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STIFFNESS ANALYSIS OF AN ELECTRIC CAR COMPOSITE BUMPERS

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Abstract: *A bumper system is a vehicle front and rear components designed to absorb kinetic energy during low-speed impacts and dissipate energy during high-speed impacts without damaging the vehicle. The present work presents numerical and experimental analyses of the front and rear bumpers fascia made of carbon fiber composites. Considering a supporting system similar to the reality, the methods analyze the stiffness of composite parts under static loads applied along and aside of the longitudinal symmetry axis of the car. The comparative results showed a good convergence, allowing future investigations of the bumper system under static and impact loads.*
Key words: *bumper fascia, carbon fiber composites, numerical simulation, experimental test.*

1. INTRODUCTION

The use of lightweight materials in the vehicle is one of the potential approaches to accomplish structural and eco-friendliness requirements. Important automotive parts like bumper, door panel and headliners have been manufactured with polymeric composites.

A bumper system is a set of vehicle front and rear components designed to absorb kinetic energy during low-speed impacts and dissipate energy during high-speed impacts without damaging the vehicle. Additionally, it serves aesthetic and aerodynamic purposes. New environmental regulations have increased the complexity of bumper system design, the new bumper variants are flexible enough to reduce injury to the occupants and pedestrians, remaining intact in low-speed impacts, but also stiff enough to dissipate kinetic energy in high-speed impacts [1-4]. Besides the ability to keep the vehicle intact and capacity to absorb kinetic energy under impact conditions, other key factors when choosing a bumper system are weight, cost, repairability and manufacturability of the elements. The bumper system is composed of three main elements fascia, energy absorber and bumper beam. Fascia is a more aesthetic component that reduces the aerodynamic drag force, but also can have a structural role. The energy absorber dissipates part of the kinetic energy during collision, while the bumper beam is a structural component which absorbs the low-impact energy by bending strength and energy dissipation. Current fascia design trends focus on aerodynamic efficiency where more complicated designed curves should be adopted to harmonize with modern vehicle design [5,6]. Using composite materials solves this problem especially for small series or unique electric city cars developed by innovative startups or medium enterprises. Evaluation of stiffness behavior of the fascia element of a bumper has also a practical impact. It can be done by Finite Element Analyses (FEA) [5] and by means of experimental methods [7].

The present work presents numerical and experimental analyses for front and rear bumpers fascia. The experimental procedure is presented at the beginning of work followed by the FE studies for two load cases of the composite elements. A comparison of the results is presented at the end of the paper together with the conclusions.

2. MATERIALS AND METHODS

In this study carbon fiber reinforced composite (CFRP), is selected as material for bumper fascia. Polymeric based composites are commonly used among all the composite materials, due to lower weight, aesthetically attractive, comparable strength and stiffness properties compared to the conventional materials. 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. The polymerization of the composite car body elements was performed in an industrial autoclave with the following cycle steps:

- Step 1: pressure of 4 bar, vacuum level - 0.85-0.9 bar, heating rate 2-3°C/min., heating temperature 80 °C, time 30 min;
- Step 2: pressure of 4 bar, vacuum level - 0.85-0.9 bar, heating rate 2-3°C/min., heating temperature 120 °C, time at 30 °C;
- Step 3: pressure of 4 bar, vacuum level - 0.85-0.9 bar, heating temperature 80 °C, time120 min. at 120 °C;
- Step 4: Cooling time 30 min with a cooling rate 2-3°C/min, pressure, and vacuum release. The final products were painted in white as it can be noticed in Figure 1, representing the front bumper fascia.

Fig. 1. Front bumper fascia on the test bench with lateral ball point force application mechanism and transducer

An experimental test bench was used to determine the stiffness of various elements of the car body. It was designed and built to offer multiple attaching points in order to replicate as close as possible the assembly of the elements to the chassis and to provide various loading cases (position, magnitude and contact surface). Furthermore, the structure of the experimental test bench has a rigid construction to minimize the influence of its own deformations on the measured values of the car body parts deflections.

A screw mechanism has been attached on the upper transverse beam of the bench that ensures the controlled application of force. Its value is being determined by the means of an HBM 10 kN force transducer. Figure 1 shows a front bumper fascia with the force transducer attached at one end and, partially, the test bench. A HBM WA-T 10 mm displacement transducer is measuring the deformation on the inner side of the car body element at the same point and in the same direction as the screw mechanism is applying the force, as shown in Figure 2.

Fig. 2. Displacement transducer placement on the inner side of the investigated car body part

Figure 3 presents a rear bumper fascia, with central application of force and a cylindrical contact surface attachment on the force transducer.

Fig. 3. Rear bumper fascia with central cylindrical surface force application mechanism and transducer

The lateral (off-center) application of force experiment is also conducted for the rear bumper fascia, as seen in Figure 4.

