Resistance and Behavior to Cavitation Erosion of Semi-Finished Aluminum Alloy 5083

Prof.PhD.Eng**. Ilare BORDEAȘU[1],** Lecturer PhD.Eng. **Cristian GHERA[2],**
Eng. **Dionisie ISTRATE[3],** Univ. assist.PhD.Eng. **Laura SĂLCIANU[4],**
Prof.PhD.Eng**. Brandușa GHIBAN[5],** Eng. **Dumitru Viorel BĂZĂVAN[6],**
Assoc. prof. PhD.Eng**. Lavinia Mădălina MICU[7*],** Lecturer PhD.Eng. **Daniel-Cătălin STROIȚĂ[8],**
Eng. **Alexandra SUTA[9], Ileana TOMOIAGĂ[10],** Dipl. Eng. **Alexandru Nicolae LUCA[11]**

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

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

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

[4] Politehnica University of Timisoara, salcianu.laura@yahoo.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 from Romania, lavimicu@yahoo.com

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

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

[10] Politehnica University of Timisoara, Ileana_tomoiaga@yahoo.com

[11] Politehnica University of Timisoara, alexandru.luca2@student.upt.ro

*****Corresponding author: Micu Lavinia Mădălina, lavimicu@yahoo.com

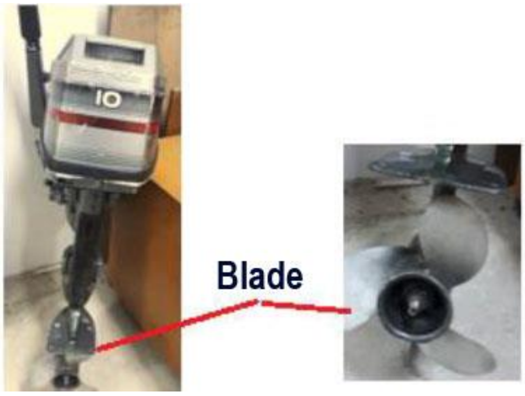
Abstract: *Among the applications of aluminum-based alloys is that in the field of hydraulic installations and equipment. Some components of their structure, such as the rotors of the cooling pumps of motor vehicles, or the blades of propellers from the engines of fishing boats, or pleasure boats, and even the radiators of motor vehicles are subject to corrosion by the cavity created during operation. Among the aluminum alloys used in the manufacture of such components is the alloy 5083. These parts can be made by casting (rotors / pump housings and steam propeller) or laminated semi-finished products, such as blades for rotors / propellers with adjustable vanes. Cavitation operation inevitably leads to damage by erosion caused by cyclic stresses of micro-jets and shock waves generated by the implosion of cavitation bubbles. As a result, the paper presents the results regarding the degradation by vibration cavitation of alloy 5083, in the form of cast and rolled semi-finished product. The curves and parameters specific to the resistance of the alloy to cavity erosion, as well as the images of eroded surfaces, show, surprisingly, that the cast semi-finished product has a higher resistance than the laminated one, due to the mechanical properties and the type of microstructure.*

Keywords: *Cavitation erosion, semi-finished, cast, laminate, erosion rate, erosion depth, cavity resistance, mechanical properties, microstructure*

1. Introduction

Aluminum-based alloys, known as duralumin, have a very high industrial application, due to their low specific mass (less than 3 g / cm^3) and high mechanical properties. The best known are from the food, automotive, aircraft and naval industries [1, 2]. A series of components more or less mechanically, hydrodynamically or chemically stressed made from these alloys are made. For those required hydrodynamically, specialists are looking for solutions to increase the surface resistance to cyclic stresses of micro-jets and shock waves, which cause degradation by erosion. Such parts are the rotors of household well pumps, the rotors of water pumps for cooling car engines (fig.1 c and d), the stern of boats (where the cavitation vortex is manifested), the propellers of boat engines (fig.1 b) and of the pleasure boats (fig.1.a), respectively the attack board of the aircraft wing and its warhead. Therefore, it is necessary to know the strength of the alloy, regardless of the type of semi-finished product (cast or rolled), to look for ways to increase it, by using modern or traditional heat treatment technologies, so as to increase the service life when they are operated in hydrodynamic conditions with developed cavitation. In this sense, the research on aluminum alloy 5083 (cast and rolled) is included, the results of which are presented below, whose purpose is to present the differences in strength between the two semi-finished states and to look for methods of structural modification and properties. mechanical, which increase the resistance of the surface to the hydrodynamic stresses of the cavity.

