TESTING AND SIMULATION OF VISCOELASTIC REINFORCEMENT APPLIED INTO CAR SEAT CONSTRUCTION

Michal Petrů
***Ondřej Novák**

Technical University of Liberec
Faculty of Mechanical Engineering
Studentská 2, 461 17, Liberec 1, Česká republika
michal.petru@tul.cz
*Technical University of Liberec
Faculty of Textile Engineering
Fakulta textilní, Katedra netkaných textilií
Studentská 2, 461 17, Liberec 1, Česká republika
ondra.novak@tul.cz

Abstract

Currently, the car manufacturers are dealing with optimization of seats, especially by reduction of weight and height, considering energy and ecological aspects of the used materials, at the same time maintaining or improving the existing parameters of the seat and back seat. Much emphasis is given to parameters of seating comfort and safety of car seats during a car crash. One possibility of seat weight reduction is by changing the construction of the seat cushion by incorporating viscoelastic composite reinforcement. Experimental quasi-static and dynamic tests were performed for samples of viscoelastic composite reinforcement materials for evaluation of mechanical properties. For deformation analysis of viscoelastic reinforcement, dummies (virtual human body) were loaded in a car seat and FEM simulation models were applied.

Introduction

At present, the research and development activities of car seats is focused on innovation that can bring weight reduction and energy efficient and environmentally friendly materials. The weight reduction of the car seat comes from car manufacturers´ concept of car weight reduction for decreasing fuel consumption and improving environmental friendliness. The principle is to reduce the weight of each component of the whole car, which in total leads to a significant reduction of the car weight. Therefore, a great effort is currently focused on supplementing or replacing the dominant material of car seats i.e. comfort layer - polyurethane foam - with low-density and energy efficient materials, which should be easily recyclable [5], [16]. That can bring not only energy savings and environmental improvements, but also certain improvement of desired properties. For significant weight reduction of car seats, it is required to make constructional changes of the whole seat, especially of the frame. Basically, the seat consists of a supporting frame, seat and backrest, which firmly holds a comfortable layer coated with upholstery fabric. It is known that the weight and body build of a passenger directly affects the interaction with the seat [7], [8], [12] [13]. Therefore, the passenger´s weight becomes a major parameter, which is crucial for modification of the seat, because the seat is designed especially for safety and comfort of the passengers. Weight reduction for the seat frame will ultimately reduce the weight of the whole seat, but it also reduces the deformation stiffness which is required for the crash safety [6]. Thus the optimization may be done by modification of the seat frame [8], where the security parameters are maintained and a metal plate, which supports the layer of comfort cushion, is removed. The solution may induce the replacement of reinforcement with another low density construction. In this case, viscoelastic composite materials, which will have the same function as the metal reinforcement, but with lower weight, were tested. The main aim of this work was to analyze and test the viscoelastic composite fabric that could be applied to the seat frame structure and thus significantly reduce the weight of the seat, as shown in (*Fig. 1*). The experimental measurements were complemented by FEM simulation. FEM simulations were carried out to compare the behavior of composite reinforcements loaded with a virtual dummy. Current developments and optimization of automotive seat components lead to the creation of prototypes in the FEM environment [11].

Fig. 1 Design with steel reinforcement, without steel braces, Substitute for viscoelastic composite material, Viscoelastic composite material applications in car seat design

1 Theory

Tested samples of viscoelastic composite reinforcement consist of two different layers of orthotropic fabric with isotropic or hyperelastic coating. The resulting structure has a different behavior compared with the individual layers. It leads to the change of viscoelastic property, to hyperelastic behaviour. These mechanical properties are similar to upholstery fabrics for certain deformation and they can be approximately described with 2.Piola-Kirchhoff stress tensor and Green-Lagrange strain tensor [16]. This behavior may be described as hyperelastic and can be assumed according to [2], [4], as a mathematical description of hyperelastic anisotropic material energy, which is divided into an equilibrium part which is responsible for the elastic behavior of the material and "free energy" configuration, describing a change in volume (Jacobian deformation is in the range $0 < J < 1$). Then the strain energy is given by (1) and is described in the tensor dependence. Then the strain energy A is given by (1) and is described in the tensor dependence.

