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# STUDY OF CAVITATION-INDUCED DEGRADATION OF THE AM50 ALLOY WITH ARTIFICIAL AGING HEAT TREATMENT

**Lavinia Madalina MICU[1], (ORCID: 0000-0002-3471-7099)**
**Ilare BORDEAȘU[2], (ORCID: 0000-0003-3580-8168)**
**Alina DRAGOESCU-PETRICA[1*], (ORCID: 0000-0003-1270-0728)**
**Anișoara Claudia DUMA COPCEA[1*], (ORCID: 0000-0002-7152-7307)**
**Sorin-Tiberiu BUNGESCU[1], (ORCID: 0009-0009-2849-7593)**
**Daniel POPA[1], (ORCID: 0000-0001-5185-7196)**
***[1] University of Life Sciences Timisoara, Faculty of Agriculture***
***[2]Politehnica University of Timișoara, Faculty of Mechanical Engineering***
*Corresponding author: andreeadragoescu@usvt.ro, anisoaradumacopcea@usvt.ro*

***Abstract.*** *Due to the good combination of mechanical properties, low density, and the biocompatibility specific to magnesium, the AM50 alloy is a promising material for biomedical applications. However, in order to be widely used in cardiac devices, several issues must be addressed, such as: controlling the corrosion rate, ensuring structural stability during implant operation, and resistance to mechanical and cavitation stresses. The paper presents an experiment which was carried out using a standard 20 kHz vibratory apparatus, in accordance with ASTM G32-2016 standards. The results pave the way for further study of bio-alloys for use in medical fields such as reconstructive surgery. Additionally, the findings contribute to a better understanding of material behavior under aggressive conditions, supporting future optimization of alloy composition and heat treatment processes for improved performance and durability. However, in order to be widely used in cardiac devices, it is necessary to solve problems such as: controlling the corrosion rate, structural stability during the operation of the implant, and resistance to mechanical and cavitation stresses. It is necessary to test the alloy in a liquid medium with physico-chemical characteristics in which the resistance of the AM 50 alloy to the erosive stresses of cavitation is no longer influenced by its degradation property as in aqueous media.*

***Keywords****: aluminum alloy, biomedical applications, mass loss, erosion rate, cavitation erosion*

## INTRODUCTION

The AM50 alloy was initially used in the automotive and aerospace industries, particularly for lightweight components such as transmission housings, steering system elements, and body parts. Over the past two decades, magnesium alloys, including AM50, have attracted researchers' attention for their use as biodegradable biomaterials from which the following can be produced: cardiovascular stents, temporary orthopedic implants, screws and plates for fracture fixation, and resorbable medical devices.

Interest in these materials is due to the fact that magnesium alloys can gradually degrade within the body, eliminating the need for an additional surgical intervention to remove the implant. Their mechanical properties, which are similar to those of bone tissue or biological structures, have led to increased interest in the use of magnesium alloys in cardiovascular devices (stents, implantable structures) subjected to mechanical and hydrodynamic stresses.

In modern biomedical research (ANTONIAC,2022; BORDEASU, 2025; CIUNGU,2024; GHIBAN, 2025; IORDACHE,2024; LUCA, 2024), magnesium alloys are studied mainly for their biodegradable behavior. Unlike conventional materials (stainless steel, titanium), magnesium alloys can corrode and be resorbed in the body. In the case of temporary cardiovascular devices, this phenomenon can be advantageous, as the implant provides mechanical support only during the critical period, after which it gradually degrades; additionally, no surgical intervention is required for its removal (ANTONIAC, 2022; DRAGOMIR, 2023; MANESCU, 2023; ZHANG, 2010).

However, there are situations in artificial valves or cardiac pumps—where vapor bubbles and liquid microjets may form, i.e., cavitation phenomena, which can lead to surface erosion, accelerated corrosion, or crack initiation. For these reasons, researchers investigate how the composition and microstructure of magnesium alloys, including AM50, influence corrosion resistance and mechanical and chemical performance under conditions similar to the biological environment (ANTONIAC, 2022; DRAGOMIR, 2023; MANESCU, 2023; ZHANG, 2010; https://aludiecasting.com/ro/proprietati-ale-aliajului-de-magneziu-turnat-sub-presiune-az91d/).

The results of several studies on the mechanical properties of the AM50 alloy (MARSAVINA, 2019; MITELEA, 2019) have shown that the areas most susceptible to crack initiation are those with high porosity, which can reduce the material's ductility.

