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STATIC ANALYSIS AND SIMULATION OF THE BEHAVIOR OF ALUMINUM COMPOSITE MATERIALS

Munteanu M.V. *[1], Scutaru M.L.[1], Cerneleac I.[1]

1.Transilvania University of Brașov, Romania, v.munteanu@unitbv.ro, lscutaru@unitbv.ro

Abstract: *The mechanical behavior of aluminum-based composites (MMC) under static stress is investigated, focusing on Aluminum 2024 and Aluminum 2024-T3 alloys. Through a series of mechanical tests, such as tensile and bending, the strength and stiffness properties of the materials were evaluated, with a significant improvement observed in the case of heat treatment. Numerical simulations using the finite element method (FEM) were also performed to validate the predicted behavior of these materials. The obtained results showed a strong correlation between experimental and simulated data, highlighting the potential of using aluminum-based composite materials in industrial applications, such as aeronautics and the automotive industry.*

Keywords*: Composite materials, Aluminum 2024, Static loads, Tensile and bending, MEF simulation*

1. INTRODUCTION

Aluminum-based composite materials, or metal matrix composites (MMCs), play a crucial role in industry due to their improved mechanical and physical properties, such as high strength-to-weight ratio, corrosion resistance and thermal conductivity[1-14]. These advantages make them ideal for applications in the aeronautical, automotive and construction industries [11-19]. The objective of this study is to analyze the static behavior of aluminum-based composite materials, focusing on Aluminum 2024 and Aluminum 2024-T3 alloys, with reference to manufacturing methods and experimental results.

Aluminum 2024 and Aluminum 2024-T3 alloys are widely recognized materials for their applicability in industries with high structural requirements[17-25]. Aluminum 2024 is a high-performance alloy with additions of copper, magnesium and manganese, being heat treated to enhance mechanical properties.

2. MATERIAL AND METHOD

Material Selection Aluminum 2024 and Aluminum 2024-T3 alloys were chosen for industrial applications due to their mechanical properties.

Mechanical tests were performed to evaluate the strength and stiffness of the materials under static load. In the case of tensile tests, Aluminum 2024 and Aluminum 2024-T3 showed significant differences in elongation and maximum stress. These tests highlighted that the T3 heat treatment significantly improves the mechanical properties of the material, with a notable increase in tensile strength.

2.1 Optical Spectral Analysis

To verify the chemical composition of the samples, optical spectral analysis was performed using an optical emission spectrometer, SPECTROMAXx M (Figure 1). The samples were prepared by polishing (Figure 2) to remove surface contaminants, and the analysis results (Figure 3 and 3) confirmed the chemical composition according to accepted standards for Aluminum 2024.

Figure 1. SPECTROMAXx M optical emission spectrometer

Figure 2. Presi-Minitech 233 Polishing Machine

Aluminum, Al	90.7 - 94.7 %	90.7 - 94.7 %
Chromium, Cr	<= 0.10 %	<= 0.10 %
Copper, Cu	3.8 - 4.9 %	3.8 - 4.9 %
Iron, Fe	<= 0.50 %	<= 0.50 %
Magnesium, Mg	1.2 - 1.8 %	1.2 - 1.8 %
Manganese, Mn	0.30 - 0.90 %	0.30 - 0.90 %
Other, each	<= 0.05 %	<= 0.05 %
Other, total	<= 0.15 %	<= 0.15 %
Silicon, Si	<= 0.50 %	<= 0.50 %
Titanium, Ti	<= 0.15 %	<= 0.15 %
Zinc, Zn	<= 0.25 %	<= 0.25 %

Figure 3. Chemical composition of Aluminum 2024 - minimum and maximum limits

Program: DACIA
Comment: Al-Dacia
Average (n=1)

121566/06

06.03.2023 14:18:15
Elements: Concentration

Sample No: 2024 PLT3
Sample Id:

Quality:
Customer:

