Effect of electromagnetic radiation in space on aluminum alloy AA7075

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Abstract: *Electromagnetic radiation in space presents a significant challenge to the durability of aluminum alloys used in spacecraft construction. This study analyzes the effects of ionizing radiation (gamma rays, cosmic rays, solar particles), ultraviolet and solar radiation, electromagnetic pulses (EMP), and extreme temperature fluctuations on a novel composite material based on AA7075 (B95) aluminum alloy. The results demonstrate that prolonged exposure of the material in outer space (28 months) leads to structural changes and alterations in mechanical properties. To ensure the reliability of the results, the space-exposed samples were compared with reference samples stored under terrestrial conditions.*
Keywords*: ALUMINUM ALLOYS, AA7075, ELECTROMAGNETIC RADIATION, SPACE*

1. Introduction

Aluminum alloys are among the most widely used materials in the space industry due to their combination of high physical-mechanical properties and specific characteristics such as strength, hardness, and more. The vast variety of aluminum alloys, each with its own unique combination of material properties and chemical composition, along with the need for lightweight, stress-resistant, fatigue-resistant, and deformation-resistant materials, makes them a primary choice for constructing spacecraft structures, hulls and supporting elements, rocket nose cones, launch vehicle fuel tanks, fastening elements, and more. These alloys allow for a reduction in the mass of structures and components without compromising their reliability and operational lifespan. Additionally, they are heat-resistant, making them ideal for use under high loads and extreme temperatures—a critical requirement for spacecraft. The versatility of aluminum enables it to be formed into necessary shapes, sheets, plates, extrusions, and castings, along with heat treatments, each tailored for specific aerospace applications [1-5].

For example, the International Space Station (ISS) extensively uses aluminum in its trusses, station modules, solar panels, and other components. The frames and panels of satellites are predominantly made of aluminum alloys. They are also an integral part of the construction of antennas and communication systems for satellites and the ISS [6].

Aluminum alloy AA7075 is one of the most widely used high-strength alloys in space missions. It belongs to the Al-Zn-Mg-Cu system and is characterized by exceptional strength, good fatigue resistance, and relatively low weight, making it an ideal material for manufacturing critical space components where reliability and performance are of vital importance.

Satellite and probe housings require lightweight yet robust load-bearing structures capable of withstanding the mechanical stresses of launch, resisting thermal expansion and contraction in space, and supporting various payloads. Rocket stages are also subjected to extreme mechanical loads. Solar panel frames and antennas demand high stability and low weight.

Thanks to its high tensile strength (~500–570 MPa), AA7075 is also used to produce fastening elements such as bolts and nuts. Modern aluminum alloys like 7075-T6 and 7050-T7451 have been developed to provide even higher tensile strength and improved fatigue resistance, which are crucial for components exposed to repeated stress and harsh environments [7-9].

Space exploration and the study of the Solar System represent the most demanding environment for materials used in space missions. They must withstand extreme vibrations and mechanical stresses, vacuum conditions, severe temperature fluctuations, and electromagnetic radiation.

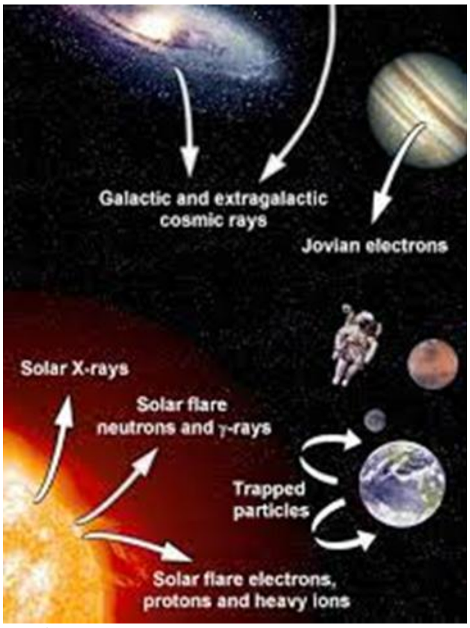

Fig. 1 *Sources of radiation in the Solar System [10].*

Electromagnetic radiation in space is intense and originates from various sources – both natural (stars(sun), galaxies, black holes) and artificial (satellites, spacecraft). It is a form of energy that propagates as waves across different spectral ranges from low-energy radio waves to high-energy gamma rays or particles (photons) in the vacuum of space. Solar radiation and Galactic Cosmic Rays include: ultraviolet, X-ray, and infrared radiation, ionizing radiation (gamma rays, cosmic rays, solar particles), and electromagnetic fields from the solar wind [11-12]. All these forms of electromagnetic radiation affect the mechanical and physicochemical properties of aluminum alloys, particularly under long-term exposure.

