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STUDY OF THE MECHANICAL BEHAVIOR OF A TAILGATE MADE OF CARBON FIBER COMPOSITE MATERIAL

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Abstract: *Carbon Fiber Reinforced Plastics composite materials are increasingly used at the expense of traditional metallic materials due to their superior mechanical characteristics. In this paper is presented the experimental and numerical study of stiffness of an electrical vehicle tailgate made of CFRP composite material. For this purpose, the tailgate was subjected to a vertical static force, applied centrally and laterally to its symmetry axis. Finite element simulations were done for similar loading conditions in order to validate a numerical model. Material constants and strain-stress behavior were experimentally measured by standard tensile test considering an orthotropic material model. The obtained results of the tailgate stiffness test and simulation show a good convergence, the relative deviations being below 2%. Future works can be extended to other structural elements, such as doors, roofs, floors, etc., under static and dynamic loading conditions.*

Key words: *CFRP material, tailgate, stiffness, mechanical properties, experimental test, numerical simulation.*

1. INTRODUCTION

Composite materials, such as CFRP (Carbon Fiber Reinforced Plastics), are increasingly used over metallic materials because of their superior mechanical properties, such as: light weight, high strength and elastic modulus, good fatigue and corrosion resistance, good stiffness property [1-3].

Although composite materials and manufacturing technology are expensive, electric vehicle manufacturers have begun to invest in both the research and development of carbon fiber materials and high-performance equipment. Manufacturers are considering the mass production of CFRP structural components (doors, hood, tailgate, bumpers, roof panels, etc.) and their use to body vehicle construction, due to the mechanical properties, but also to reduce the weight of the vehicle. A reduced vehicle mass is advantageous because engine efficiency, acceleration force and braking power are maximized, fuel consumption is reduced and battery autonomy in the case of electric vehicles is improved, respectively [4,5].

Among the vehicle doors, the tailgate is considered an essential body vehicle component and is the closing door of the luggage compartment. The tailgate must be designed in order to fulfill some requirements such as: good rigidity property, respectively small deformations because it is usually subjected to bending and torsion, to provide an aerodynamic surface for the wind flow, to eliminate external noises (i.e. wind rush, friction with metals), to be easy and safe to handle by the customer, to ensure the aesthetic design [6,7]. In [6] some aspects are presented for reducing the tailgate closing effort with the help of analysis and dimensional corrections of the vehicle body. In this case, dimensional analysis in Body-In-White (BIW) at sub-component levels and tailgate optimization was performed, respectively.

In papers [4,8,9] the authors present in detail the benefits of using the CFRP materials in production of vehicle components (bumper, hood or bonnet, roof, tailgate etc.), and give a substantial review regarding the mechanical properties of CFRP. Also, in these works it is

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specified that compared to a standard metal tailgate, the overall weight of the tailgate can be reduced by 35% if it is used CFRP material.

In [10] the main objective of the authors was to achieve a tailgate with reduced mass by using a composite material. Thus, some structural and design modifications were made. Various structural loadings, including latch, torsional and bending were considered. After FEA optimization, the total mass of the prototype carbon fiber tailgate panel was 3.4 kg, meaning a mass saving of 6.6 kg (or 66%), compared to the corresponding standard steel panel.

Studies regarding the optimization and design of the structural elements of the cars made by CFRP composite materials, respectively numerical simulations of the stiffness can be found in the works [11-13].

In this paper is presented the experimental and numerical stiffness study of an electrical vehicle tailgate made of CFRP composite material. The tailgate was subjected to bending by a vertical force, applied in two points: in a point situated on the symmetry axis of the tailgate and one point laterally to the axis. In order to perform comparative numerical analysis, it was necessary to determine by tensile tests the mechanical properties of the composite material. Evaluation of elastic moduli (Young's modulus in two perpendicular directions and shear modulus) corresponding to a homogenized orthotropic material was realized by standard tensile tests.

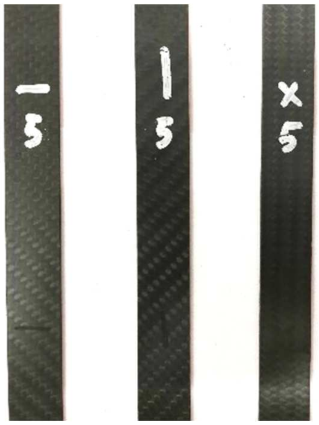
In the last part of the paper, the obtained results are comparatively presented, and the conclusions are emphasized.