$$A(\overline{\mathbf{C}}) = A_{izo}(\overline{\mathbf{C}}) + A_{vol}(\mathbf{J}), \tag{1}$$

where $A_{izo}(\overline{\mathbf{C}})$ decribes izochoric part of the deformation energy function, $A_{vol}(\overline{\mathbf{C}})$ is volumetric the deformation energy function, responsible for a volume change. $\overline{\mathbf{C}}$ (2) is modified Cauchy strain tensor $\mathbf{C}$ (3), $\mathbf{F} = \frac{\partial \mathbf{X}}{\partial \mathbf{x}}$ is material deformation gradient, $\mathbf{I}$ is identity matrix and the expression $\mathbf{J}^{1/3}\mathbf{I}$ is connected with parts changing volume during the deformation.

$$\overline{\mathbf{C}} = \overline{\mathbf{F}}^{T}\overline{\mathbf{F}} \tag{2}$$

$$\mathbf{C} = \mathbf{F}^{T}\mathbf{F} \tag{3}$$

$$\mathbf{F} = \mathbf{J}^{1/3}\mathbf{I}\overline{\mathbf{F}} \rightarrow \overline{\mathbf{F}} = \mathbf{J}^{-1/3}\mathbf{I}\mathbf{F} \tag{4}$$

Therefore, the resulting stress is describable with 2.Piola-Kirchhoff stress tensor $\mathbf{S}$ (5), which is also divided into two parts (izochoric and volumetric).

$$\mathbf{S} = 2\frac{\partial A(\mathbf{C})}{\partial \mathbf{C}} = \mathbf{S}_{izo} + \mathbf{S}_{vol} \tag{5}$$

$$\mathbf{S}_{izo} = 2\frac{\partial A_{izo}(\overline{\mathbf{C}})}{\partial \mathbf{C}} \tag{6}$$

$$\mathbf{S}_{vol} = 2\frac{\partial A_{vol}(\mathbf{J})}{\partial \mathbf{C}} \tag{7}$$

where $\mathbf{S}_{izo}$ is 2. Piola-Kirchhoff stress tensor for izochoric part of deformation energy function, $\mathbf{S}_{vol}$ is 2. Piola-Kirchhoff stress tensor for izochoric part of volumetric deformation energy function.

2 Experimental measurements and simulation

2.1 Experimental example

Tested samples of composite reinforcement material have differently arranged structures. *Fig. 1* shows isotropic elastic coating and *Fig. 2* shows isotropic hyperelastic coating. It leads to different mechanical properties. Important material and geometrical parameters of tested samples are given in *Tab. 1*.

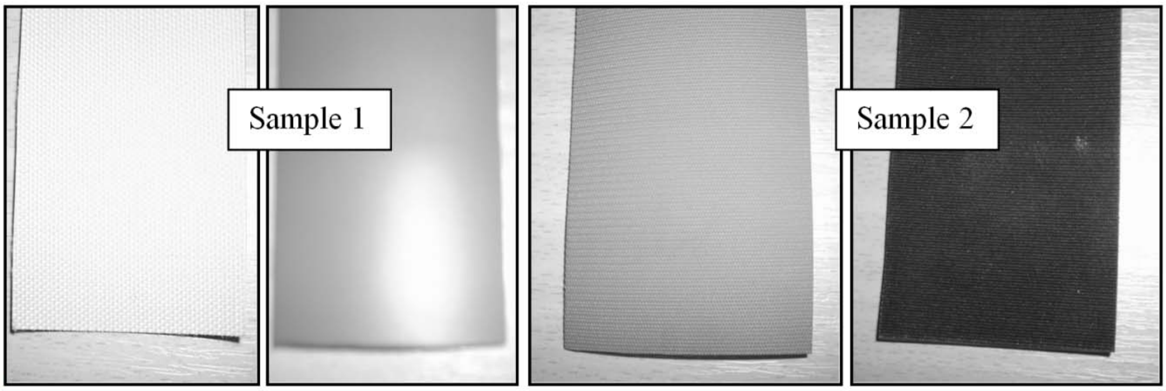

Fig. 2 *Tested samples of composite reinforcement material applied into car seat construction*

Tab. 1 *Material and geometrical parameters of tested samples*

Sample	Thickness [mm]	Size [mm]	Surface weight [kg/m^2]	Density [kg/m^3]
Sample 1	0,67	100x50	858,92	1768
Sample 1	1,61	100x50	1695	1052,8

2.2 Experimental measurements

For determination of sample mechanical properties, quasi-static and dynamic experimental measurements were carried out. Firstly, the tensile test of samples was carried out according to ISO ČSN EN ISO 13934-1 (100 mm.min^{-1}) standard on dynamometer Labortech 2.050 (*Fig. 3*). Samples in the machine and cross direction were loaded at force of 60 N. This corresponds with the weight of 120 kg. Whereas, a man weighing 100 kg loads the comfortable layer of car seats with the load of 60kg [5], [13]. Measurements were carried out in 5 cycles.