	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
	%	%	%	%	%	ppm	%	%
$\bar{x}$	0.07	0.151	3.859	0.353	0.989	31.5	0.008	0.08
	Ti	Pb	Sn	Bi	Ca	Na	P	Sb
	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm
$\bar{x}$	236.7	32.6	0.007	<3.0	15.7	<1.0	12.6	<1.0
	Sr	Hg	Cd	SUM	ID	Ga	Ce	Ag
	ppm	ppm	ppm	ppm	%	%	%	%
$\bar{x}$	<1.0	30.2	7.8	338.9	0.896	0.015	<0.0015	0.0001
	Ba	B	Be	V	Zr	Al	Bg	Co
	%	%	%	%	%	%	%	%
$\bar{x}$	<0.0001	0.0010	0.0001	0.0079	0.0022	93.9	93.9	<0.0005
	Li	In						
	ppm	%						
$\bar{x}$	<1.0	<0.0003						

Figure 4. The result of the spectral analysis

2.2 Optical Micrography

The internal structure of the samples was examined by optical micrography using a Zeiss Axio microscope, equipped with an AxioCam Erc5s digital camera. The samples were prepared by polishing, using abrasive cloths with variable grain sizes to obtain a smooth and imperfect surface. This analysis method provided a detailed assessment of the microstructure of the materials, verifying compliance with the ASRO standards for Aluminum 2024.

2.3 Mechanical Tensile and Bending Tests

For the tensile test, the tests were performed on the LLOYD Instruments LS100 Plus machine. The resulting mechanical properties are summarized in Table 1.

Table 1. Properties of the samples after tensile loading.

Aluminum alloy type	**Sample number**	**Maximum force at maximum load**	**Maximum voltage at full load**	**Elongation at break**	**Young's modulus**	**Stiffness**
		[kN]	[MPa]	[mm]	[MPa]	[N/m]
Al 2024	Sample 1	2.336645729	389.4409549	7.676661398	61795.02271	7415402.725
	Sample 2	2.546943845	424.4906408	7.753428012	61177.07248	7341248.698
	Sample 3	2.327299147	387.8831912	8.060494468	67974.52498	8156942.998
	Sample 4	2.383378644	397.229774	7.446361557	62721.94805	7526633.766
	Sample 5	2.430111559	405.0185932	7.90696124	66120.6743	7934480.916
ε	**Average values**	**2.404875785**	**400.8126308**	**7.768781335**	**63957.8485**	**7674941.82**
Al 2024 T3	Sample 1	2.407104824	401.1841374	6.529193232	66939.30789	8032716.947
	Sample 2	2.567459975	427.9099958	5.219486094	71313.692	8557643.04
	Sample 3	2.406676443	401.1127405	2.072679759	70189.23021	8422707.625
	Sample 4	2.493541506	415.590251	4.736249309	57658.21122	6918985.346
	Sample 5	2.493541506	409.0690923	4.746554598	66673.42067	8000810.48

ε	Averag e values	2.46583946	410.9732434	4.660832599	66554.7724	7986572.688

The results of the tensile tests were presented by the Force-Displacement and Stress-Deformation characteristic curves (Figures 5 - 10), which provide a clear picture of the behavior of composite materials under static loading.

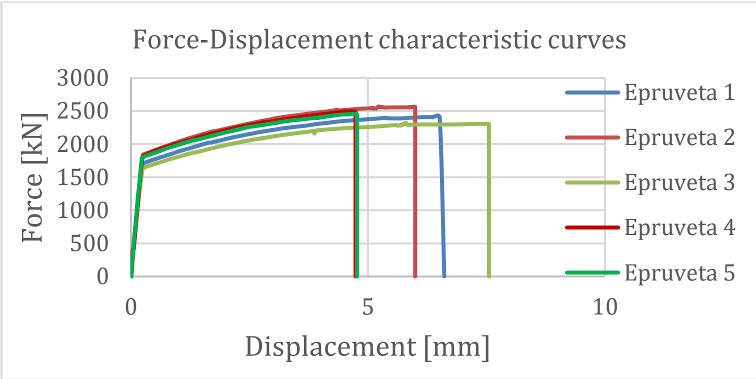


Figure 5. Force-Displacement characteristic curves for 2024 T3 aluminum samples subjected to tensile testing