2. MATERIAL AND METHOD

2.1 Material

Tensile tests represent the most common approach for determining the mechanical characteristics, respectively the behavior of CFRP composite materials [14-16]. For the tailgate studied in this work, the mechanical characteristics of the CFRP material (elastic and shear modulus, tensile stress at maximum load, tensile strain), and respectively the characteristic curve (σ – ε) was necessary to be achieved.

The CFRP sheet contains carbon fiber twill type as reinforced material, and epoxy resin as matrix. The composite material used in the manufacturing of the investigated components has the following lay-up: first layer of prepreg carbon fiber type GG 245 with lamination direction 0/90; mid layer from GG 430 with rolling direction +/- 45 and a third layer of GG 630, with rolling direction 0/90. Total thickness of the composite material was about 1.66 mm. For the manufacture of CFRP sheet vacuum bag technology was used. To determine the mechanical properties of the CFRP composite material (considered orthotropic), three sets of flat specimens (each set contains five specimens) were cut from the same plate at 0°, 45° and 90° to the loading direction and orientation of the outer layers (warp fibers) [15,16]. The dimensions of the specimens are according to the ASTM D3039M-00. The specimens are presented in Fig.1 and the dimensions are given in Table 1.



a) b) c)

Fig. 1. CFRP specimens cut from a plate with the orientations: a) 0°; b) 90°; c) 45°

Table 1

Specimen dimensions.

Length [mm]	**Width** [mm]	**Thickness** [mm]
200	25	1.66

2.2 Method

The mechanical constants, respectively the σ – ε characteristic curve of the composite material for each specimen sets, were obtained by performing tensile tests. Servo-hydraulic testing machine Instron 8801 Dual Column (100kN) was employed to obtain the elastic (σ – ε) characteristic curve and corresponding materials parameters like Young's moduli (E_1, E_2), shear modulus (G), tensile strength (UTS) and maximum tensile strain. The crosshead speed was set to 1 mm/min, measured strain values were based on crosshead position. Data acquisition and processing was carried out by the Instron's Bluehill software. The tensile tests were run taking into account the procedures presented in the ASTM D 3039/M-00 for specimens with the warp fibers parallel to the load (denoted 0° and 90°) and a tensile test of a ±45° laminate is performing by the ASTM D3518M standard to evaluate the in-plane shear response.

In Fig.2 is presented the experimental set-up for tensile tests.

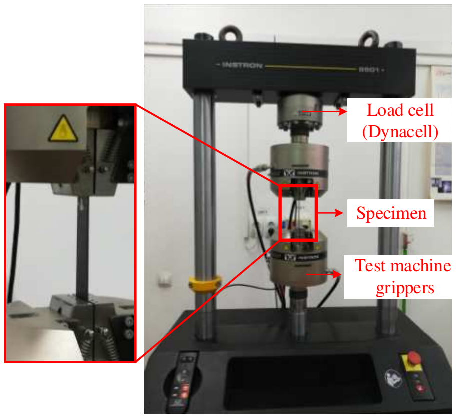


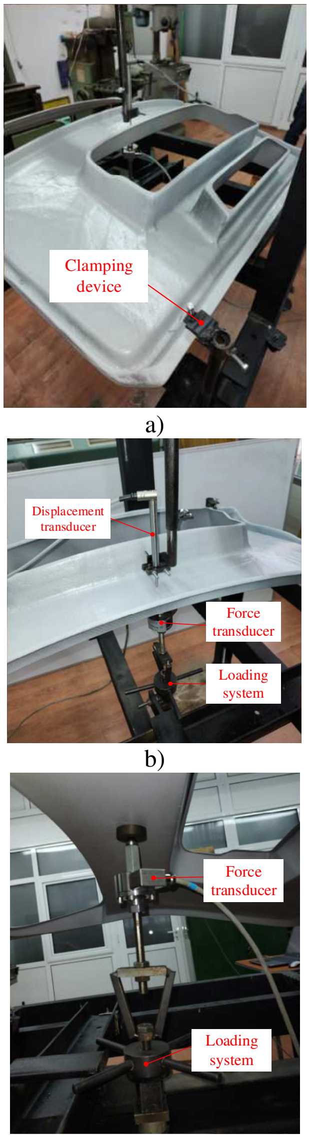
Fig. 2. Servo-hydraulic testing machine Instron 8801 for tensile test of CFRP specimens

