MECHANICAL PROPERTIES MEASUREMENT AND COMPARISON OF POLYURETHANE FOAM SUBSTITUTE

Michal Petrů
***Ondřej Novák**

Technical University of Liberec
Faculty of Mechanical Engineering
Department of Design of Machine Elements and Mechanisms
Studentská 2, 461 17, Liberec 1, Czech Republic
michal.petru@seznam.cz
Technical University of Liberec
Faculty of Mechanical Engineering
Department of Design of Machine Elements and Mechanisms
Studentská 2, 461 17, Liberec 1, Czech Republic
ondra.novak@tul.cz

Abstract

Currently, great emphasis is placed on improving and optimizing of sitting comfort (car seats, chairs, sofas, hospital mattresses...). The comfort is also related to safety, quality, air permeability and ergonomics, which all depend on the mechanical properties of the used material. Polyurethane foams (PU) are most widely used for comfort layers. PU together with upholstery fabrics creates complete comfort layers. With the rapid oil disappearance and its price growth there are efforts to find new solutions which allow replacing PU foam with suitable materials. Preferably recyclable materials are wanted for that purpose. An experimental quasi-static indenting of a load body to a PU sample is the starting point for simulations. Obtained experimental data are used as a comparison for the model simulated in FEM. An evaluation criterion is essentially the contact pressure of the tested sample.

1 Introduction

An identification and characterization of material properties of layers forming a comfortable fill of the seats, mattresses, etc. is very important to optimize the sitting and lying comfort [1], [4]. These parameters are very important especially for people who are in constant contact with a layer of comfort such as professional drivers or patients in hospitals. In these cases a risk of pressure sores is high. During the design of seats and mattresses the experimental measurements and evaluation of contact pressures is required. The main objective of the article was to create the FEM models of polyurethane foam and recyclable nonwoven with an upholstery fabric that will show similar mechanical properties like real samples. Especially, the contact pressures of various materials, without using an expensive experimental device (e.g. Xsensor) can be measured, tested and compared. The contact pressures measured experimentally between indenter and the sample will be compared with simulation results. Currently, the suitable replacement of the Polyurethane (PU) foam with recyclable textile is found, the result will be compared. The experimental data from the tested samples will be used for virtual simulation of FEM, because FEM simulation are very helpful tool for biomechanical applications and their results can serve for the optimization and obtaining of desired properties. For example, data which is non-measureable can be obtained (stress and strain in different directions...). For comparison of the contact pressures obtained from FEM simulations with real contact pressures the pressure mapping device XSensor was used.

2 Theory

Characteristic mechanical properties of samples, especially PU foam, nonwoven Struto and upholstery fabric, are strongly nonlinear. The PU foam shows viscoelastic behaviour [1]. The textile Struto, due to its specific orientation of fibers (perpendicular laiding), is anisotropic and has viscoelastic behaviour, and the upholstery fabric has orthotropic properties in individual direction of stress [2]. Therefore, for a complex simulation of the mechanical properties, the significant FEM software PAM CRASH from the ESI Groups was selected. PAM CRASH is a high performance software that allows simulations of the anisotropic and viscoelastic behaviour, which is defined directly from experimental measurements. The software method uses H-convergence [8]; the solving processor is built on an explicit algorithm [1], [3] [6]. The foam material model and Struto (Fig.2) is defined for Solid elements (material type 45 - General Nonlinear Strain Rate Dependent Foam Energy Absorption with Optional), based on a hypothetical modified Kelvin model (Fig.1), which is defined by relation (1).