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



b) Boat engine propellers

c) Car cooling pump

[3]

d) Tractor cooling pump

[4]

Fig. 1. Various propellers and motor vehicle cooling pumps, made of aluminum-based alloys

2. The investigated material

The aluminum alloy, whose behavior and resistance to cavity erosion has been studied, is 5083 from the 5000 series [5] (known by the symbol AlMg4.5Mn), from the Polytechnic University of Bucharest.
The research was carried out on test specimens, taken from the two forms of semi-finished product, cast and laminated, under which the alloy is used in practice [5, 6]. The samples offered for the cavitation tests (with a diameter of 15.8 mm, according to the requirements of ASTM G32-2016), as well as those from which the specimens for the mechanical tests were made, are taken from laminated and cast sheets, purchased from Color Metal [5, 6].
The laminated semi-finished product is in the H111 [7] laminated state, followed by solution hardening from 454 ° C to 399 ° C and aged at 343 ° C, followed by air cooling. The molded semi-finished product is not subjected to any heat treatment, so it is characterized by low internal stress, microstructural homogeneity and constant properties throughout the volume [6].
Table 1 shows the values of the mechanical properties, according to the standard EN AW 5083 and those determined in the Specialized Laboratory of the Polytechnic University of Bucharest.

Table 2 shows the chemical, standard and measured compositions.

Table 1: Standard and measured mechanical properties

Specimen	$R_{p0,2}$ MPa	R_m MPa	HB daN/mm^2	KCV J/cm^2	A5 %	Z %
5083 T (standard)	110-130	230-290	68-73	-	10-15	
5083 T (measured)	141.66	294.824	72.8	25.2	-	23.4
5083 L Standard	105-125	260-340	70-75	-	12-15	
5083 L (measured)	135.78	235.367	80.1	5.3	-	4.15

T- cast semi-finished product, L-laminated semi-finished product

The data in Table 1 show that, compared to the laminated semi-finished product (5083 L), the cast alloy 5083 T has higher values for the mechanical breaking strength Rm (by about 4%), the yield strength $Rp_{0.2}$ (by about 25%) and KCV resilience (about 4.8 times) and HB hardness lower by about 10%). These values are reflected in the destruction of the structure of the cavity surfaces, by the evolution in plan of the cavity area by increasing the number, depth and width of the caverns (see table 3).

Table 2: Standard and measured chemical compositions

Alloy	Chemical composition, [%]									
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other	Al
5083 (standard)	< 0.4	< 0.4	< 0.15	0.4-1.0	4-4.9	0.05-0.25	< 0.25	< 0.15	0.05	rest
5083 T (measured)	0.38	0.36	0.141	0.85	4.69	0.23	0.223	0.142	-	rest
5083 L (measured)	0.39	0.37	0.137	0.89	4.71	0.21	0.243	0.137	-	rest

The data in Table 2 show that the chemical elements, identified, are in the standard range, but with slight differences from one material to another, which, also, through compounds formed at the micro level produce their effect on the resistance of caristal bonds to collisions with micro-jets. shock waves.

3. Experimental research

3.1 Apparatus and method used

The experimental research program was carried out on the vibrating device with piezoceramic crystals, from the Cavitation Erosion Growth Laboratory within the Polytechnic University of Timișoara. The experimental procedure was with a stationary sample, in accordance with the standard procedure, described by ASTM G32-2016 [8] and according to the custom of the laboratory, in terms of total and intermediate durations of exposure to cavitation attack, how to record and process data. experimental [9-11].
Three samples were tested from each type of material.
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 the micro-jets and shock waves produced by the implosion of the cavitation bubbles, were kept at constant values, due to the fact that the whole operation program is computer software specially built for this purpose [12].