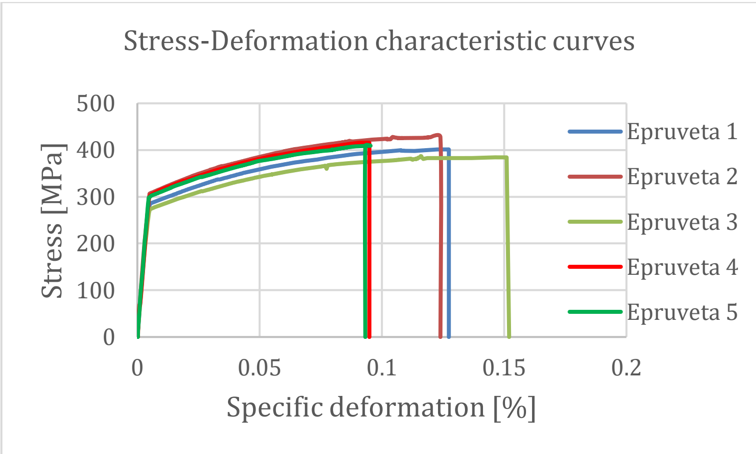


Figure 6. Stress-Deformation characteristic curves for 2024 T3 aluminum samples subjected to tensile testing

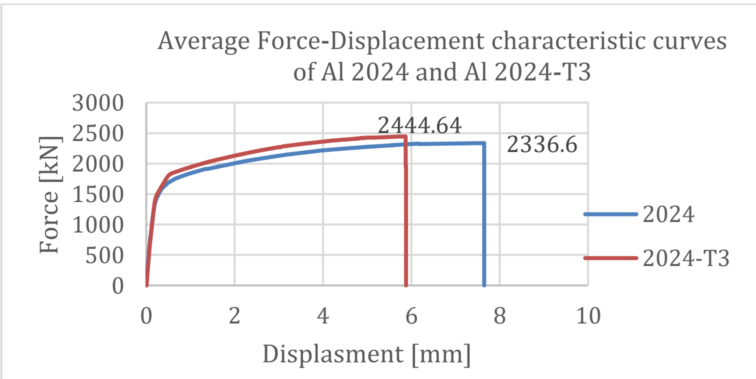


Figure 7. Average Force-Displacement characteristic curves of Al 2024 and Al 2024-T3 subjected to tensile testing

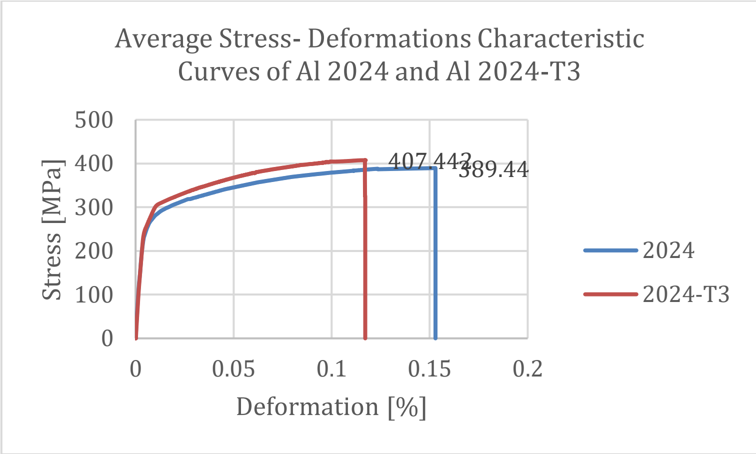


Figure 8. Average Stress- Deformations Characteristic Curves of Al 2024 and Al 2024-T3 Subjected to Tensile Testing

For the bending tests, the LLOYD LR5K Plus bending testing machine was used. The mechanical properties resulting from the bending tests are presented in Table 2, and the force-displacement and stress-deformations characteristics are represented in Figures 9 - 13.