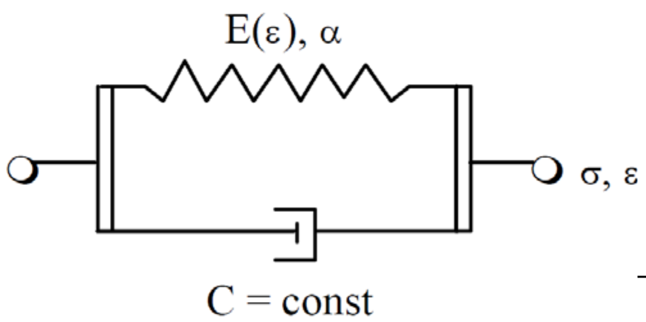


Fig. 1 Kelvin model used in PAM CRASH

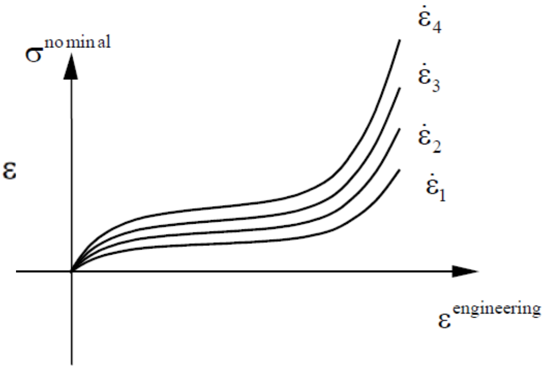


Fig. 2 Material 45 allows to define a dependence of stress and strain

$$C \cdot \frac{d\varepsilon}{dt} + E \cdot \varepsilon = \sigma \qquad (1)$$

Where: C is Newton member (damping) and E is Hook member (stiffness), σ is Stress and ε is strain.

The material model of the upholstery fabric (material type 151 - Fabric Membrane Element with Nonlinear Fibers) allows to define the different behaviour of membrane components in different directions of loading; it is based on constitutive relations of a continuum mechanics - the material model is based on an energy conjugated pair of a Green-Lagrange deformation tensor (2) and 2.Piola-Kirchhoff stress tensor (3).

$$E^G = \frac{1}{2}\left(F^T \cdot F - I\right) \qquad (2)$$

$$S = JF^{-1}\Sigma(F^{-1})^T \qquad (3)$$

Where:

E^G is Green-Lagrange deformation tensor,

S is 2. Piola-Kirchhoff stress tensor,

F is material deformation gradient,

$$F = \frac{\partial x_i}{\partial x_j^0} \quad i,j = 1,2 \ , \qquad (4)$$

F^{-1} is spatial deformation gradient,

$$F^{-1} = \frac{\partial x_i^0}{\partial x_j} \quad i, j = 1,2 \ , \tag{5}$$

I is identity matrix,

$$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \tag{6}$$

J is Jacobian of deformation,

$$J = \det|F| \ , \tag{7}$$

Σ is Cauchy stress tensor in matrix notation (8)

$$\Sigma = \sigma_{ij} \ .$$

The loading body (Indentor) was made of the polyamide, according to our own design from the CAD data. The indentor was defined in software as a Rigid Body created from SHELL elements (material type 101 - Elastic - Plastic For Shell Elements). The elastic behaviour of this material model is defined by the shear modulus G (9) and the bulk modulus K (10),

$$G = \frac{E}{2(1+2\mu)} \ , \tag{9}$$

$$K = \frac{E}{3(1-2\mu)} \ . \tag{10}$$

Characteristic properties of the indentor material model are in the table 1.

Tab. 1 Mechanical properties of the indentor

Part	Material model	Density ρ [kg/m^3]	Young's modulus E [GPa]	Poisson number μ [-]	Shear modulus G [GPa]	Bulk modulus K [-]
Indentor	Elastic - plastic	1140	3.6	0.41	0.989	6,666

3 Experiment and simulation measurement

3.1 Experimental measurement

The experimental samples of the foam and Struto were put to the experimental device. Each sample consisted of four layers. The total dimension of the PU sample was 500x500x100 mm; in the case of the Struto sample it was 500x500x93 mm (Fig.3, 4).