3.2 Cavitation test results. Analysis and discussions

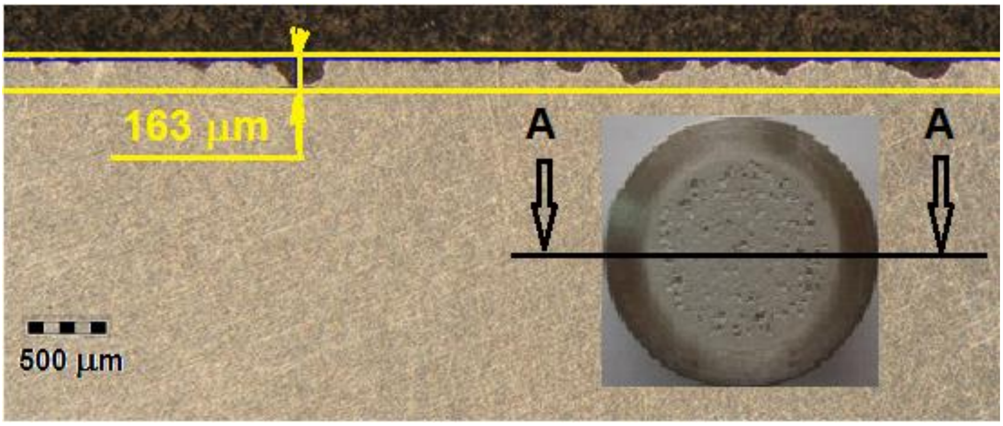
3.2.1 Destruction of the surface exposed to the vibrating cavity

Table 3 gives images of eroded surfaces, at three significant times, for one of the three samples tested in each material. The images, depending on the size of the caverns and the area in which they extend, highlight the differences in behavior and resistance to the cyclical stresses of local fatigue produced by micro-jets and shock waves.
The larger shape and dimensions of the caverns produced in the layer of laminate semi-finished product (5083 L) are observed. This is the effect of lower values of KCV resilience (property that strongly influences the absorbed energy to break the bonds between the crystalline grains), but also of the mechanical breaking strength Rm and the yield strength $Rp_{0.2.}$

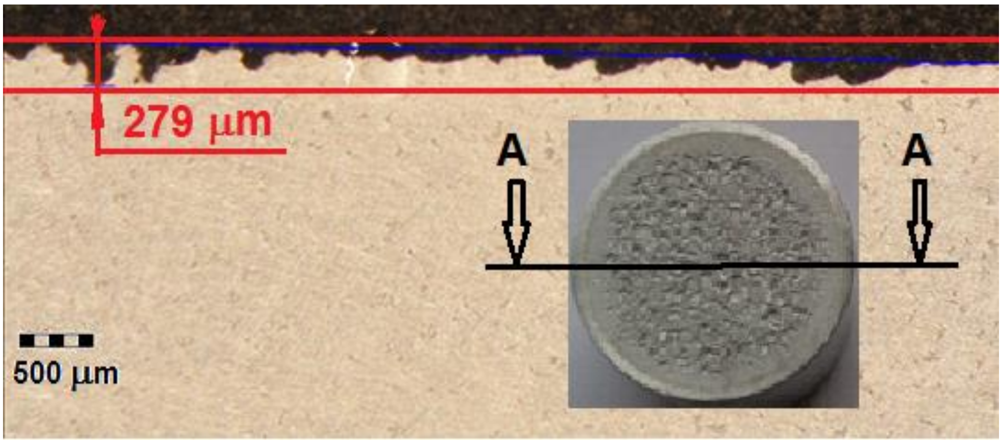
Table 3: Macro-photographed images at significant times

Material	45 min	105 min	165min
5083 T			
5083 L			

Although hardness is a property with great influence, positive, on the resistance to cavitation erosion, according to the studies of most specialists, the most cited being Bordeasu [9], Garcia ao [13], Hobbs [14], Franc ao [15], Steller [16], Sakai-Shima [17], made of various types of metals, especially ferrous and copper alloys, in this case does not help due to the low values of other mechanical properties, equally influential on the strength of stresses. cavitation fatigue.
Fig. 2 shows images under an optical microscope on sections A-A made by the cavitationally eroded surface, which highlight the maximum penetration depths of the cavitation and the dimensions of the caverns in the cavity area.



a) 5083 T



b) 5083 L

Fig. 2. Images under the metallographic optical microscope (caverns, cracks, deformations) and macrostructural images of the eroded structure in the specimens required for cavitation in the two structural states

Moreover, these images, from fig. 2, confirms the lower resistance of the 5083 L alloy compared to the 5083 T. It is observed both the differences in roughness created by erosion, but also the cavern with the greater depth at 5083 L (279 µm compared to 163 µm). At 5083 T there are fewer and deeper caverns, and at 5083 L more, wider and deeper. These developments of deformations and fractures are also related to the values of mechanical properties. The more frequent ruptures of the 5083 L alloy are also caused by the higher hardness value (80.1 HB).

