EAN 2018
56th conference on experimental stress analysis

Numerical Simulation of Reinforced Polyurethane Foam

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Keywords: natural fibers, polyurethane foam, composite, FEM

Abstract. Nowadays there is a significant demand of use eco-friendly technologies in industry included automotive. Legislation is constantly increasing the pressure to reduce emissions, especially carbon dioxide and nitrogen oxides. One of ways to reduce car emissions is reduce fuel consumption, which can be achieved by reducing the weight of the car, which means reducing weight of all parts including car seat. A possible solution of weight reduction is the use of new low-density materials with better properties instead of commonly use materials. The usage of natural composite materials is currently widespread in all fields of technology. A foam composite material has been designed to use in car seat cushions. Numerical simulations are a very powerful tool of mechanical parts design. A composite material model has been designed and verified.

Introduction

The car seat consists of many parts. One of them is a comfortable cushion, despite its low density, there is also the effort to reduce weight and price with the same comfort [1, 2, 3]. One way to get a lower weight cushion can be using of a composite low-density foam with good damping and comfort properties. For combination with polyurethane foam cheap natural fibers (cellulose, coir, hay etc.) can be used [4, 5]. The addition of natural fibers increases a tensile and compressive strength of flexible polyurethane foam. Many studies describe using reinforced polyurethane foams. Banik [5] has found that adding of only few percent of the fibers to the polyurethane foam significantly improves its mechanical properties. Shan [6] states that adding 2.5 % of coir to the flexible polyurethane foam resulted an improvement of damping properties. A useful tool for designing and optimizing mechanical parts are numerical simulations [7,8]. Simulation software usually contains a number of material models of homogeneous materials [9]. For simulating of composite materials, there are usually tools for creating of laminated materials [10]. For other composite materials is a possible way simulation on samples of the microstructure. In that case, the notion of representative volume element (RVE) is of paramount importance [11, 12]. The RVE is usually regarded as a volume of heterogeneous material that is sufficiently large to be statistically representative of the composite, i.e., to effectively include a sampling of all microstructural heterogeneities that occur in the composite. RVE must include a large number of heterogeneities (grains, voids, fibers, etc.) It must however remain small enough to be considered as a volume element of continuum mechanics.

Materials and methods

The aim of this work was to create a numerical model of a sample of composite polyurethane foam with a fiber reinforcement and to verify its behavior as compared to experimentally tested samples. The numerical model was created for a brick shape sample with dimensions 100x100x100 mm. First was created model of neat polyurethane foam without reinforcement. The numerical model was created according to real compression test Fig.1 a). The numerical model consist two rigid plates between them was the test sample Fig. 1 b). The bottom plate is fixed - motion is prevented in all directions, the top plate is only allowed to move in the vertical axis where the compression is applied at a speed of 100 mm.min^{-1}, compression was carried out to 70 % of sample height. A friction coefficient of 0.1 was applied to the contact surfaces. The polyurethane foam was defined as hyperfoam material in Abaqus. The abaqus hyprefoam [11, 12] model is a nonlinear, isotropic material model that is valid for cellular solids with porosity that permits large volumetric changes and is suitable for hyperelastic foams. The model is based on the strain energy function of the form

$$\mathbf{U} = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i^2}\left[\hat{\lambda}_1^{\alpha_i} + \hat{\lambda}_2^{\alpha_i} + \hat{\lambda}_3^{\alpha_i} - 3\frac{1}{\beta_i}\left(\left(J^{el}\right)^{-\alpha_i\beta_i} - 1\right)\right] \quad (1)$$

where N is a material parameter; μ_i, α_i and β_i are temperature dependent material parameters. The independent variables λ_i are principal stretches and are related to strain in a continuum. The term J^{el} is the elastic volume ratio and is a function of the principal stretches. Parameter β_i is related to the to the Poisson's ratio ν_i by the expression

$$\beta_i = \frac{\nu_i}{1 - 2\nu_i} \quad (2)$$

The model order N = (1÷6), must be chosen and the material parameters α_i, β_i and μ_i can either be specified, or computed by Abaqus using a least square fit that minimizes error in the computed stress when given experimental data. The Poisson's ratio can also be specified or computed. The acceptable experimental data for this model are uniaxial, biaxial and volumetric.