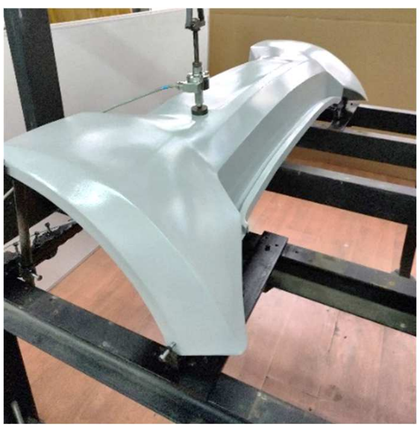

Fig. 4. Rear bumper with lateral force application and cylindrical contact surface attachment

The Spider 8 amplifier and the Catman Easy software from HBM were used for the acquisition, visualization and processing of the experimental data. Each test was repeated 5 times and the mean value of the stiffness was determined for both car body parts and for the two placement positions and contact surface attachments of the load generating mechanism. The stiffness is the slope of the force/displacement curve determined for each loading cycle of the car body part.

Table 1 presents the experimental results for the investigated parts and the load cases described above. The stiffness value was determined to be lower for the ball point force application cases and also irreproducible and damaging to the part due to local plastic deformations.

Table 1

Experimental results for the stiffness of the studied car body parts under different load cases

Car body element	Load position	Contact surface	Stiffness [N/mm]
Front bumper	Central	Ball-point	40.87
		Cylindrical	42.46
	Lateral	Ball-point	41.45
		Cylindrical	45.05
Rear bumper	Central	Cylindrical	62.91
	Lateral	Cylindrical	60.36

It showed a further possible research topic in determining a non-linear material model required to reproduce these results in simulation. Taking these into consideration, the ball-point load case has been dropped for the rear bumper fascia investigations.

Numerical analysis was performed using the Ansys Academic 2019 R.2 finite element method software. The Static Structural module was used in order to determine the deformation in-line with the applied force for the two car body elements.

Some flat sheets of CFRP were manufactured alongside with the investigated car body parts having the same number and orientation of layers, fiber to resin ratio and technological parameters in order to experimentally test and characterize the material for the finite element analysis. For this study, we have defined an orthotropic material model having the moduli of elasticity Ex = 54963 MPa and Ey = 50910 MPa and a Poisson ratio of 0.024.

Figure 5 shows cylindrical regions in the mesh of the front bumper corresponding to the locations of the placement of the force during the experimental testing.

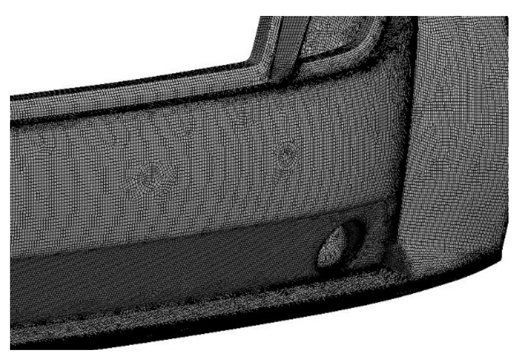

Fig. 5. Local detail generation in the mesh using the imprint face feature in ANSYS

Similar definitions were performed for the regions where the parts were anchored on the test bench and also for the rear bumper fascia. The boundary conditions were defined as shown in Figures 6 and 7 for both the car body elements and both load positions.

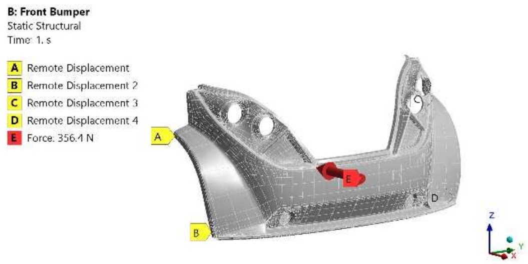

Fig. 6. Boundary conditions definition for the finite element analysis of the front bumper fascia, central positioning of the force

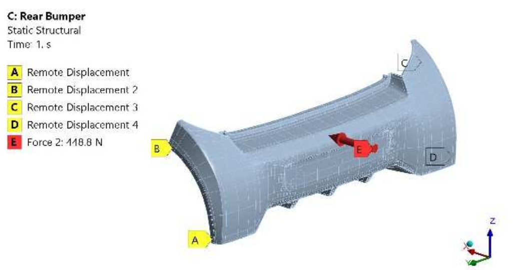

Fig. 7. Boundary conditions definition for the finite element analysis of the rear bumper fascia, lateral positioning of the force

The deformation of the investigated structures was numerically determined for all the cases described before and some examples are shown in Figures 8, 9, 10 and 11.