Fig. 3 *Experimental device, Tensile test sample of viscoelastic composite fabric*

Experimental samples were also tested for the dynamic mechanical behavior by the help of "crash" test. The experiment was performed on the test equipment placed in laboratories of Department of Technology. The principle of the experimental test is shown schematically in *Fig. 4* (lefthand side). This is a free fall of loading board from height $h = 800mm$ on jaws, with which the experimental sample is clamped. The impact speed is $v = 14{,}2 km \cdot h^{-1}$. The speed and path of free falling test was captured with high speed camera system Aramis.

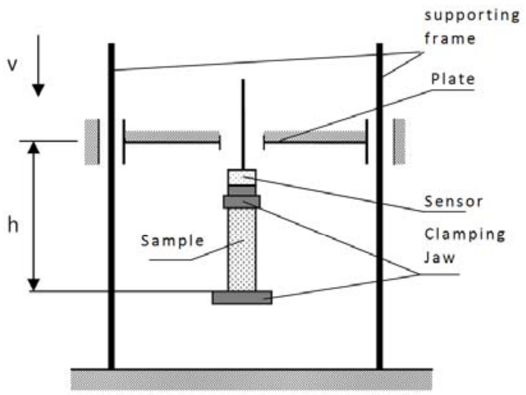

Fig. 4 Principle of the experimental test

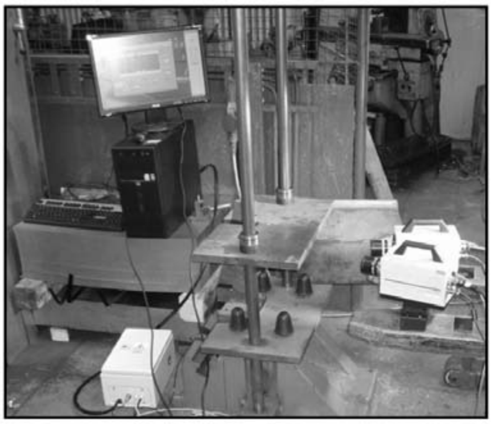

Fig. 5 Experimental test

2.3 Methodology of FEM simulation tests

Virtual simulation model was created in the program PAM CRASH for composite reinforcement applied in the construction of the seat cushion holder. This program is suitable for simulation of the material non-linearities, contact non-linearity and large geometric strains [5] [6]. It also allows to simulate the viscoelastic composite materials. The finite element mesh of designed seat cushion was created in special program Altair HyperMesh 9.0 [14]. For the simulation of tested viscoelastic composite reinforcement samples, "Materials 150 - Layered Membrane Element" was chosen. This material model allows defining the parameters for orthotropic layer and isotropic coating [15], which are derived from experimental measurements. This material model uses the total Lagrange formulation of strain and works on the principle of strain energy according to equation (1). Material parameters of the virtual dummy are based on [10]. The features of material model for the designed car seat cushion and a virtual dummy are given in *Tab. 2*. Boundary conditions were set as follows: bottom part of the seat was fixed in all directions (rotation $R_i = 0$ and shifts $U_i = 0$, where $i = X, Y, Z$). The virtual dummy with a weight of 100 kg was kept under gravity into the seats on the viscoelastic composite reinforcement with pretension of 60 N. The way of dummy position setting is schematically shown in *Fig. 6.*

Tab. 2 Material characteristics of the virtual dummy and seat model

Part	Material model	Density [mm]	Young`s modulus [GPa]	Poisson number [-]
Virtual Dummy	Elastic Plastic	1000	0.250	0.3
Seat	Elastic	7850	210	0.3