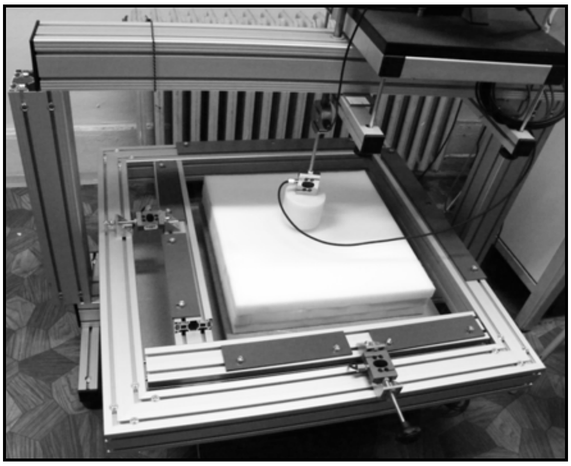


Fig. 3 Sample of PU foam

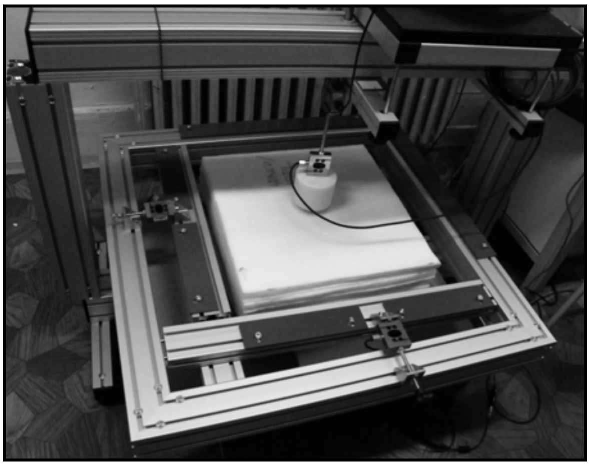


Fig. 4 Sample of Struto

The experimental device enables a pre-loading of the upholstery fabric in both directions (X, Y) at an initial preload of 60 N, which is controlled by load cells (Fig.3). The dimensions of the upholstery fabric were 500x500x0, 799. Subsequently, the sample was quasi-statically pushed with the indentor in Z-direction 30 mm deep into the sample. The applied speed of movement was 50mm/min. For the measurement and evaluation of contact pressures XSensor device was applied. This device can measure the contact pressures between the indentor and sample. Because this device is an additional layer, its mechanical properties must secure only minimal increasing of contact pressures. The complete arrangement of the experiment is seen in Fig.5 and 6.

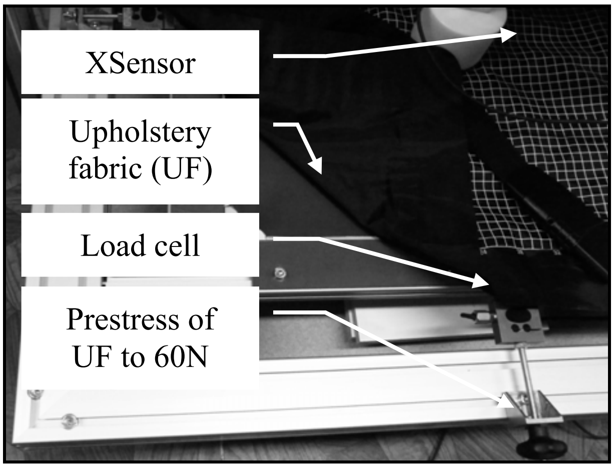


Fig. 5 Prestress of UF on 60 N

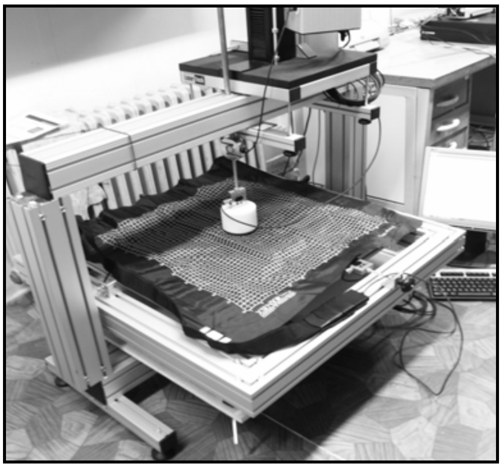
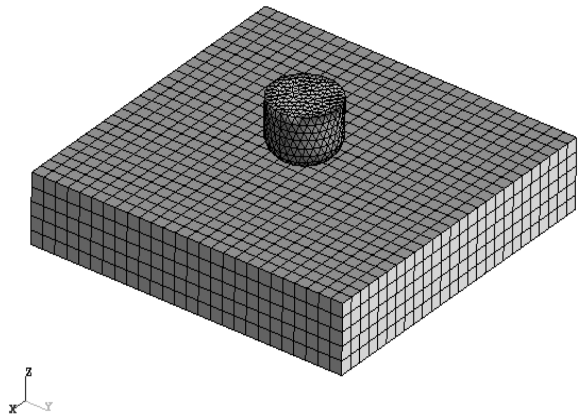


Fig. 6 Complete testing device

3.2 Simulation measure

A virtual model of a mattress sample (Fig.7, 8) of the same geometrical dimensions was created in the PAM CRASH software. This software is very suitable for the simulation of materials with strong nonlinear behaviour [6]. A finite element mesh of the simulation model of individual parts (fabric, PU foam, and indentor) was created in a special pre-processor Hypermesh Altair [7]. Material properties of upholstery fabric model were defined by [2] and the fabric was loaded in X and Y directions on the value of pretension 60N as well as in experimental measure. Subsequently, the indentor was pushed to the sample to the depth of 30mm. For this purpose, the sensor function was used. Boundary conditions were defined for the movement of the upholstery fabric. Unloaded sides of fabrics were fixed against shift in all directions.