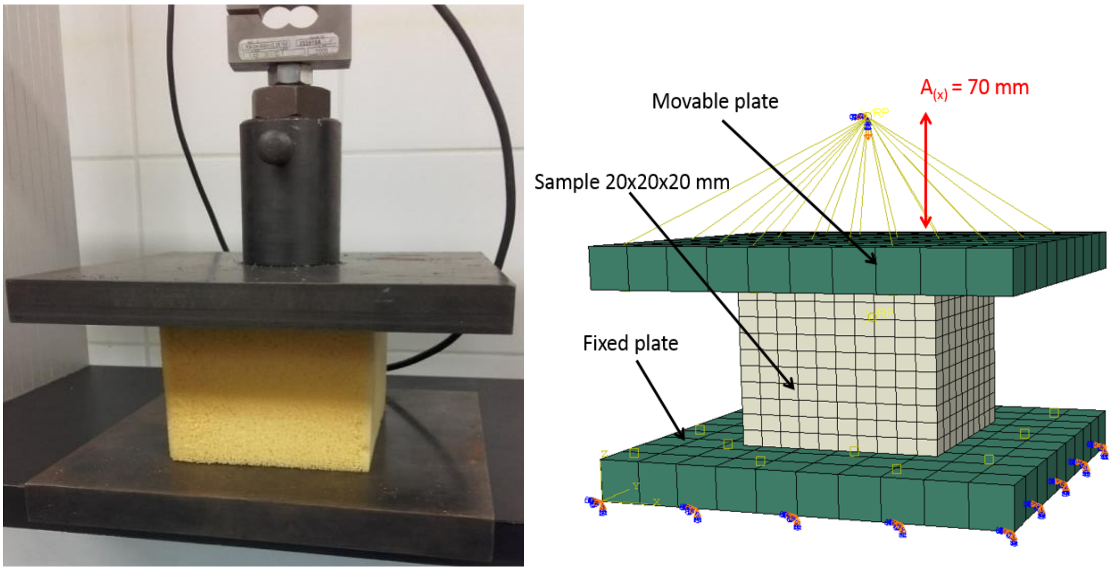

Fig. 1 a) arrangement of experiment b) numerical simulation of compression test

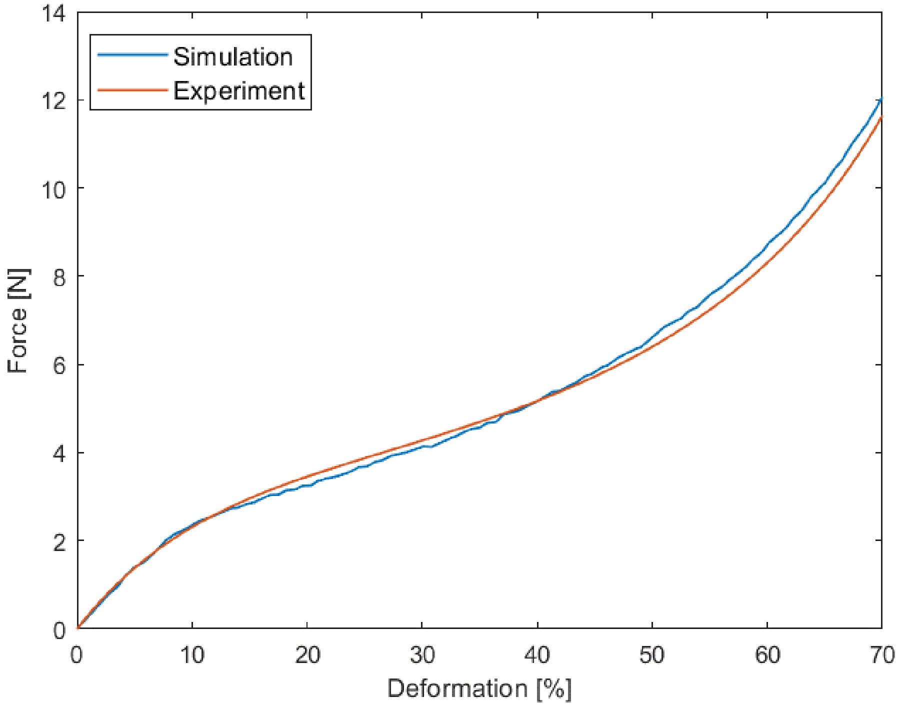

Fig. 2 Comparison of compression curves of neat polyurethane foam.