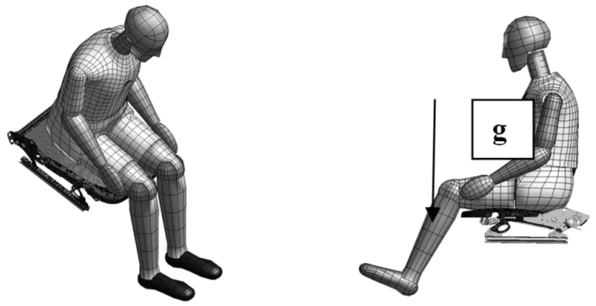

Fig. 6 FEM model of car seat cushion with applied viscoelastic composite reinforcement

3 Results

Results of experimental measurements for the tested samples exhibit an anisotropic behavior. From quasi-static tests the fifth cycle was evaluated. Both samples exhibit hysteresis but sample 2 shows about 20% higher hysteresis. That causes higher damping effect. The measured data from the dynamic experiments were filtered and obtained results exhibit a significant elongation of samples. The sample 2 with hyperelastic coating exhibits higher elongation (about 32% approx.), which may lead to higher dynamic load beading capacity. Also force at break was 28% higher. Complete results are shown in *Fig. 7*, including a comparison of simulation and experiment.

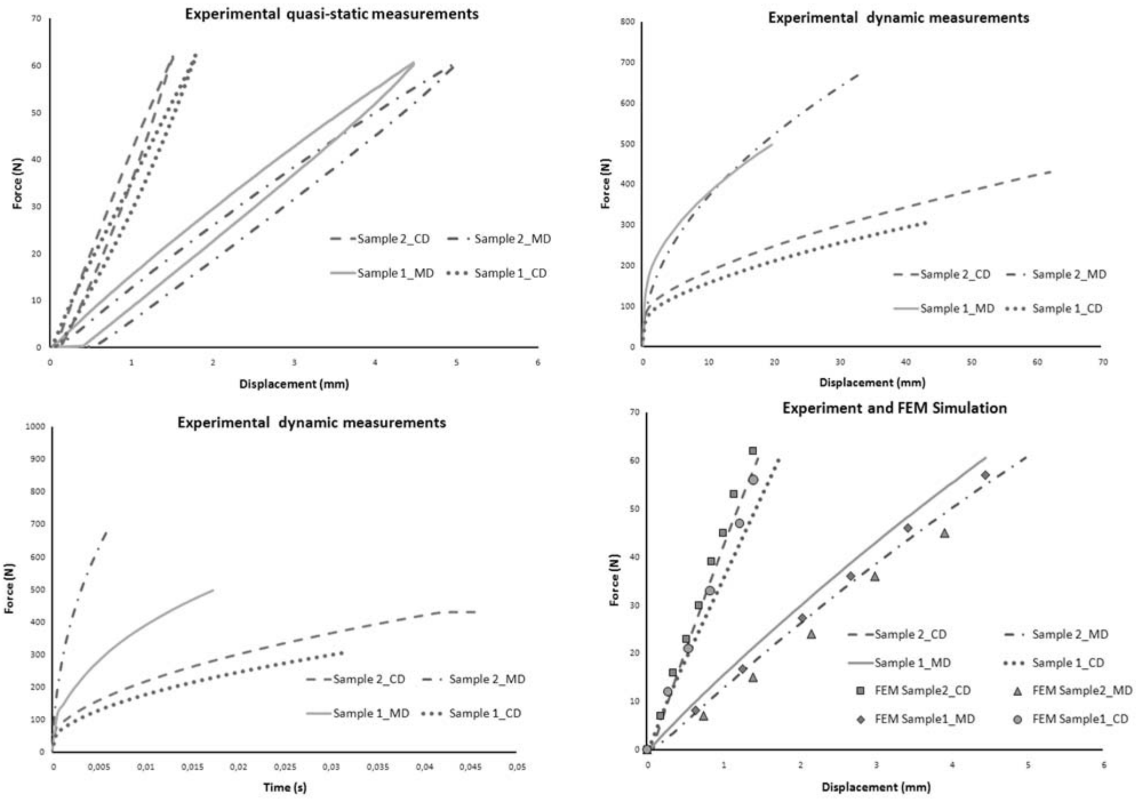

Fig. 7 Complete results

Results of dummy position settings on pretensioned composite reinforcement are shown in *Fig. 8*. The distribution of deformation on tested composite reinforcements are shown in *Fig. 9*. In the case of sample 1 the deformation is distributed on the whole area of reinforcement with elongation of 7.3mm. Sample 2 exhibits signifiant deformation especially in the area of pelvis bone contact with the einforcement. The elongation of sample 2 is 12.1mm, which is similar to the hyperelastic materials behaviour [3].

