior, with erosions on the small surface, developed in depth.

a



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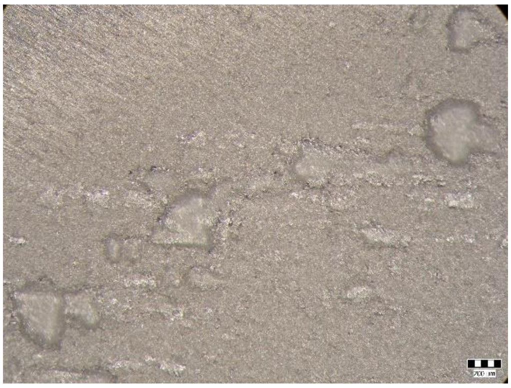

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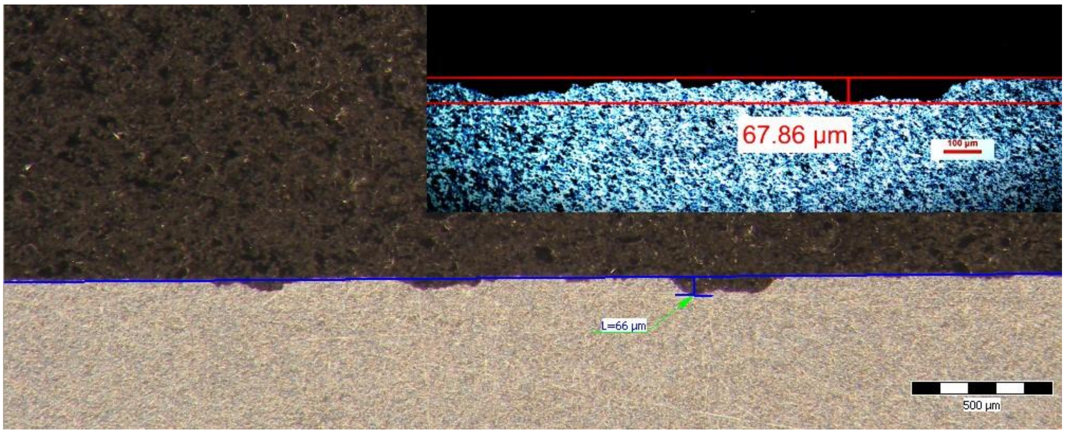

d

Fig. 7- Macroscopic aspects of cavitational surfaces for sample after ageing at 120°C/24h and microstructural aspect of eroded surfaces samples after ageing at 120°C/24h revealed by stereomicroscopic analysis (base image) and metallographic analysis (right top image)

By maintaining this at lower temperature, most of the mechanical properties of the material are preserved, and by precipitating some intermetallic compounds, increases in particular the ultimate strength Rm. The results concerning measurements of the surface diameters of cavitation affected zone and also the maximum depth of the cavitational attack in different states are given in table 4.

Table 4

Measurements of the surfaces diameters and the maximum depth of the cavitational attack of the samples in different state

sample	Cavitational attacked surface					Maximum depth of the cavitational attack, μm	
	Exterior diameter, μm		Interior diameter, μm		%	Stereomicroscopic analysis	Metallographic analysis
	value	average	value	average			
Delivery state	14330	14326	10228	10420	73	82	79.17
	14327		10643				
	14322		10290				
ageing 180°C/24h	14599	14590	10557	10578	73	127	126.68
	14597		10645				
	14573		10531				
ageing 140°C/24h	14454	14456	10618	10731	74	88	85.96
	14458		10775				
	14453		10800				
ageing 120°C/24h	14554	14617	9267	9387	64	66	67.86
	14650		9005				
	14647		9889				

These results are in accordance both with mechanical characteristic behavior and with mass loss values. Generally, the cavitation affected surface is about 73-74% for the samples in delivery state or after ageing at 180°/24h or 140°/24h, the lowest values being for the samples after ageing at 120°C/24h. The same observation can be made concerning the maximum depth of the cavitational attack. So, the highest values of the depth is for samples aged at 180°/24h or 140°/24h (respectively 127μm and 88μm) in comparison with that of the delivery state, about 82μm. The lowest value of the maximum depth is also met at the samples after ageing at 120°C/24h, respectively 66μm.