Studies conducted in deionized water (PIRVULESCU, 2026) and saline solutions (various environments) have indicated that the main degradation mechanisms occurring in the AM50 alloy are anodic dissolution and hydrogen-induced embrittlement.

Corrosion resistance and changes in phase distribution can be influenced by the application of heat treatments to the alloy. Furthermore, to reduce the degree of degradation, researchers are also investigating the possibility of applying biocompatible protective layers, such as polymer coatings, calcium phosphate coatings, or electrochemical surface treatments. These coatings can reduce corrosion and improve the interaction of the material with biological tissues.

## MATERIAL AND METHODS

### *Presentation of the AM50 Material*

The AM50 alloy belongs to the family of magnesium alloys with aluminum and manganese additions and is frequently used in applications where a good combination of mechanical strength, low weight, and ductility is required.

The typical composition of this alloy (Table 1) contains approximately 4–5% aluminum, small amounts of manganese, and traces of zinc, with the remainder being magnesium.

The AM50 alloy exhibits low density (specific to magnesium), a high strength-to-weight ratio, good energy absorption capacity, and relatively ductile behavior compared to other Mg–Al alloys.

*Table 1*

Chemical composition of the investigated Mg alloy (values in %) (MARSAVINA, 2019; MITELEA, 2019)

| Material | Al | Mn | Zn | Fe | Ni | Cu | Si | Be | Mg | Others |
|---|---|---|---|---|---|---|---|---|---|---|
| AM50 | 4.70 | 0.32 | 0.13 | 0.002 | 0.001 | 0.004 | 0.03 | 0.0014 | 94.77 | 0.005 |

*Table 2*

Tensile properties of the Mg alloy in the as-cast semi-finished state (CIUNGU,2024)

| Material | Elastis modulus $[MPa]$ | Ultimate Tensile Strength $[MPa]$ | Yield Strength $[MPa]$ | Elongation at Fracture $[\%]$ |
|---|---|---|---|---|
| **AM 50 from tests** | 45.870 | 236.9 | 122.84 | 14.5 |

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Analyzing the data in Table 2, it can be observed that the AM50 magnesium alloy exhibits a favorable balance between mechanical strength, stiffness, and deformation capacity, making it suitable for applications where reducing component weight is necessary without significantly compromising the material's mechanical properties. These characteristics explain the frequent use of magnesium alloys in fields such as the automotive and biomedical industries, where structural efficiency is important.

***Working Methodology***

Three samples of the AM50 alloy were studied, heat-treated at 200°C for a duration of 12 hours, and tested using a standard 20 kHz vibratory apparatus in the Cavitation Laboratory of Politehnica University of Timișoara. The testing was carried out following the standard procedure specified in ASTM G32-2016 (ASTM, Standard G32, 2016), supplemented by the laboratory's customary practices regarding the total and intermediate test durations, as well as the method of recording and processing the results (BORDEASU, 2025; BORDEASU,2020; GHIBAN, 2025; LUCA, 2024).

## RESULTS AND DISCUSSIONS

***1. Analysis of the Dispersion of Experimental Values***

Graph 1 shows the evolution of cumulative mass loss as a function of exposure time to cavitation erosion and highlights both the experimental values obtained from the cavitation tests and the mean approximation curve that describes the general trend of the degradation process.

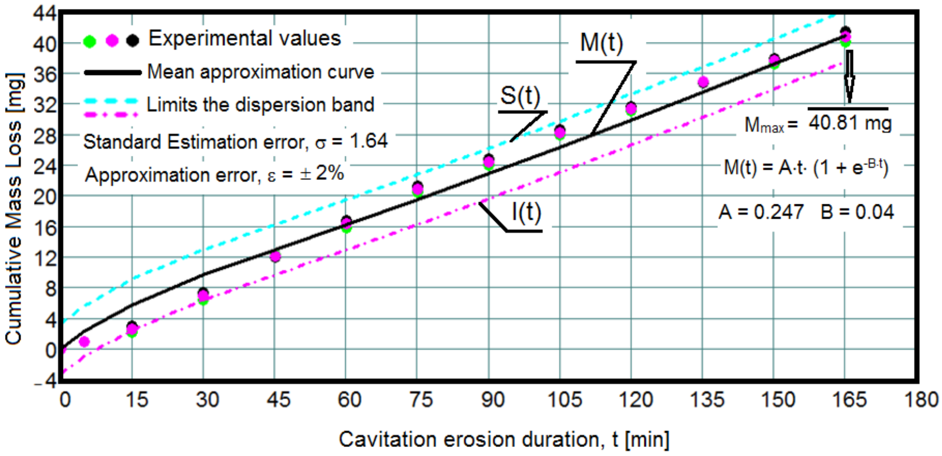


Figure 1. Variation of cumulative mass loss with cavitation duration (AM50-200/12 h)