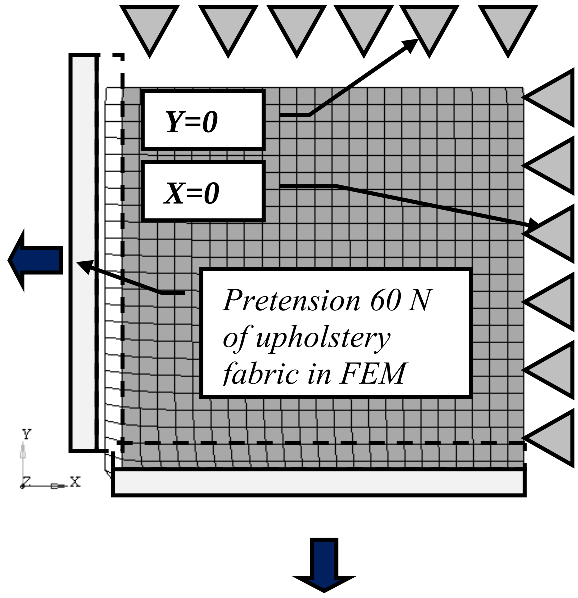
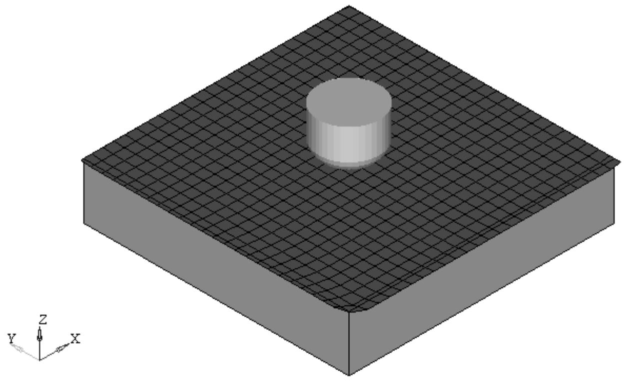


Fig. 7 Simulation model in FEM *Fig. 8 Prestress of UF in FEM*

The prestressing of upholstery fabric on prestress 60N is shown in fig. 9. There can be seen elongation of sample sides and a deformation of the mesh. In the fig. 10 is seen the indentor pushed 30mm deep to the sample.



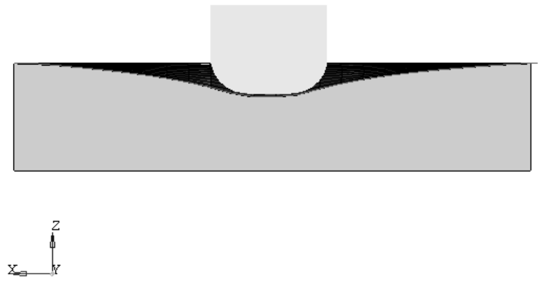


Fig. 9 Prestressed UF in FEM *Fig.10 Pushing of indentor*

4 Results

The simulation gives lots of results, but for an evaluation of comfort quality the contact pressure is most important. The comparison of the measured experimental data from XSensor and obtained from the simulation are shown in tab. 2. In fig. 13-16 are displayed pressure maps of both samples. Also graphs (fig.17,18) with dependence of the force on displacement are added. In these graphs it is possible to compare the course of the experimental and simulated curve.

Tab. 2 Comparison of experimental and simulated contact pressure peaks

	Experimental measure	**Simulation measure**
Sample	*Contact Pressure in displacement 30 mm [GPa]*	*Contact Pressure in displacement 30 mm [GPa]*
PU foam with Fabric	**1.442E-5**	**1.492E-5**
STRUTO with Fabric	**1.287E-5**	**1.236E-5**