Due to the exceptional importance of issues related to the development of new materials for space applications and the characterization of their structures and physico-mechanical properties, a new material was created in the "Space Materials Science" section at the Institute of Space Research and Technology - Bulgarian Academy of Sciences (BAS). Based on an extensive literature review, the aluminum alloy AA7075 (7075 by USA standartds and B95 by Russian clasification) was selected with the potential to upgrade its basic properties. A method was chosen to achieve this enhancement through the addition of ultra-dispersed nanodiamond powder and tungsten alloying, along with the application of an appropriate heat treatment process.

The newly developed composite material was exposed to space mounted on the exterior of the Russian module Zvezda of the International Space Station (ISS) between 2013-2015. This marked Bulgaria's first technological experiment in open space, where the SRTI-BAS participated with a device called the "DP-PM" block, forming part of the international space project "Obstanovka (1-step)" [13].

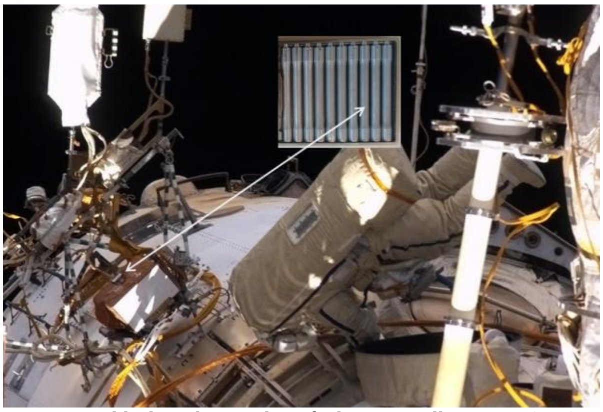

Fig. 2 *DP-PM block with Samples of aluminum alloy 7075 (B95) with quantitative addition of ultradisperse diamond powder and tungsten mounted on a plasma-wave complex (PWC) on the ISS, Zvezda module*

The objective of the experiment was to study the material's resistance to long-term radiation and thermal exposure, its reliability in extreme environments, and the changes that occurred in its physicochemical, particularly mechanical properties. To ensure the validity of the results, the space exposed samples were compared with reference samples stored under Earth conditions.

2. Effect of electromagnetic radiation in space on aluminum composite AA7075

Effects of Ionizing Radiation Exposure (Cosmic Rays and Solar Particle Radiation)

Structural Changes:

High-energy particles induced alterations in the material's microstructure:

- Transformation in the crystal lattice. Increasing the size of Al and $MgZn_2$ crystallites on the surface of the samples;

- Transformation in the distribution of precipitates. Decomposition and formation of new unstable phases [14];

- Vacancy generation and interstitial atom clustering.

These microstructural transformations consequently degraded mechanical performance.

Mechanical Properties:

- Reduced tensile strength;

- Increased material embrittlement.

Effects of Ultraviolet (UV) and Solar Radiation

Ultraviolet (UV) and solar radiation in space exert surface effects on AA7075, primarily through photochemical degradation and alterations in corrosion properties.

- High-energy UV radiation induced surface oxidation of the samples, leading to the formation of a thicker and more brittle aluminum oxide (Al_2O_3) layer;

- UV exposure caused microcracks on the surface of some specimens;

- In combination with the space vacuum, UV photons broke chemical bonds in surface oxides [14].

Thermal Effects (Heating/Cooling) from Solar Radiation

The extreme temperature fluctuations caused by solar radiation in space significantly impact the structural integrity of materials. The tested material underwent cyclic thermal stress from alternating heating (up to +150°C in sunlight) and cooling (-150°C in shadow) every two hours. This led to additional thermal aging of the material on the surface and had an impact on the microstructure and mechanical properties of the material.

- Due to the different thermal expansion coefficient of the different phases, deformation of the crystal lattice on the surface of the studied samples was found. Loss of dimensional stability.

Electromagnetic fields (solar storms)

- High-energy particles from solar storms induce variable magnetic fields, which generate eddy currents, leading to localized heating of the material. Strong magnetic fields can cause minor deformation of the crystal lattice, but in combination with thermal cycles from solar radiation, they have resulted in thermal stress in the material's structure.

- Electrostatic discharges (ESD), accumulated from the solar wind in combination with radiation, have caused microcracks on the surface of some samples.

The combined effects of ionizing radiation, vacuum, thermal cycling, and electromagnetic fields have altered the structure of the AA7075 (B95) alloy-based composite reinforced with nanodiamond and tungsten exposed to open space. Consequently, this has led to changes in the composite's mechanical properties.

Alteration in the composite's mechanical properties

- The introduced radiation defects in the crystal lattice outweigh the effects of thermal stress and make the material (space-exposed samples) harder and more elastic than the reference samples [15-16].