3.2.2 Curves and characteristic parameters

In fig. 3 and 4 show the specific cavitation diagrams, constructed based on the mediation of the mass losses recorded at the end of each intermediate period "i" (one of 5 and 10 minutes and 10 of 15 minutes each [9]), on the three samples tested, using the relationships:

$$M_i = (1/3)\sum_{i=1}^{12} \Delta m_i \text{ - cumulative mass loss (experimental values)}$$

$$v_i = (1/3)\Sigma\frac{\Delta m_i}{\Delta t_i} \text{ - erosion rate (experimental values)} \qquad (1)$$

where:

Δm_i - represents the value of mass losses in each of the 12 periods
Δt_i - duration of the intermediate period (5, 10 and 15 minutes respectively)

The approximation of the experimental values is made by analytical curves, built with the relations established in the Cavitation Erosion Research Laboratory by Bordeașu and the team [9, 18-21]:

$$M(t) = A \cdot t \cdot (1 - e^{-B \cdot t})$$
$$v(t) = A \cdot (1 - e^{-B \cdot t}) + A \cdot B \cdot t \cdot e^{-B \cdot t} \quad (2)$$

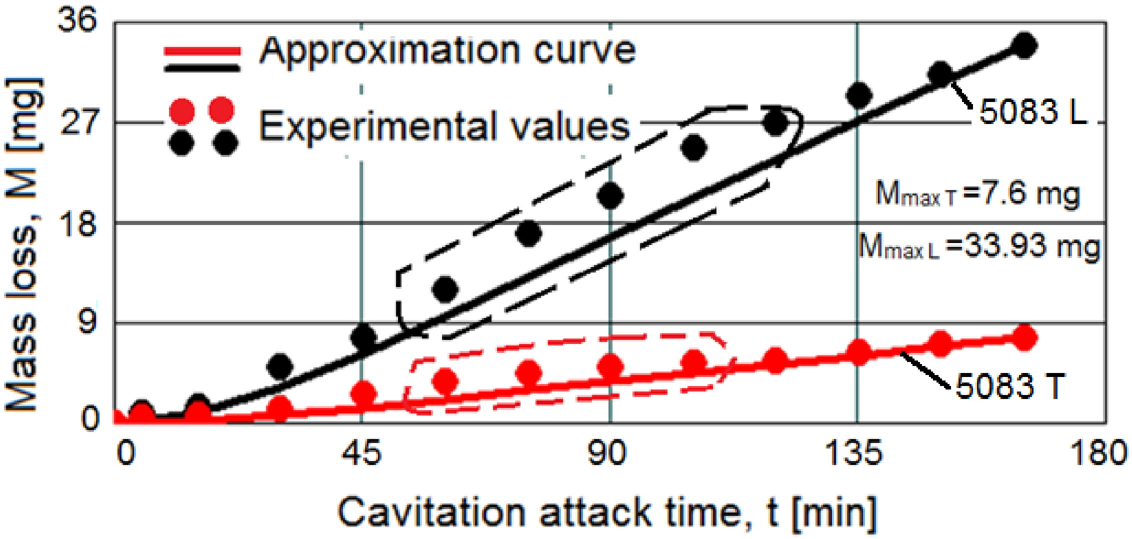


Fig. 3. Variation of mass losses with the duration of the cavitation attack

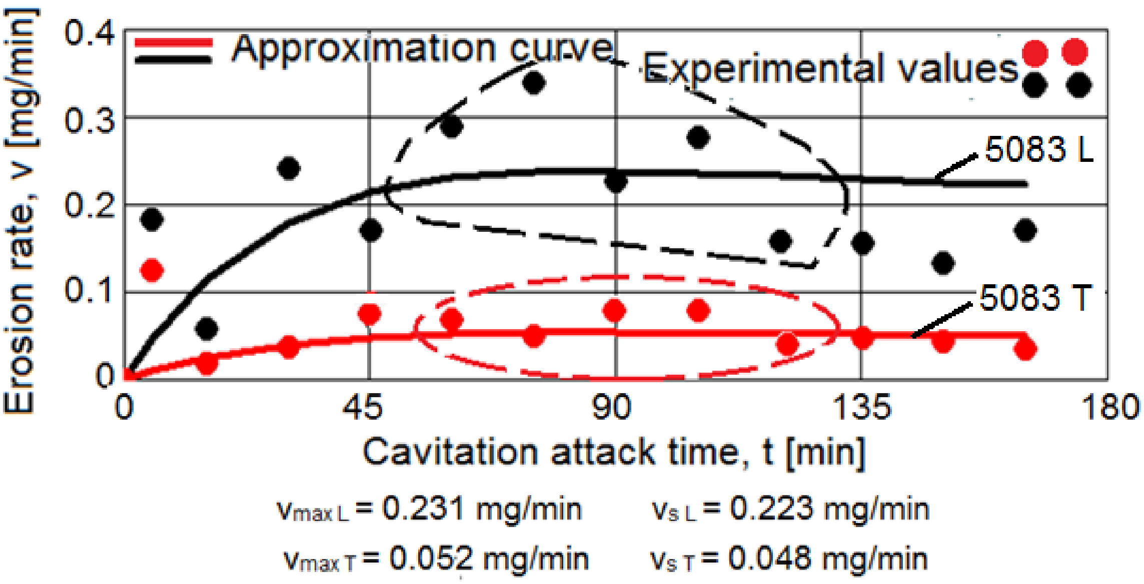


Fig. 4. Variation of the erosion speed with the duration of the cavitation attack

The dispersion of the experimental values, regardless of the diagram, M (t) or v (t), compared to the mediation curves, shows that the two materials have a similar behavior, a fact proven by the interval of 60-120 minutes. This resemblance is natural, due to the fact that they are the same material (see chemical composition in Table 2). The