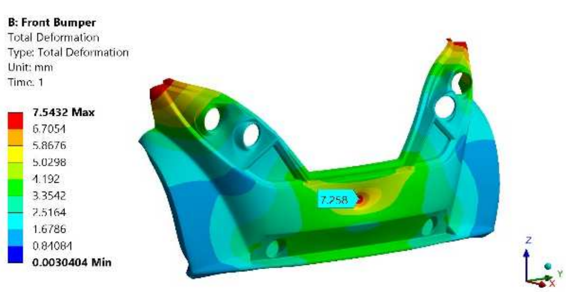

Fig. 8. Front bumper displacement for the central application of the load

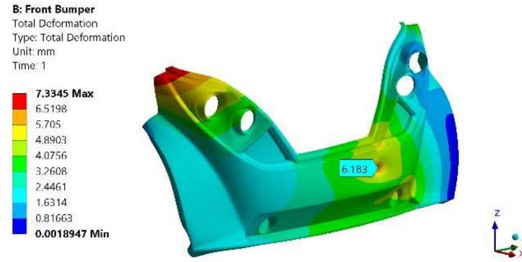

Fig. 9. Front bumper displacement for the lateral application of the load

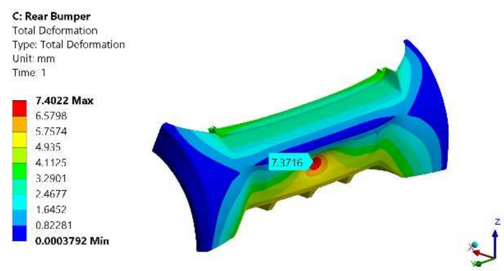

Fig. 10. Rear bumper displacement determination for the central position of the applied force

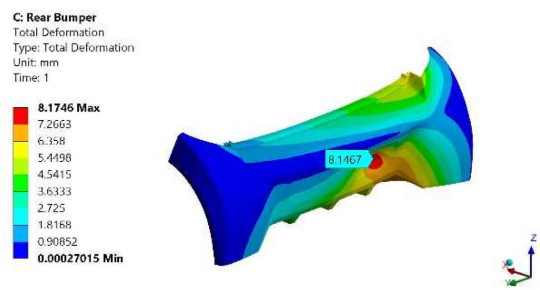

Fig. 11. Rear bumper displacement determination for the lateral position of the applied force

3. RESULTS

The experimental and numerical results obtained for the front and rear bumper fascia deformation under central and lateral application of the load are presented in Table 2. The parts were first investigated experimentally up to about 80% of the active travel range of the displacement transducer and then the same force was used in the numerical simulations.

Table 2

Comparative experimental and numerical results for the car body elements deformation along the direction of the applied force

Part	Load position	Force [N]	Deformation [mm]		Relative error [%]
			exp	num	
	Central	356,4	8,586	7,303	14,94

Front bumper	Lateral	337,2	7,905	6,086	23,01
Rear bumper	Central	500,4	7,765	7,397	13,51
	Lateral	448,8	7,552	8,148	7,89

From the comparative analysis between the experimental and numerical results we can see that the deformations we have obtained are in good agreement, thus validating the methodology of the investigations.

4. CONCLUSSIONS

Although the outer most surfaces of the car body elements are usually designed based on aesthetics and fluid flow considerations, these parts must also be able to withstand mechanical loads from flying debris, low speed collisions with other vehicles or environmental features and, unfortunately, sometimes even collisions with pedestrians.

For safety and low maintenance considerations, the front and rear bumper fascia should deform elastically without it suffering structural damage that would lead to future unpredictable behavior. In this paper we have presented a testing methodology for two such car body elements designed by a local producer of small series electric vehicles for industrial plant mobility.

The investigations were focused on determining a material model for the custom CFRP structure proposed by the manufacturer in order to be able to analyze both experimentally and numerically the behavior of the front and rear bumper fascia. Once the numerical models are validated, the studies can be extended to other load cases and even other car body elements.

Future work can be done in determining a transvers orthotropic material model in order to quantify the out-of-plane behavior of the CFRP structure and also high-speed impact testing in order to be able to study the dynamic loading of such parts.

For the moment, the methodology we have proposed ensures reliable determinations of the fascia elements stiffness and deformation analysis under various load cases.

5. ACKNOWLEDGEMENT

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ANALIZA RIGIDITATII BARELOR DE PROTECTIE ALE UNEI MASINI ELECTRICE

Un sistem de bare de protecție este o componentă a vehiculului concepută pentru a absorbi energia cinetică în timpul impactului la viteză mică și pentru a disipa energia în timpul impactului de mare viteză fără a deteriora pe cit posibil vehiculul. Lucrarea de față prezintă analize numerice și experimentale ale exteriorului barelor de protecție față și spate realizate din materiale compozite pe baza de fibră de carbon. Componentele au fost testate pe un stand ce ofera conditii de rezemare similare cu realitatea. S-au realizat teste experimentale pentru determinarea rigiditatii statice in doua situatii de incarcare, cu forta aplicata central in directia axei longitudinale de simetrie a vehiculului si respective forta aplicata excentric avand directia identica. Rezultatele comparative au arătat o bună convergență]ntre analiza numerica si cea experimentala, permițând investigații viitoare ale sistemului barei de protecție sub sarcini statice și dinamice (impact).

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