In the initial stage, during the first minutes of the test (0–30 minutes), the observable mass losses shown in the graph, according to the testing laboratory results (BORDEASU, 2025; BORDEASU,2020; BORDEASU,2021; MITELEA,2019), are primarily due to the removal of abrasive dust and the peaks of surface roughness asperities. Material damage is limited to local plastic deformations and the formation of microcracks. Consequently, the experimental values in the graph exhibit relatively higher dispersion compared to the mean curve, although the difference in mass loss among the three tested samples remains small.

In the 30–120 minute interval, the cavitation erosion phenomenon enters a relatively stable phase, with a linear increase in cumulative mass loss; the experimental points align more closely with the direction of the mean curve.

In the final stage of the test (120–165 minutes), the experimental values again show slight deviations from the mean curve, but these remain within the dispersion band. The slight increase in differences can be associated with changes in the material surface topography, the formation of cracks, and the detachment of larger fragments.

The graph indicates a standard estimation error of σ ≈ 1.64 mg, as well as an approximation error of approximately ±2%, demonstrating that the mathematical model established in the cavitation laboratory (BORDEASU,2006, MICU, 2017) accurately describes the evolution of the erosion process. Furthermore, the dispersion band defined by the upper and lower limits shows that the majority of experimental values fall within the estimated range.

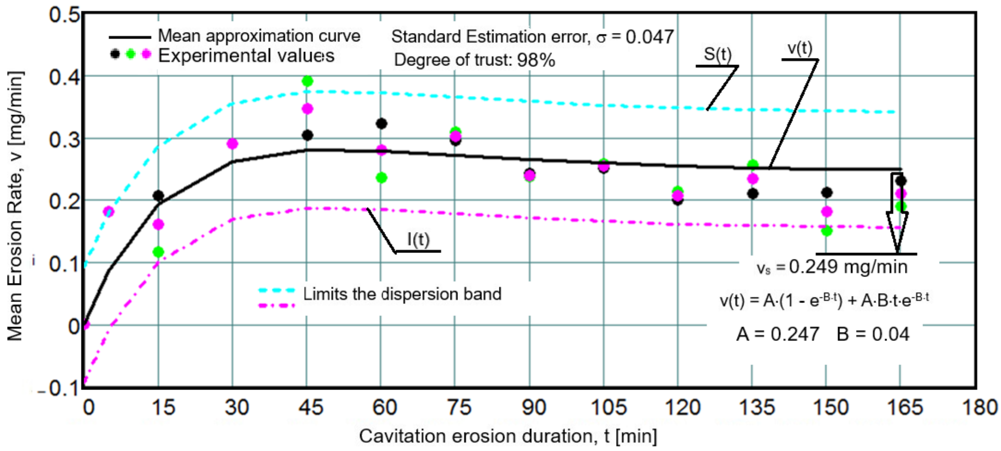


Figure 2. Variation of erosion rate with cavitation duration (AM50-200/12 h)

The dispersion band shown in Graph 2 defines the range within which most of the experimental values lie relative to the mean curve. It can be observed that the experimental points are distributed fairly uniformly around the theoretical curve, indicating good agreement between the mathematical model used and the experimentally obtained data.

The standard estimation error indicated on the graph is σ ≈ 0.047 mg/min, and the model confidence level is approximately 98%, confirming that the mathematical relationship accurately describes the evolution of the erosion rate over time. The coefficients A = 0.247 and B = 0.04 in the equation describing the approximation curve characterize the evolution of the erosion process.

The mathematical model, whose relationship is displayed in the chart legend, appropriately reproduces the evolution of cavitation erosion, with the experimental values falling within the dispersion band limits. The coefficients A = 1.27 and B = 0.03 describe the evolution of the material's resistance over time. This relationship reflects that cavitation resistance is inversely proportional to the erosion rate, which explains why the values tend to stabilize once the degradation process reaches equilibrium.

