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Mechanical Properties Comparison of Steel and Carbon Fiber Composite Frame

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Abstract The paper deals with numerical analysis of mechanical properties of car seat backrest frames made of a structural steel and carbon fiber prepreg composite. The initial numerical simulation used Finite Element Method (FEM) provides results which show comparison of mechanical properties of both frames with identical geometry. The weight of both frames are also compared. The loading of the frame corresponding to the load from the passenger. Results of the analysis show the direction of carbon frame design optimization.

Keywords composite frame, carbon fibre, structural analysis, structural steel.

1. INTRODUCTION

These days, there is an effort to replacing the heavy material such as structural steel and its alloy with modern material like carbon fiber. The properties as light weight, high strength and no corrosion are demanded in various industrial applications such as aerospace, automotive, railways wagons, sports etc. The first aim of this study is to analyze the safety of the car seat backrest frame structure through the total deformation behavior of the load direction in Ansys workbench, second aim is to identify the weight reduction and the structural safety of the frame that was made of the carbon fiber prepreg materials.

2. MATERIALS AND METHODS

2.1 Materials

Carbon Fiber Reinforced Materials (CFRMs) are broadly fame for their auxiliary application in a wide range of fields, for example, car and aviation**.** CFRMs are usually designed and produced as relatively thin objects, called laminates. In a laminate several layers, made up of fibers and resin precursors, are stuck one on the other: playing on the composition of the layers, orientation of the fibers and on the stacking sequence, physical and mechanical properties can be controlled and tuned for specific applications. When the number of layers is increased, the composite can reach outstanding properties, regarding the high strength to weight and stiffness to weight ratios. Thick composites engineering, however, introduces some additional problem to the manufacturing of CFRMs based parts. [3]

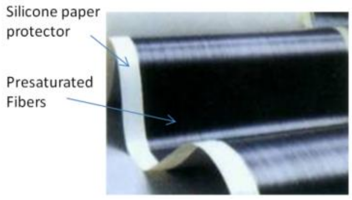


Fig. 1: Prepreg plate, basic material [4]

Fiber materials reinforced with long fibers are widely used because of their high strength-to-density ratio [4]. High strength composite materials can transform the tension only in the direction of the fiber (Figure 1). The tensile strength in the direction of the longitudinal direction of the longitudinal fibers is even lower than the strength of the matrix itself caused by the concentration of local stress in their interface. The material used is an epoxy UD prepreg with a thickness of 0.2 mm [5].

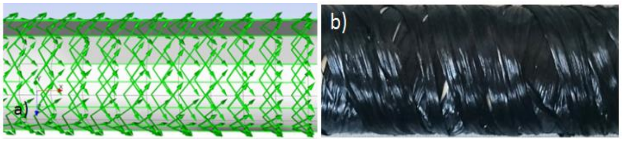


Fig. 2: The winded tube a) CAD model b) Real part [5]

However, in this paper carbon fiber stack up of individual layer with four plies (45, -45, 0, 90).

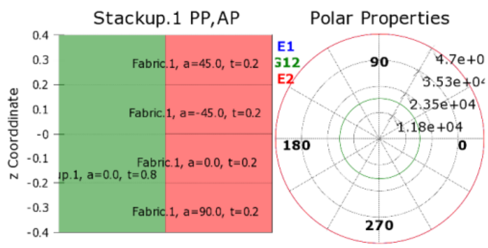


Fig. 3: UD composite: Polar properties of the created carbon stack-up (45, -45, 0, 90)

There are two different materials used in this study: steel materials and the carbon fibre prepreg. The mechanical properties of each material are shown in the following table.

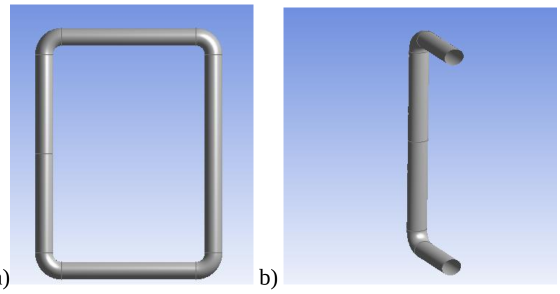
Table 1: Properties of material

Properties	Structural steel	Carbon fibre
Young's modulus	2E+05 MPa	See Fig. 3
Density	7850 kg/m^3	1490 kg/m^3

Since the specification of carbon fibre prepreg materials has a very low density and better Young's modulus compared to the structural steel materials or aluminium, it was assumed to be able to decrease the weight of the backrest seat frame structure.