3. STIFFNESS DETERMINATION OF THE TAILGATE

3.1 Experimental set-up

An experimental set-up was used to determine the stiffness of the tailgate made of CFRP material. The experimental set-up was built from standardized I shape profiles ensuring a rigid structure and the accuracy of the measurements were not affected during measurements. The boundary conditions (supports) of the tailgate coincide with the real ones (on the vehicle).

An HBM WA-T 10 mm displacement transducer was mounted on the upper beam of the experimental set-up to measure the vertical deformations of the tailgate in the loading point. In Fig.3 is presented the experimental set-up for determining the stiffness in the case of centrally applied force.



a)

b)

c)

Fig. 3. Experimental set-up (centrally applied force): a) general view; b) upward and c) downward view

A screw-nut/disc mechanism was mounted on the lower assembly of the experimental set-up that ensures the controlled application of the force. The force value is measured by HBM 10 kN force transducer. To determine the displacements and to calculate the stiffness, the tailgate was subjected to bending with vertical forces successively applied centrally and laterally respectively with respect to the longitudinal symmetry axis of the part and vehicle.

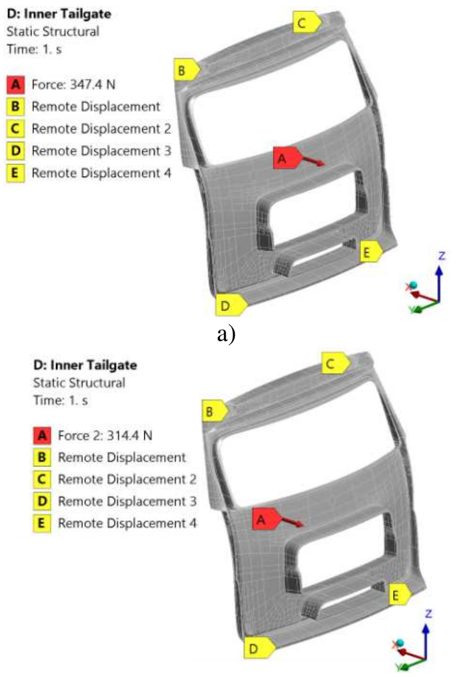
The acquisition, visualization and processing of experimental data were done with a HBM Spider 8 data acquisition system, controlled by the Catman Easy software (HBM).

3.2 Numerical simulation

Finite element analysis (FEA) is a widely used numerical method in computational mechanics where meshes are used to create a grid of elements that allow the simulation of models/parts with complex geometry [17].

Numerical simulation was performed with Ansys Academic 2019 R.2 software, the Static Structural module, respectively. The purpose of the numerical simulation is to determine the displacements and to calculate the stiffness of the tailgate, in the case of the two positions of the applied forces, and to compare the simulation with the experimental results.

The fixed supports and loading conditions of the tailgate must correspond to the experimental set-up. Thus, the tailgate loading is achieved by means of a concentrated force, successively applied centrally and laterally with different values. The fixed supports and the loading force are highlighted by the yellow and red labels and depicted in Fig. 4.



a)

b)

Fig. 4. Boundary conditions and applied forces: a) centrally; b) laterally

The FE mesh was done automatically by the Ansys software, obtaining a number of 725407 nodes and 735663 shell elements (Fig.5).