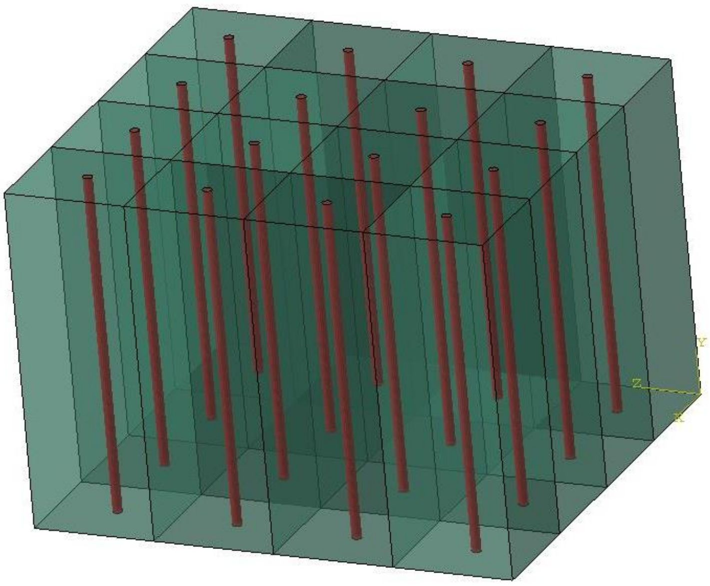

Fig. 3 Composite foam with vertical fibers.

Material parameters were determined using curves obtained by uniaxial compression of foam samples. Fig. 2 shows the force course of experimental compression of the neat polyurethane foam sample compared to the numerical model, the deviation is at most 5%. The first model of reinforced foam was designed as brick of edge length of 20 mm with 16 holes of 0.4 mm diameter. Vertical fibers of 0.4 mm diameter were inserted into these holes and connected to the foam by tie constraint fig. 3. Tie constraint connect the nearest nodes of the selected surfaces and prevents their mutual movement. An elastic material model has been selected for fibers. At the beginning of loading fibers behave like beams and greatly increase stiffness of composite. With increasing deformation, the buckling occurs the fibers will deflect and their effect on the composite stiffness will be greatly reduced. In real experiments, the buckling appears immediately after compression starts due to foam and fiber in homogeneities and uneven fiber configurations. In the simulation, the buckling may not occur at all because of the idealization of many aspects. In this simulation a buckling occurred, which is due to the contact setting when certain shocks that initiate deformation. Fig. 4 shows deformed composite foam with vertical fibers. This high stiffness at the beginning of compression is not suitable for flexible foams which are significantly deformed during use. Second was created geometry resemble the shape of the real fibers o 0.4 mm diameter fig. 5 a. shows fiber dimensions. Then a geometry of the foam segment (5x5x20 mm) was created with a cavity corresponding to the dimensions of the fiber. The fibers were connected to foam segments by tie constraint. The individual segments of foam with fiber were assembled into a block of 20x20x20 mm. Each segment was rotated at a different angle according to the longitudinal axis. The arrangement of the fibers in foam is shown in fig. 5 b.