***2. Analysis of the Results Regarding the Evolution of Cumulative Mass Loss, Average Erosion Rate, and Cavitation Resistance***

The mean curves determined from the experimental data describe the general trend of the material degradation process during testing and allow for the assessment of the stability of the erosion mechanisms.

The mean curve corresponding to cumulative mass loss shows a progressive increase throughout the entire duration of the test. As the testing time increases, the mean curve approaches an almost linear evolution, indicating that the phenomenon has entered a stable erosion regime. At this stage, the detachment of material particles occurs at roughly the same rate, and the experimental values of mass loss are distributed relatively uniformly around the approximation curve, within the dispersion band.

**The average erosion rate** represents the derivative of the mass loss evolution over time and reflects the intensity of the degradation process. The mean curve of the erosion rate shows a rapid increase in the initial stage, corresponding to the transition from the beginning period to the active erosion regime. After this increase, the erosion rate reaches a maximum or near-maximum value and tends to stabilize around an average value for the remainder of the test.

The experimental values of the erosion rate exhibit slight deviations from the mean curve, but most fall within the dispersion band limits, indicating good agreement between the mathematical model and the experimental results.

A comparative analysis of the two curves highlights a direct correlation between the studied parameters:

- The increase in cumulative mass loss reflects the progressive accumulation of material degradation.
- The erosion rate describes the instantaneous intensity of the degradation process.

During the test, three main stages of the phenomenon could be identified:

1. **Incubation (initial) period** – characterized by small mass losses, a rapid increase in erosion rate, and a decrease in cavitation resistance.
2. **Transition stage** – in which mass loss begins to increase more noticeably, and the erosion rate approaches its maximum value.
3. **Stable erosion regime** – characterized by an almost linear increase in mass loss, stabilization of the erosion rate, and nearly constant cavitation resistance values.

The mathematical models used to approximate the experimental data accurately describe the material's behavior, and the experimental values fall within the established dispersion limits.

***3. Analysis of the Influence of Mechanical Properties and Microstructural Compounds on the Dispersion of Data Points***

The dispersion of experimental points observed in Figures 1, 2, and 3 is largely influenced by the mechanical properties of the material and its microstructural characteristics.

Mechanical properties such as hardness, strength, and plasticity determine how the surface responds to the repeated stresses generated by the implosion of cavitation bubbles. The AM50 alloy, with its nearly homogeneous structure and good plastic deformation capacity, exhibits a relatively uniform evolution of the analyzed parameters. As a result, the experimental points cluster closer to the mean curve, and the dispersion of values is reduced. This behavior can be explained by the alloy's ability to absorb part of the energy produced by cavitation bubble implosions without causing sudden detachment of material particles.

The presence in the AM50 microstructure of a softer, ductile phase (α-Mg matrix) and harder, brittle phases (β-Mg intermetallics) leads to a more pronounced dispersion of experimental values. These sensitive points correspond to regions where cracks or microcracks appeared under repeated stresses. As these defects develop, local material detachment occurs, causing significant variations in mass loss and erosion rate across different time intervals.

Therefore, the distribution of experimental points on the graphs and the shape of the mean curves are influenced both by the material's mechanical behavior and its internal structure. The mechanical properties of the AM50 alloy are considered good, though not superior to all other magnesium alloys. Its mechanical strength and hardness are moderate, lower than those of some alloys with higher aluminum content. For this reason, the AM50 alloy is suitable for lightweight applications, exhibiting moderate cavitation resistance. Its main advantage lies in the combination of good ductility and impact resistance.

### *4. Analysis of the Causes Behind the Evolutionary Shape of the Curves (Mass Loss, Erosion Rate, and Cavitation Resistance)*

The evolutionary shape of the curves obtained during the cavitation tests can be explained by the fact that the material degradation process occurs progressively. Over certain time intervals, the mass loss exhibits an almost linear trend, indicating that the erosion phenomenon has reached a relatively stable stage. In this phase, the processes of material particle formation and detachment occur at an approximately constant rate, and the surface affected by cavitation evolves uniformly. Essentially, the material enters a stabilized erosion regime, where the degradation rate no longer shows abrupt variations.