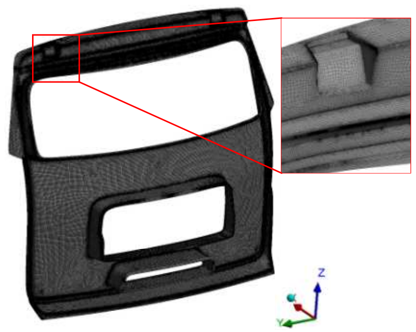
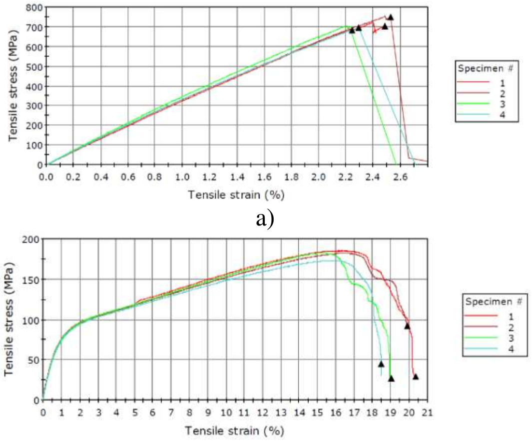


Fig. 5. The FE mesh of the CFRP tailgate

4. RESULTS

4.1 Mechanical properties of CFRP material

After performing the tensile tests, the mechanical properties of each type of specimens have been obtained. The elastic modulus (E_1, E_2) for each specimen orientation was determined automatically by Bluehill software. In Fig. 6 the σ – ε diagrams obtained from tensile test machine highlight the mechanical behavior of specimens with different orientations until break. In Fig. 7 the linear elastic region of the stress - strain diagrams are presented, and it is used to calculate the Young's moduli as the slope of elastic region. The shear modulus (G) of the CFRP composite material for 45° specimen was also calculated according to ASTM D3518M standard base on E modulus (G=E/2).



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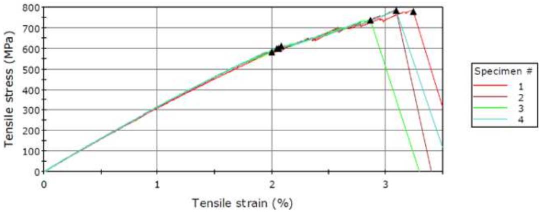
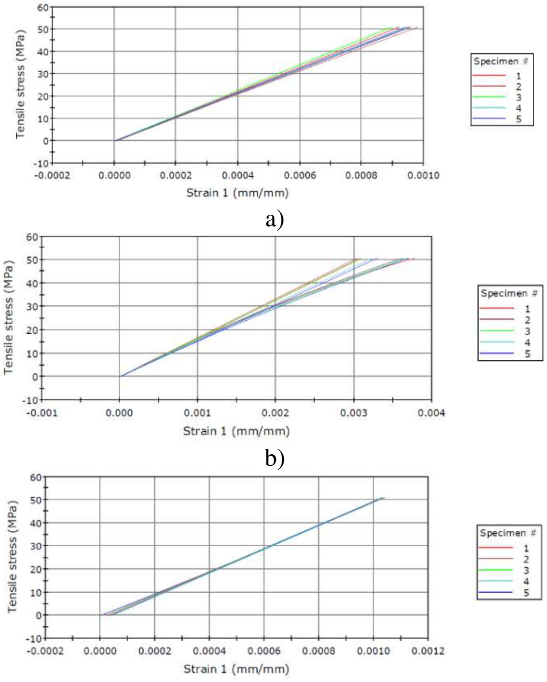


c)

Fig. 6. The σ – ε diagrams obtained from tensile tests for specimen's orientation: a) 0°; b) 45°; c) 90°



a)

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Fig. 7. The elastic region of σ – ε diagrams for specimen's orientation: a) 0°; b) 45°; c) 90°

In Table 2 are given the average values of the tensile strength at maximum load, the strain at tensile strength, and respectively the Young's moduli for each type of specimen. The standard deviations are also provided (in brackets).

Table 2

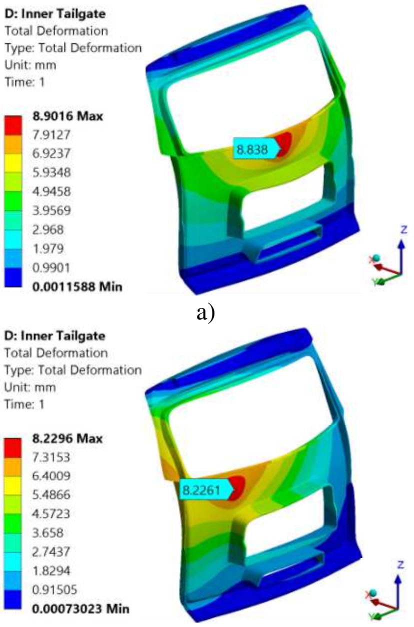
CFRP material properties.