3.2 Cavitation characteristic curves

The characteristic cavitation curves shown in Figs. 8 and 9 were prepared based on the analytical relationships established statistically in the Laboratory within the Polytechnic University of Timişoara [11-20], based on partial mass losses, the procedure being in accordance with the requirements of international standards in the field ASTM G32-2010.

Comparing the values resulting from the aging process of the 2017 aluminum alloy with the material in the delivery state, are observed different cavitation behaviors depending on the value of the holding temperature.

Analyzing the curves of variation of the mean depth of erosion MDE(t), after the 165 minutes of cavitational attack, compared to the delivery state, are observed decreases of the values of the average erosion depth only al the samples treated at 120 °C with approx. 26%, the other samples registering increases of this parameter by 32.6% in the case of samples after ageing at 140°C/24h and by 68.2% in the case of samples after ageing at 180°C/24h.

The material treated at 120°C shows the best cavitational behavior, which can also be seen from the evolution of the variation curves of mean depth of erosion rate MDER (t).

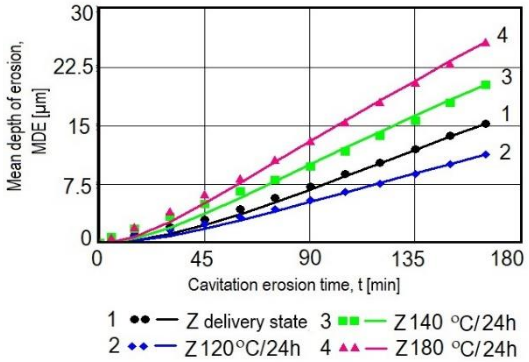

Fig. 8. Mean depth of erosion vs. cavitation erosion time of the experimental 2017A aluminum samples

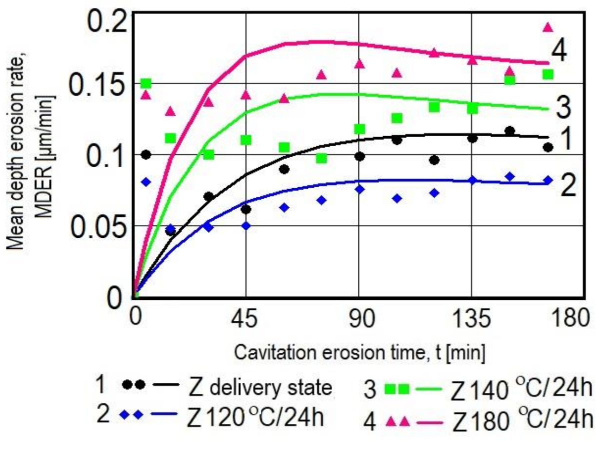

Fig. 9. Mean depth erosion rate vs. cavitation erosion time of the experimental 2017A aluminum samples

4. Conclusions

The 2017 aluminum alloy, researched in this paper, has good mechanical characteristics, including in the delivery state, respectively a good behavior at cavitational erosion.

The analysis of samples subjected to different states of ageing heat treatment with different temperatures, maintained for 24 hours, revealed that by increasing the holding temperature above 120°C, respectively at 140°C or to 180°C, the mechanical characteristics depreciate, having negative effects on cavitational behavior.

All the results are in accordance, both results concerning mechanical properties, loss mass, structural features and cavitational measurements, leading to the conclusion that there is a correlation between structure – properties - cavitation behaviour of the samples of aluminum alloy type 2017, subjected to different ageing treatments.

However, the treatment of aging at a temperature of 120°C/24h, had as an effect an increase in mechanical strength at break and a decrease of approx. 26% of mean deptf of erosion.

Consequently, due to the beneficial results obtained in the samples aged at 120°C, we recommend the use of this treatment process for parts made of aluminum alloy 2017 that work in a cavitation environment and there is the intention to extend the research on this material to other treatment regimes.

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