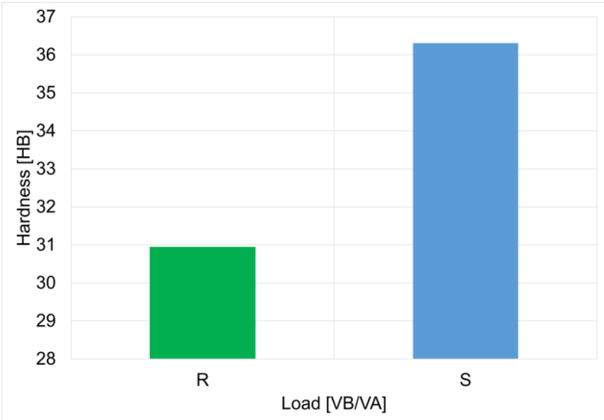

Fig. 3 *Average results of Leeb hardness measurements for "reference" (R) and "space" samples (S)*

Figure 3 presents averaged results from Leeb hardness measurements for reference (R) and space exposed (S) samples. The experimental studies on penetration resistance were conducted using a universal digital hardness tester in accordance with the Leeb/Al-150A standard. This approach was necessary because the investigated space samples have a diameter of d = 5 mm and a length of 70 mm, making them unsuitable for testing on standard hardness testers.

Both the space exposed and reference samples were shaped as cylindrical samples to facilitate their use in subsequent experiments. The dimensions and weight of the samples were designed in compliance with the strict specific requirements for space experiment implementation [13].

Following the conducted Leeb hardness (HL) tests, it was determined that the absorbed radiation dose (~425 kGy [17-19]) and temperature fluctuations (-150°C in shadow to +150°C) induce modifications in the crystal lattice, particularly in the specimen's surface layer. A specific elemental redistribution is observed - migration of elements leading to the formation of new intermetallic phases that alter the base material's properties, consequently resulting in increased hardness.

Figure 4 displays tensile testing data comparing three reference (R) and three space exposed (S) samples. Testing was performed on a Tira Test 2300 universal testing machine featuring automated test diagram recording capabilities.

A comprehensive pre test inspection was conducted for each samples to identify surface defects including cracks and swelling. Geometrical parameters including 90° cross-section (S_0), initial gauge length (L_0), and diameter (d) were precisely measured for all cylindrical specimens prior to testing.

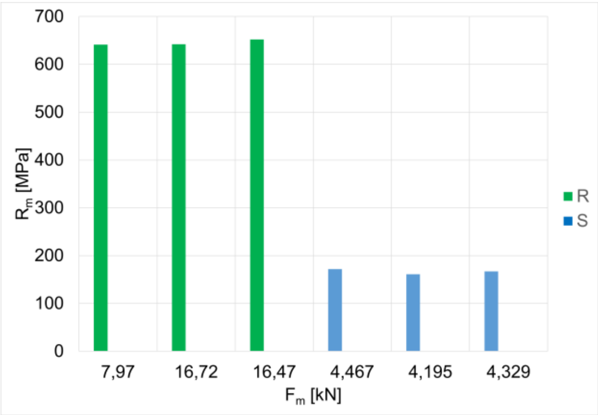

Fig. 4 *Tensile test results for three reference (R) and three space exposed (S) samples*

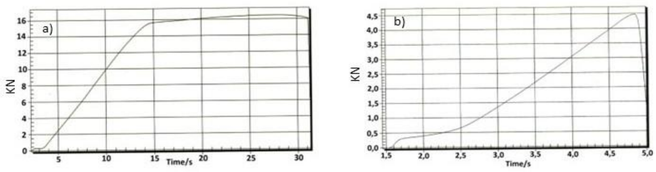

Fig. 5 *Tensile diagrams: a) reference sample and b) space sample*

Following tensile testing of cylindrical specimens made from AA7075-based composite (UDDP+W), it was established that:

- A substantial strength degradation in space exposed samples relative to reference samples

- Mean tensile strength values:

Reference samples: R_m = 645 MPa

Space exposed samples: R_m = 167 MPa (74% reduction)

- Space exposed samples exhibit low fracture resistance (Fig. 5b). The material is brittle with low plasticity. No yield strength $Rp_{0,2}$ is observed.

- The reference samples exhibit a clearly defined yield plateau $Rp_{0.2}$, characteristic of ductile materials.

4. Conclusions

Electromagnetic radiation in space poses a significant challenge to the durability of the newly developed AA7075 aluminum composite. The material shows sensitivity to ionizing radiation, particularly during prolonged space exposure (28 months).

The observed changes in material properties result from:

- The intensity of the radiation environment
- The accumulated radiation dose during exposure (~425 kGy)
- The thermal energy from temperature fluctuations during exposure

These factors led to improvements in certain mechanical properties (hardness and elasticity) in the space exposed samples. However, the accumulated radiation dose simultaneously caused degradation in other mechanical characteristics.

Space exposed samples under cosmic environmental effects exhibited:

- Reduced strength parameters
- Defects in the crystalline structure

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