Specimen orientation	**Tensile strength at max. load**	**Tensile strain at tensile strength**	**Young's modulus**
	[MPa]	[%]	[MPa]
0°	718.5 (25.16)	2.35 (0.12)	54962.90 (1640.67)
45°	180.8 (5.18)	16.06 (0.58)	16057.10 (563.05)
90°	772.0 (22.95)	3.07 (0.14)	50910.50 (506.99)

4.2 Experimental and numerical results for tailgate

Deformations and stiffness of the tailgate for the centrally and laterally applied forces were obtained after experimental tests and numerical simulations. For the numerical simulations, it was necessary to define the CFRP material properties experimentally determined and previously presented. Thus, the elastic modulus in the simulation were E_1=54962.90 MPa, E_2=50910.50 MPa and shear modulus G=8028.55 MPa.

The displacements in the direction of the applied forces are highlighted in Fig. 8.



a)

b)

Fig. 8. Numerical deformations obtained for: a) centrally and b) laterally applied force

Table 3

The experimental and numerical displacements obtained for tailgate.

Position of the applied force	**Applied force F** [N]	**Displacement δ** [mm]		**Rel. dev. δ** [%]
		$\delta_{exp.}$	**$\delta_{num.}$**	
Centrally	347.4	8.762	8.874	1.27
Laterally	314.4	8.189	8.090	1.20

Table 4

The experimental and numerical stiffness values obtained for tailgate.

Position of the applied force	**Applied force F** [N]	**Stiffness k** [N/mm]		**Rel. dev. k** [%]
		$k_{exp.}$	**$k_{num.}$**	

Centrally	347.4	39.65	39.14	1.28
Laterally	314.4	38.39	38.86	1.22

In Table 3 and 4 are given the experimental and numerical values obtained for each applied force. It is specified that the forces used to perform the experimental measurements, and the numerical simulations, are the following: the central force is 347.4 N and the lateral force is 314.4 N.

Comparing the numerical results with the experimental ones, errors less than 2% were obtained. Thus, the displacements and the stiffness of the tailgate analyzed in this article are in good agreement, validating the methodology of the study and identified material parameters.

7. CONCLUSION

In this paper was presented the experimental and numerical determination of the stiffness (k) and the maximum displacement (δ_{max}) for a tailgate in the structure of an electric vehicle. The maximum displacement, respectively the stiffness, were determined for two concentrated forces, applied in the center, respectively on the side of the tailgate.

The material used for the tailgate is a CFRP composite material for which it was necessary to determine the mechanical properties and respectively, the characteristic curve of the material, $\sigma - \varepsilon$ through tensile tests. The specimens were cut from the same sheet of CFRP composite material with different directions to the loading with respect to outer fabrics disposal (0°, 45°; 90°).

The experimental and numerical results were given in graphical and tabular form, respectively. The obtained results of the tailgate stiffness show a good convergence, the relative deviations being below 2%. Future works can be extended to other structural elements, such as doors, roofs, floors, etc., under static and dynamic loading conditions.

8. ACKNOWLEDGEMENT

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STUDIUL COMPORTAMENTULUI MECANIC AL UNEI UȘI DE PORTBAGAJ REALIZATĂ DIN MATERIAL COMPOZIT ARMAT CU FIBRE DE CARBON

Abstract: *Materialele compozite CFRP sunt din ce în ce mai utilizate în detrimentul materialelor metalice tradiționale datorită caracteristicilor lor mecanice superioare. În această lucrare se prezintă studiul experimental și numeric al rigidității unei uşi de portbagaj din structura unui vehicul electric realizat din material compozit CFRP. În acest scop, uşa de portbagaj a fost solicitată de forțe statice verticale aplicate central și lateral față axa sa geometrică. În plus, prin încercări de tracțiune s-au determinat proprietățile mecanice și curba caracteristică a materialului compozit CFRP. Rezultatele obținute a rigidității uşi de portbagaj arată o bună convergență, abaterile relative fiind sub 2%. Investigațiile viitoare pot fi extinse și în cazul altor elemente structurale, cum ar fi uşi, acoperiș, podea etc., în condiții de încărcare statică și dinamică.*

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