Table 2. Properties of the samples after bending stress

Aluminum alloy type	**Sample number**	**Maximum force at maximum load**	**Maximum voltage at full load**	**Maximum Deformation at Maximum Bending**	**Young's modulus**	**Bending Stiffness**
		[kN]	[MPa]	[mm]	[MPa]	[N/m]
Al 2024	Sample 1	0.023000439	408.8967012	0.044810153	32501.10341	0.008775298
	Sample 2	0.023028919	409.4029956	0.043954701	29969.78275	0.008091841
	Sample 3	0.023685193	421.0701038	0.043954205	30863.1349	0.008333046
	Sample 4	0.023892215	424.7504948	0.04395591	29862.28915	0.008062818
	Sample 5	0.023382113	415.6820023	0.043955451	28199.55946	0.007613881
ε	**Average values**	**0.023397776**	**415.9604596**	**0.044126084**	**30279.17393**	**0.008175377**
Al 2024 T3	Sample 1	0.028079	499.1751	0.035727575	34840.17959	0.009406848
	Sample 2	0.027543	489.6579	0.029746724	34727.4783	0.009376419
	Sample 3	0.0293	520.8926	0.026504176	34669.54903	0.009360778
	Sample 4	0.02871	510.4089	0.02897787	35292.79996	0.009529056
	Sample 5	0.027841	494.9553	0.057730432	34510.27769	0.009317775
ε	**Average values**	**0.028294759**	**503.0179455**	**0.035737356**	**34808.05692**	**0.009398175**

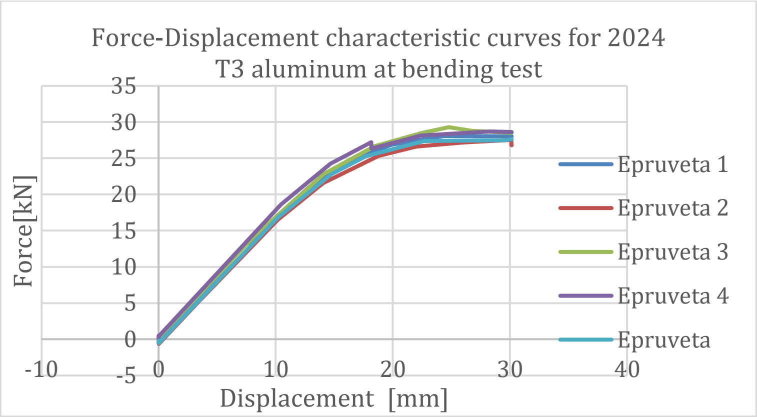


Figure 9. Force-Displacement characteristic curves for 2024 T3 aluminum samples subjected to bending test

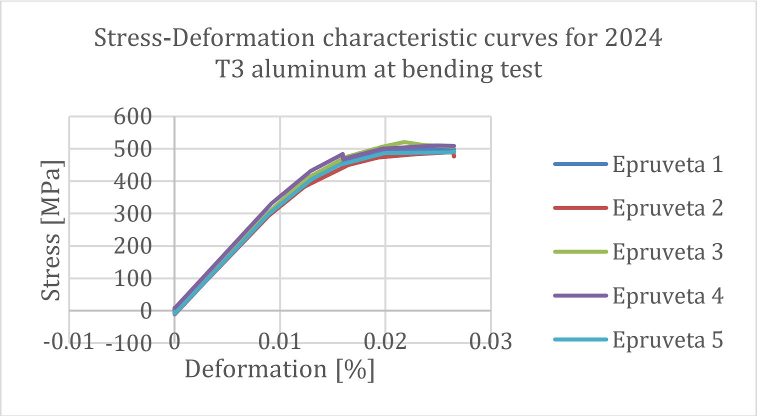


Figure 10. Stress-Deformation characteristic curves for 2024 T3 aluminum samples subjected to bending test