Analyzing the erosion rate, it was observed that it tends to decrease slightly and approach a characteristic stable value, denoted as. The changes occurring on the material surface during testing explain this evolution of the erosion rate, as also supported by the photographic images in Figure 3, which show the increasing degree of degradation over the duration of cavitation attack. At the beginning of testing, the alloy surface is relatively smooth, and the implosion of cavitation bubbles produces a locally intense impact, resulting in higher erosion rate values. As cavitation progresses, the material surface becomes rougher and develops microcavities and depressions due to particle detachment. These irregularities partially dissipate the energy of the impacts caused by bubble implosions. Consequently, the material removal process becomes more uniform and less intense, and the erosion rate gradually stabilizes.

The evolutionary shape of the experimental curves characterized by an almost linear increase in mass loss and a slight decrease in erosion rate toward the stationary value reflects the balance between cavitation-induced degradation mechanisms and the material's ability to dissipate the energy of microjets and shock waves. This behavior indicates the establishment of a stable erosion regime.

### *5. Analysis of the Morphology of Structural Degradation*

Photographic images taken with a Canon PowerShot A480 camera clearly show the effect of mechanical impact pressures on the surface from shock waves and cavitation microjets, increasing with the duration of exposure. It can be observed that, as the test progresses from one intermediate duration to the next, the number of microcavities increases, and the already formed cavities grow in geometric size, so that after 165 minutes, the surface exhibits a sponge-like appearance with high porosity.

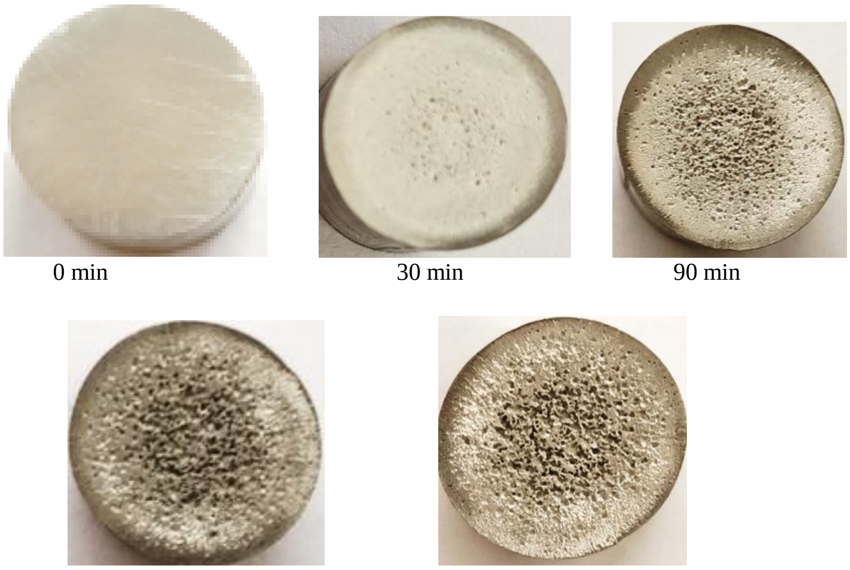


Figure 3. Evolution of cavitation erosion on the attacked surface

## CONCLUSIONS

1. The structural resistance of the AM50 alloy to cavitation generated in water, based on the values of the parameters $MDE_{max}$, $MDER_s$ , and the appearance of the damaged surface, even after heat treatment, is low. This is influenced both by the relatively low mechanical properties and the presence of brittle intermetallic compounds.

2. From the perspective of mechanical behavior under cavitation loading, the structure follows the typical mechanism: an initial stage of rapidly increasing losses (where cumulative mass loss grows exponentially and erosion rates rise toward a maximum) followed by a stabilization stage (where losses become relatively constant, leading to the linearization of the mean cumulative mass loss curve MDE(t) and the decrease of the mean erosion rate curve MDE_R(t) toward a steady value).

3. The accentuated degradation of the cavitated surface, through the multiplication of microcavities, occurs despite the mechanical properties and is also driven by the aqueous nature of the cavitation waves and microjets, beyond the amplitude of stresses induced by their impact on the exposed surface.

4. To increase the cavitation resistance of the AM50 alloy in aqueous environments, it is necessary to apply traditional or novel technologies that reduce its susceptibility to degradation.

5. It is recommended to test the alloy in liquid environments with specific physico-chemical characteristics in which the resistance of AM50 to erosive cavitation stresses is not affected by its inherent degradability, as occurs in aqueous media.

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