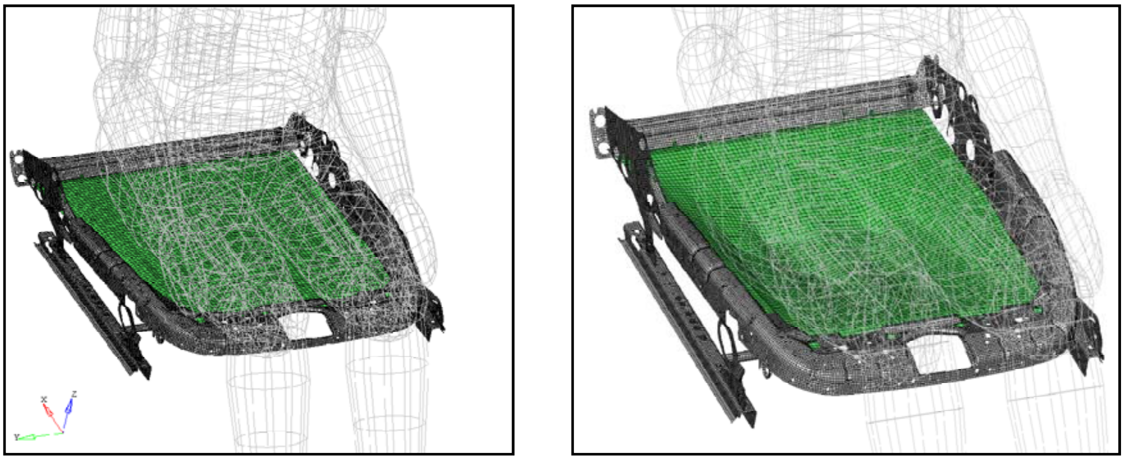

Fig. 8 Initial position (Dummy without contact), Result position(Dummy sits)

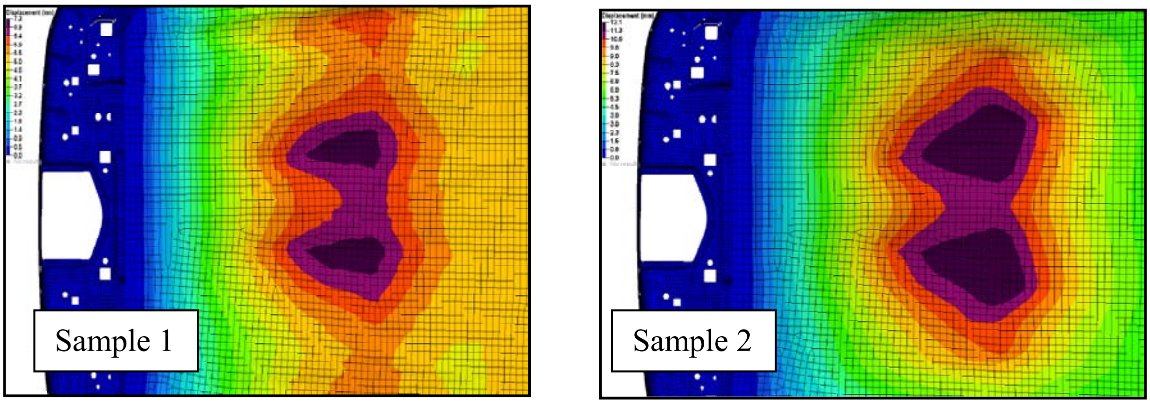

Fig. 9 Distribution of strain in samples (seated virtual dummy)

Conclusion

This article deals with testing and analysis of viscoelastic reinforcement, which can be applied in the construction of car seat as a cushion support. Its usage can lead to the weight reduction (*Fig. 1*). The experimental measurements were carried out and it was found that sample 2 exhibits more suitable properties, especially better damping (*Fig. 7*) and higher force at break. The distribution of strain on the composite reinforcement applied as a seat cushion holder (*Fig. 9*) is affected by their material properties. Sample 1 with isotropic elastic coating showed the distribution of deformation across the surface of reinforcement. Sample 2 with hyperelastic coating exhibited a significant deformation in the contact with pelvic bones of the virtual dummy. In general, it can be noted that sample 2 would be applicable to the car seat as reinforcement. Also it is necessary to determine its appropriate pretension, in order to enable its continuous setting. This would achieve the appropriate setting of the reinforcement stiffness for different passenger weights. This work was supported from project of Student Grant Competition.