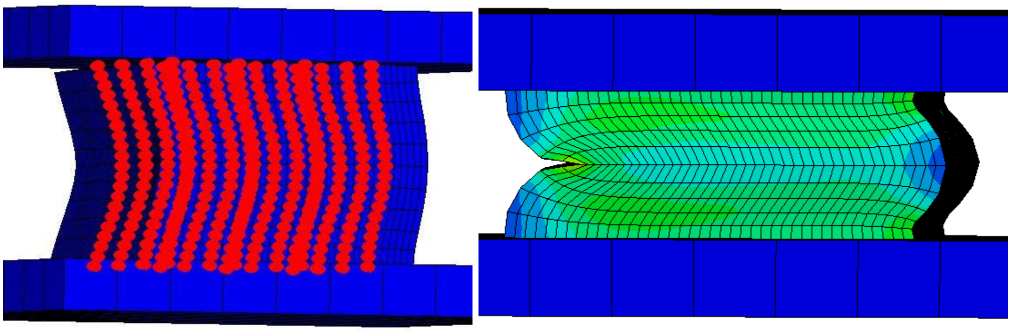

Fig. 4 Deformation of polyurethane foam with vertical fibers.

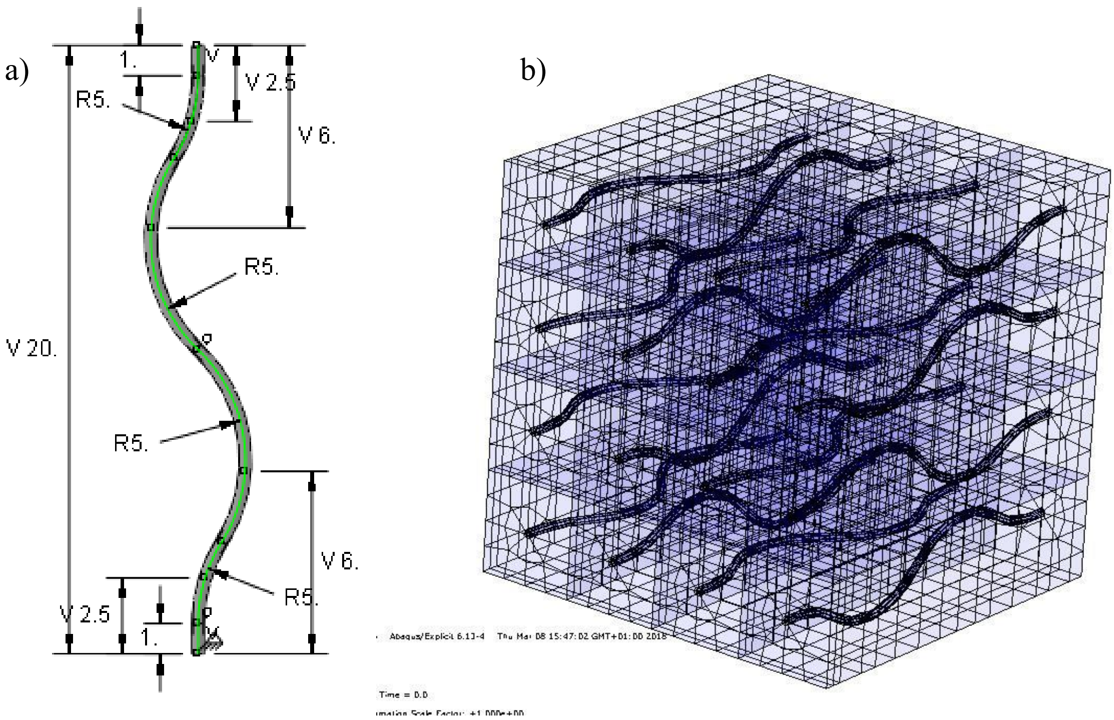

Fig. 5 a) dimensions of fiber, b) arrangement of fibers

Results

Numerical simulation of compression was performed on the assembled model of composite foam. The compression was performed both in the fiber direction and perpendicular to the fibers. Fig. 6 shows strain stress curves of individual simulations compared to the experiment. At the beginning of the compression in the fibers direction was found a significant increase of stiffness. During further compression, there was a significant uneven distortion of the fibers and whole composite sample. After compression of 18 % deformation, the simulation crashed due to too short time step. Next, was simulated compression in direction perpendicular to the fibers. At the beginning of compression, only polyurethane foam is deformed and the effect of the fibers is minimal. Between individual fibers there are spaces filled with polyurethane foam. At compression 20 %, the fibers get closer and their effect on the stiffness is beginning to show. With further compression this effect continues fibers are stressed by bending and torsion. Based on these simulations was created a real sample of composite foam with longitudinally oriented fibers. The compression test shows very good agreement with numerical model fig. 6.