differences between the values of the parameters, M_{max} (total mass lost by erosion in the 165 minutes of cavitation attack), v_{max} and vs (maximum values and towards which the mediation-called and stabilization or final curve asymptotically tends - defined by the mediation curve v (t)), which express the cavitation strength are determined, in this situation, by the values of the mechanical properties (Rm, Rp0.2 and KCV), as mentioned in paragraph 3.2.1. Thus, according to the value of M_{max}, erosion rate, vs, or cavitation resistance R_{cav} (R_{cav} = 1 / vs) the 5083 T alloy has a higher resistance than the 5083 L alloy 4.4 ... 4.6 times.

4. Conclusions

- The nature of the semi-finished aluminum alloy 5083 series 5000, from which parts are made that work in cavitation mode, influences the resistance to cyclic stresses of micro-jets and shock waves, generated by the implosion of cavitation bubbles.
- The results of this study show that hardness is not always the property that contributes to increasing the resistance of a surface to cavitation stresses, but, as studied, the values of mechanical properties, on which depends the capacity of the energy absorption structure developed by impact, to breakage and mycostructural homogeneity.
- The study calls for further research to see how the surface strengths of the two alloys change through the application of protection technologies / processes or volumetric and surface heat treatments.
- The way of destroying the structure shows that both alloys can be used for parts that work in cavitation, periodic or low intensity regimes.