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Ing. Michal Petrů, Ing.Ondřej Novák, Ph.D.

TESTOVÁNÍ A SIMULACE VISKOELASTICKÉ KOMPOZITNÍ VÝZTUHY PRO KONSTRUKČNÍ APLIKACI DO AUTOSEDAČKY

V současné době se vývoj a výrobci automobilových sedaček zabývají optimalizací autosedačky a to především v oblasti snižování hmotnosti, výšky autosedačky a také energetické a ekologické úspornosti použitých materiálů při zachování či zlepšení stávajících parametrů současného sedáku a opěráku autosedačky, zejména parametrů kvality komfortu sezení a také bezpečnosti sedačky při nárazu automobilu. Jednou z možností snížení hmotnosti je konstrukční úprava sedáku autosedačky se začleněním kompozitní viskoelastické výztuhy. Byly provedeny experimentální kvazistatické a dynamické zkoušky testovacích vzorků viskoelastické kompozitní výztuhy pro definování mechanických vlastností. Pro analyzování deformace viskoelastické výztuhy aplikované do automobilové sedačky byly sestaveny simulační modely v prostředí MKP s hmotnostním zatížením virtuální figurínou.

TESTEN UND SIMULATION VISKOELASTISCHER KOMPOSITIONSVERSTEIFUNG FÜR DIE KONSTRUKTIONSANWENDUNG BEI AUTOSITZEN

Zurzeit beschäftigen sich Entwicklung und Hersteller von Autositzen mit der Optimalisierung von Autositzen, und zwar vor allem auf dem Gebiet der Materialverringerung, der Höhe der Autositze und auch der energetischen und ökonomischen Sparsamkeit der verwendeten Materialien beim Erhalt oder der Verbesserung der bestehenden Parameter des gegenwärtigen Sitzes und der Lehne bei einem Stoß des Automobils. Eine der Möglichkeiten der Materialverringerung besteht in einer Konstruktionsverbesserung des Autositzes unter Eingliederung einer kompositorischen viskoelastischen Versteifung. Es wurden experimentelle quasistatische und dynamische Prüfungen von Testmustern viskoelastischer kompositorischer Versteifungen für die Definition der mechanischen Eigenschaften durchgeführt. Zur Analyse der Deformation der viskoelastischen Versteifung, wie sie in Autositzen verwendet werden, wurden Simulationsmodelle im Umfeld MKP mit einer Materialbelastung einer virtuellen Puppe zusammengestellt.

TESTOWANIE I SYMULACJA WISKOELASTYCZNEGO KOMPOZYTOWEGO WYPEŁNIENIA DO ZASTOSOWAŃ KONSTRUKCYJNYCH W FOTELACH SAMOCHODOWYCH

W obecnych czasach prace podejmowane w ramach rozwoju i produkcji foteli samochodowych skierowane są na optymalizację fotelu samochodowego, zwłaszcza pod kątem zmniejszania jego masy, wysokości fotelu samochodowego oraz energetycznej i ekologicznej oszczędności stosowanych materiałów przy zachowaniu lub poprawie istniejących parametrów siedziska i oparcia fotelu samochodowego, w szczególności parametrów jakości komfortu siedzenia oraz bezpieczeństwa fotelu w przypadku uderzenia samochodu. Jedną z możliwości obniżenia masy jest konstrukcyjna zmiana siedziska przy zastosowaniu kompozytowego wiskoelastycznego wypełnienia. Przeprowadzano eksperymentalne badania quasistatyczne i dynamiczne próbek testowych wiskoelastycznego kompozytowego wypełnienia w celu określenia właściwości mechanicznych. W celu przeprowadzena analizy deformacji wypełnienia wiskoelastycznego stosowanego w siedziskach samochodowych opracowano modele symulacyjne w środowisku MKP przy obciążeniu manekinem wirtualnym.