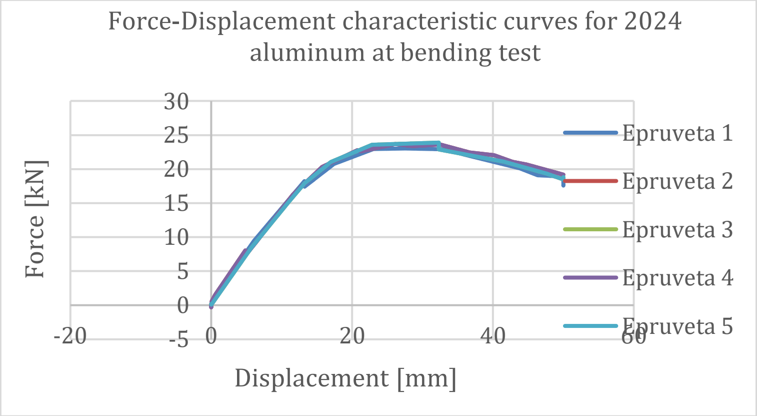


Figure 11. Force-Displacement characteristic curves for 2024 aluminum specimens subjected to bending test

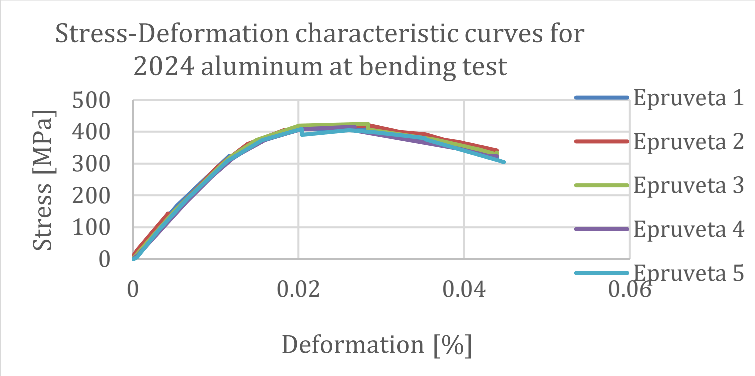
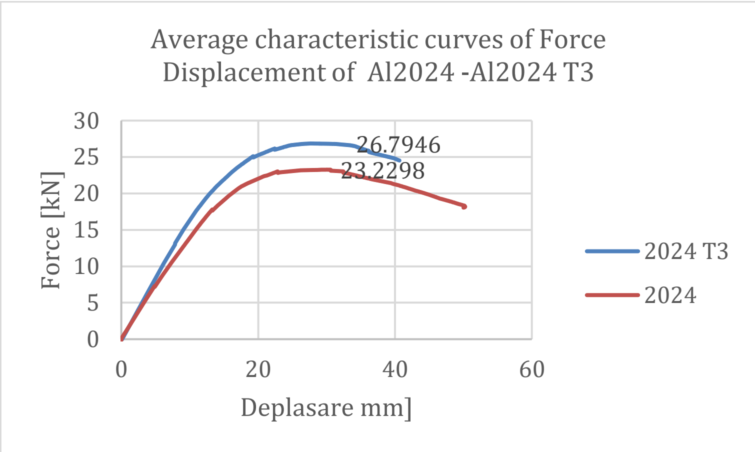


Figura 12. Stress-Deformations characteristic curves for 2024 aluminum specimens subjected to bending test