References

[1] Mitelea, Ion, and Bogdan Radu. *Selection and usage of engineering materials/Selecţia şi utilizarea materialelor inginereşti*. Timisoara, Politehnica Publishing House, 2004.
[2] https://ro.wikipedia.org/wiki/Duraluminiu.
[3] https://www.4tuning.ro/ghidul-soferului/cum-functioneaza-racirea-motorului-de-la-termostat-la-pompa-de-apa-33581.html.
[4] https://www.cromix.ro/produse/8994/pompa-apa-tractor.html.
[5] https://mal-product.ro/table-din-aluminiu-laminate-la-rece/.
[6] http://old.color-metal.ro/ro/aluminiu-turnat.
[7] https://color-metal.ro/ro/placi-laminate-aluminiu.
[8] ***. Standard Test Method for Cavitation Erosion Using Vibratory Apparatus, ASTM, Standard G32, 2016.
[9] Bordeasu, Ilare. *Monografia Laboratorului de cercetare a eroziunii prin cavitaţie al Universităţii Politehnica Timişoara: (1960-2020)/Monograph of the Cavitation Erosion Research Laboratory of the Polytechnic University of Timisoara (1960-2020)*. Timisoara, POLITEHNICA Publishing House, 2020.
[10] Micu, Lavinia Madalina. *Comportarea la eroziune prin cavitatie a otelurilor inoxidabile duplex/Cavitation erosion behavior of duplex stainless steels*. Doctoral thesis, Timisoara, 2017.
[11] Bordeasu, Ilare, and Ion Mitelea. "Cavitation Erosion Behavior of Stainless Steels with Constant Nickel and Variable Chromium Content." *Materials Testing* 54, no.1 (2012): 53-58.
[12] Oanca, Victor Octavian. *Tehnici de optimizare a rezistentei prin cavitatie a unor aliaje CuAlNiFeM destinate executiei elicelor navale./Techniques for optimizing the resistance to cavitation erosion of some CuAlNiFeMn alloys intended for the execution of naval propellers*. Doctoral thesis, Timișoara, 2014.
[13] Garcia, R. *Comprehensive Cavitation Damage Data for Water and Various Liquid Metals Including Correlation with Material and Fluid Properties*. Technical Report No. 6, University of Michigan, 1966.
[14] Hobbs, J.M. "Experience With a 20-kc Cavitation Erosion Test." *Erosion by Cavitation or Impingement*. West Conshohocken, PA, ASTM International, 1967, 159-185.
[15] Franc, Jean-Pierre, Jean-Louis Kueny, Ayat Karimi, Daniel-H. Fruman, Didier Fréchou, Laurence Briançon-Marjollet, Jean-Yves Billard, Brahim Belahadji, François Avellan, and Jean-Marie Michel. *Cavitation. Physical mechanisms and industrial aspects*. Grenoble, Presses Universitaires de Grenoble, 1995.
[16] Steller, Kazimir, Z. Reymann, and T. Krzysztoowicz. "Evaluation of the resistance of materials to cavitational erosion." Proceedings of the Fifth Conference on Fluid Machinery, Vol 2, Akad Kiado, Budapest, 1975.
[17] Sakai, I., and A. Shima. "On a New Representative Equation for Cavitation Damage Resistance of materials." Report No. 385, Tokyo, 1987.

[18] Bordeaşu, Ilare, Constantin Patrascoiu, Rodica Badarau, Liliana Sucitu, Mircea Octavian Popoviciu, and Victor Balasoiu. "New contributions to cavitation erosion curves modeling." *FME Transactions* 34, no.1 (2006): 39-43.
[19] Micu, Lavinia Madalina, Ilare Bordeasu, and Mircea Octavian Popoviciu. "A New Model for the Equation Describing the Cavitation Mean Depth Erosion Rate Curve." *Revista de Chimie* 68, no. 4 (April 2017): 894-898.
[20] Salcianu, Cornelia Laura, Ilare Bordeasu, Nicușor-Alin Sîrbu, Rodica Bădărău, Gabriel Mălaimare, Mihai Hluscu, Daniel Ostoia, and Octavian Victor Oanca. "Evaluation of the Cavitation Resistance of INCONEL 718, in Delivered and Respectively Heat Treated Condition." *Advanced Materials Research* 1157 (February 2020): 47-51. https://doi.org/10.4028/www.scientific.net/amr.1157.47.
[21] Istrate, Dionisie, Cristian Ghera, Laura Salcianu, Ilare Bordeasu, Brandusa Ghiban, Dumitru Viorel Bazavan, Lavinia Madalina Micu, Daniel-Catalin Stroita, and Daniel Ostoia. "Heat Treatment Influence of Alloy 5083 on Cavitational Erosion Resistance." *HIDRAULICA Magazine*, no. 3 (September 2021): 15-25.