2.2 FEM Analysis

The design of model was created in ACP (pre) Ansys in design modular, it is rectangular elliptical shaped, it means the cross section of the modal is elliptical and the path of the modal is rectangular. The cross section of elliptical ($W_{elliptical} > W_{circular}$). The rectangular tube dimensions are (530mm height and 385mm width), the cross section elliptical dimensions are (Ø25 mm major axis and Ø 20 mm minor axis) and radius of corners are 40mm.The total surface area of the backrest seat frame is 2,4994e+05 mm².

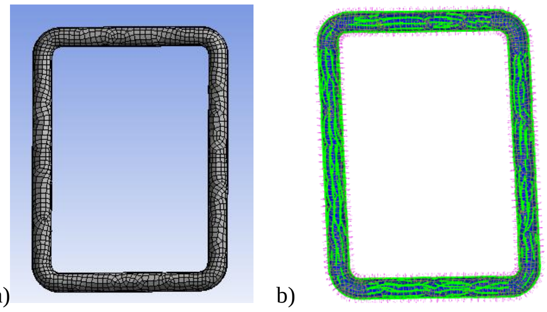

a) b)
Fig. 4: a) Design of frame b) Section view of frame

The Finite Element Method (FEM) is a powerful tool without which today it is not possible to design components effectively. It is very difficult to predict the mechanical behavior of carbon fiber, because the process induces fibre orientation, interface of plies etc [7]. During structural analysis, first, the structure of the backrest seat frame with steel materials could be evaluated the safety in terms of stress behaviour and displacement. Secondly, using carbon fibre materials for the backrest seat frame construction and deformation behaviour, the safety level was assessed by comparative analysis with steel material. Therefore, it is possible to compare the structural safety of each material with the weight reduction of the backrest seat frame structure.

Table 2: Compression of masses of frame

Structural steel	Carbon fibre
3,924 kg	0,744 kg

Meshing of frame to perform the analysis after applying each material, a meshing work was performed in order to generate the finite elements for the 3D modelling in Ansys workbench, there are 2190 nodes and 2202 elements.


a) b)
Fig. 5: a) Meshing b) Multilayer winded shell from carbon prepreg

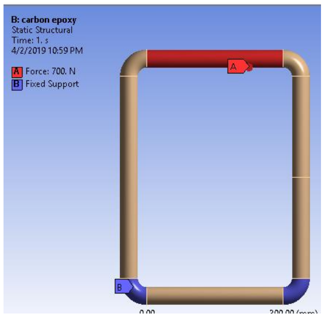
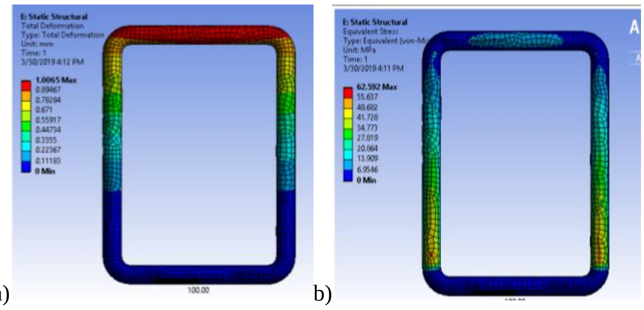


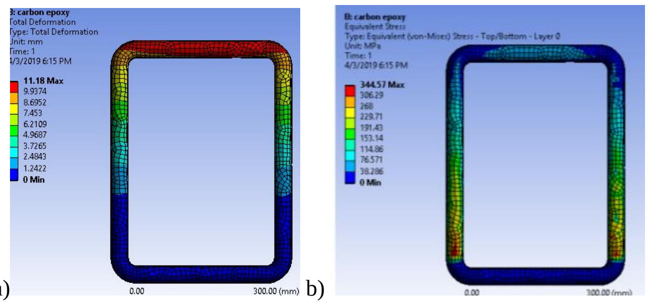
Fig. 6: Fully constrain model

3. RESULTS

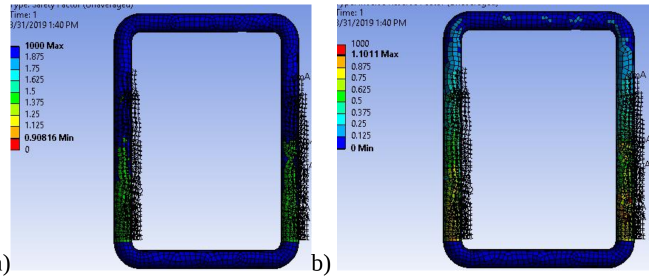
As a result of the structural analysis on the frame structure applied with structural steel materials, when applied maximum force 700 N, maximum distribution of von Mises stress, a maximum of 62,592 MPa stress had occurred on the frame, and maximum total deformation 1,0065 mm.