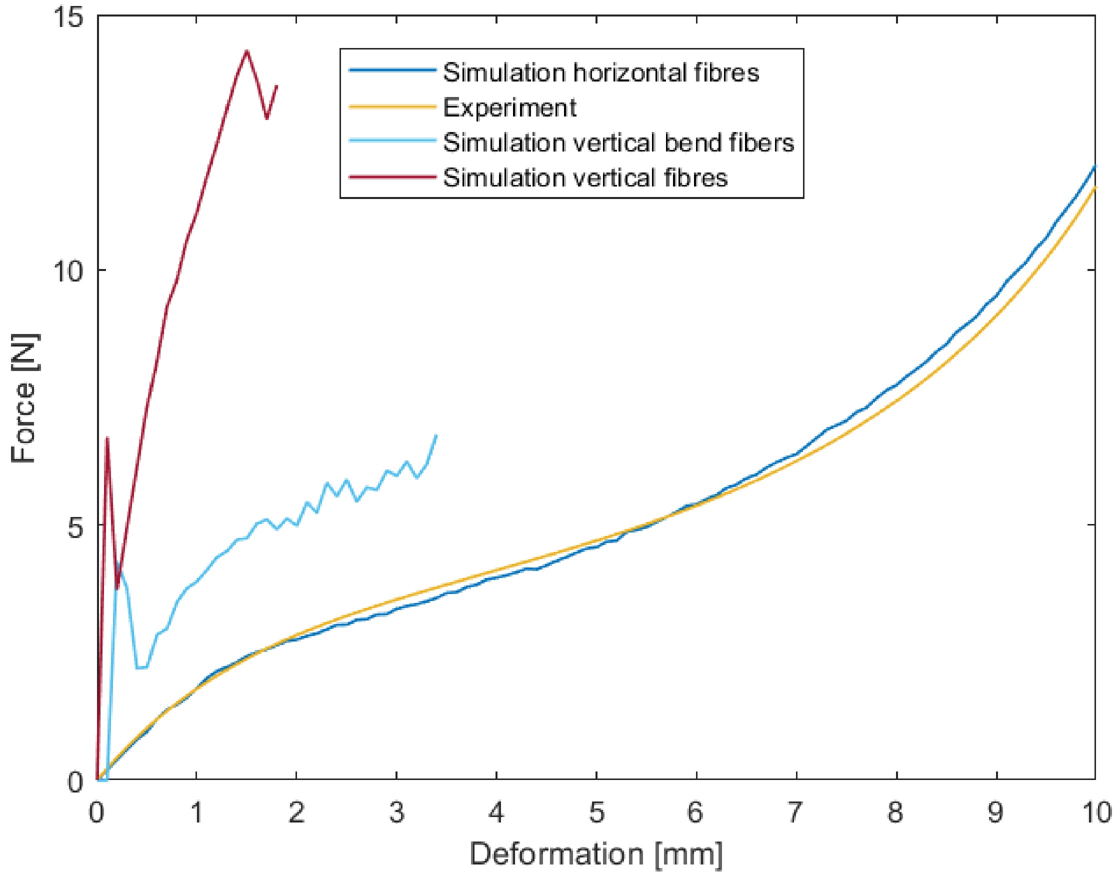

Fig. 6 Strain stress curves comparison of simulations and real experiment

Conclusions

A composite flexible foam with coir as reinforcement was designed. First, a numerical model of neat polyurethane foam was created and verified in real samples. Next, a composite foam numerical models with several fibers configurations and load modes were created. Composite foam with longitudinally orientation fibers was chosen for its good properties for use in car seat cushion. Real composite foam samples were then created to test the mechanical properties and numerical model verification. It was proved good agreement of experiments and numerical simulation. The results of numerical simulations can lead to design of whole composite car seat cushion with specific mechanical properties.

Acknowledgement

The results of this project No. LO1201 were obtained through the financial support of the Ministry of Education, Youth and Sports, Czech Republic in the framework of the targeted support of the "National Programme for Sustainability I"

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