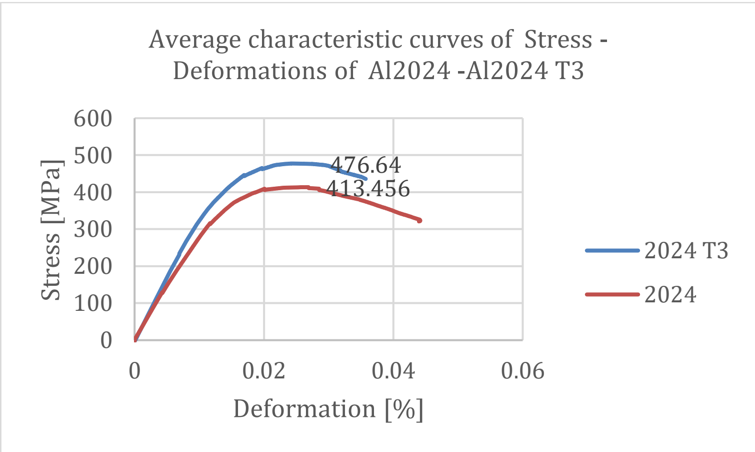


Figure 13. Average characteristic curves a) Force - Displacement and b) Stress - Deformations of Al 2024 and Al 2024-T3 subjected to bending test

2.4 Finite Element Method (FEM) Simulation

In order to better understand the behavior of composite materials under static conditions, the finite element method (FEM) was used, simulating tensile tests through Abaqus software, using 3D modeling for deformable bodies, see figure 14. The geometry of the part was entered according to the experimental dimensions. The analysis revealed that the FEM predictions are consistent with the experimental results, confirming the accuracy of the simulations in describing the behavior of Aluminum 2024 composite materials subjected to tensile stress.

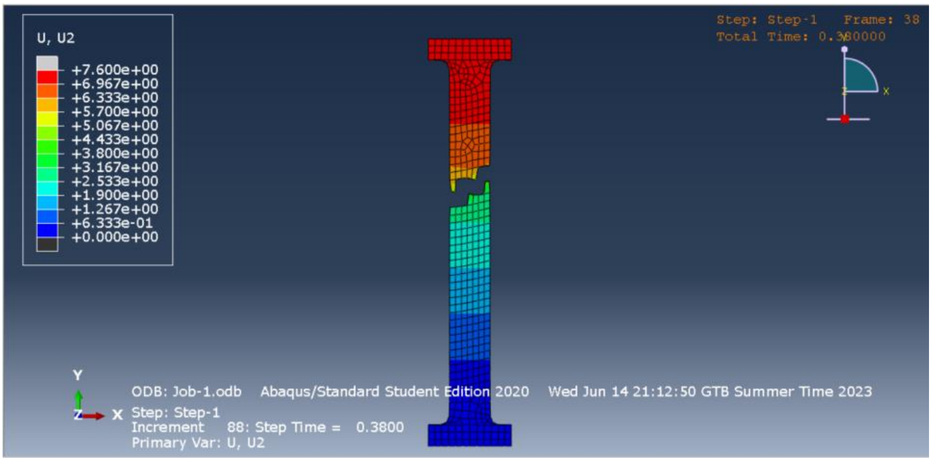


Figure 14. Finite element analysis

3. EXPERIMENTAL RESULT AND DISCUSSION

The experimental test results and FEM simulations showed a good correlation between the real and simulated behavior of the 2024 Aluminum composite materials. A significant improvement in mechanical properties was observed for the heat-treated materials (2024-T3 Aluminum) compared to the untreated materials (2024 Aluminum). The applied heat treatments increased the tensile and bending strength, and the use of Abaqus simulation allowed an accurate prediction of the mechanical behavior under static conditions.

The main factors influencing the static behavior of composite materials are the type and volume fraction of the reinforcement, the matrix-reinforcement interface, and the material microstructure. Also, the correct choice of heat treatment is essential for obtaining optimal mechanical properties.

4. CONCLUSION

Aluminum-based composite materials have shown improved performance under static loads when subjected to heat treatment. Tensile and flexural tests have demonstrated increased stiffness and mechanical strength of heat-treated aluminum, making them suitable for critical applications in the aerospace and automotive industries. Finite element simulations have provided accurate predictions and can be used to optimize the design of these materials.

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