a) b)
Fig. 7: Structural steel - a) Total deformation b) Equivalent stress

When carbon fibre materials were used, a maximum displacement of 11,18 mm occurred in the direction of the loading (700 N applied) at the location of the upper cross member, and Equivalent stress is 344,57 MPa when the load is applied 700 N along X direction.


a) b)
Fig. 8: Carbon Prepreg - a) Total deformation b) Equivalent stress

Safety of frame It is necessary to compare the safety factor (fatigue fracture) characteristics between structural steel and carbon fiber prepreg, to make this comparison, Equivalent stress was used as a standard for design safety using von Mises' stress (σ_{von}) - a value shown through combining and exchanging the stress components in the direction of three-axis applied to the three-dimensional structures. Carbon fiber is an anisotropic material, and structural steel is isotropic material, in general, the safety of composite material is evaluated by using lamina failure criteria of Tsai- Wu and Tsai-Hill [6].



a) b)

Fig. 9: a) Safety factor b) Inverse safety factor

To evaluate the safety factor, we must check the composite failure tool, it allows you to configure your composite failure criteria for composite strength evaluation, like maximum stress, maximum strain, Tsai-Wu, Tsai- hill, puck, core failure etc.

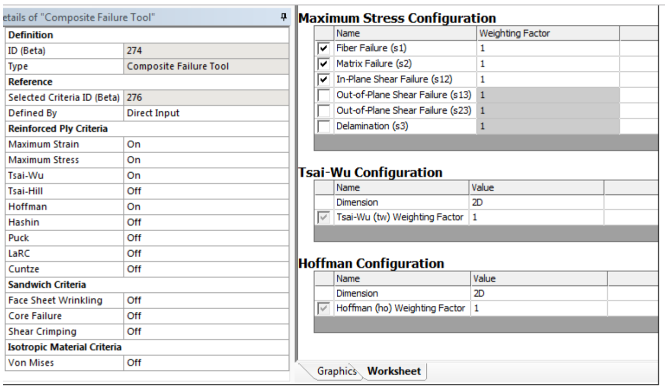


Fig. 10: Composite failure tools

The applied load multiply by safety factor determine the failure load, if the safety factor less than 1 then failure is experience. The value of safety factor is always greater than zero.

$SF \times F_{applied} = F_{f} = 0{,}9081 \cdot 700 = 635{,}67$ N

Inverse factor, when load is divided by IF, then failure load can be defined. Failure is experienced when you have an Inverse Reserve Factor greater than 1.

$IF = 1/SF = 1/0{,}9081 = 1{,}01$, which is greater than 1.

The critical value of inverse factor lies between 0 and 1. whereas the non-critical values range from one to infinity. Whether the results are shown in numeric form or as contour plots, the non-critical values tend to be emphasized in comparison to critical values. Safety margin, failure is obtained when SM is less than 1.

$SM = SF – 1 = 0{,}9081 – 1 = - 0{,}0919$, which is less than 1.

The positive safety limit indicates the relative amount that the load can increase before reaching the failure load. Accordingly, the negative safety limit indicates how much load should be reduced. The safety margins are usually expressed as a percentage.

4. CONCLUSION

The study shows the numerical comparison of mechanical properties of two car seat backrest frames, frame made of structural steel and frame made of carbon prepreg with 4 layers oriented (45, -45, 0, 90) under the demanded loading of 700N in direction corresponding to the load from the passenger. The frame made of structural steel shows better mechanical properties (maximal deformation 1,01 mm) than the frame made of carbon prepreg (maximal deformation 11,18mm). This initial simulation shows, that it is necessary to add another layers into carbon prepreg frame or increase the cross section of the frame to obtain frame with higher rigidity. On the other hand, in some application as some kind of car seat is higher deformation acceptable and low weight is strictly demanded. The weight of presented carbon frame is 0,744 kg and weight of steel frame is 3,924 kg. The replacement of steel frame by carbon frame bring significant reduction of weight, which causes desirable reduction of car exhaust emissions.

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