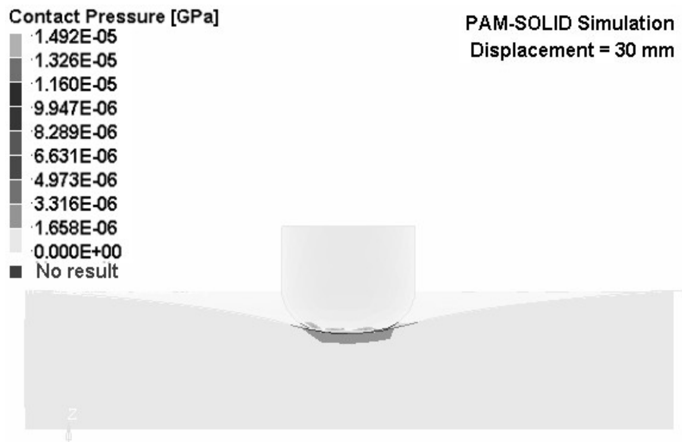


Fig. 11 FEM – Pushing of indenter to PU foam

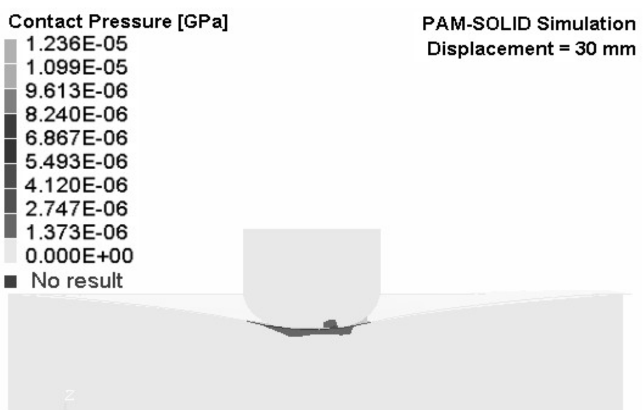


Fig. 12 FEM – Pushing of indenter to Struto

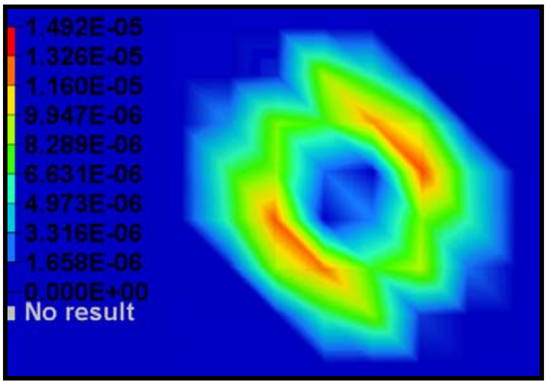


Fig. 13 FEM –detail Contact pressures of PU foam

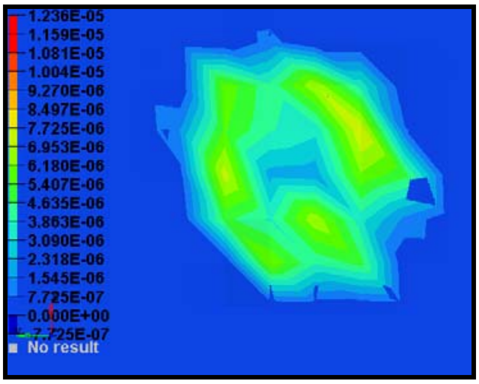


Fig. 14 FEM –detail Contact pressures of Struto

	22	23	24	25	26	27	28	29	30	31
18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19	0,0	0,0	0,0	2,65	4,61	4,66	2,87	0,0	0,0	0,0
20	0,0	0,0	5,48	11,16	12,64	12,78	10,33	6,07	0,0	0,0
21	0,0	5,33	12,1	13,44	13,43	12,97	12,89	11,68	5,77	0,0
22	0,0	9,54	13,84	10,96	5,62	5,58	10,8	12,74	10,45	1,38
23	2,18	12,94	14,42	7,99	5,44	5,53	7,86	13,53	11,67	2,04
24	1,44	11,12	13,9	12,47	6,16	6,1	11,98	14,21	9,9	1,88
25	0,0	6,07	12,66	12,79	13,07	13,96	14,01	12,72	6,23	0,0
26	0,0	1,69	7,01	12,13	14,01	14,08	12,89	7,05	1,96	0,0
27	0,0	0,0	1,58	3,28	5,55	5,19	3,55	0,0	0,0	0,0

Avg Pres.: 8,76

Fig. 15 Contact pressures of PU foam experimental measurement with XSensor

	21	22	23	24	25	26	27	28
17	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	0,0	0,0	3,97	5,84	7,12	5,1	1,96	0,0
19	0,0	4,21	10,06	10,0	11,29	10,74	9,47	1,97
20	2,75	11,26	11,1	6,93	7,1	10,12	12,87	5,46
21	4,64	11,01	6,78	4,35	4,55	5,94	10,55	6,96
22	4,3	10,27	6,76	5,12	4,99	5,78	10,33	6,71
23	2,05	11,01	7,49	6,12	5,68	7,22	9,77	4,41
24	0,0	5,13	7,6	9,93	8,67	7,87	6,77	0,0
25	0,0	0,0	2,94	4,71	5,2	3,48	0,0	0,0

Avg Pres.: 6,93

Fig. 16 Contact pressures of Struto experimental measurement with XSensor

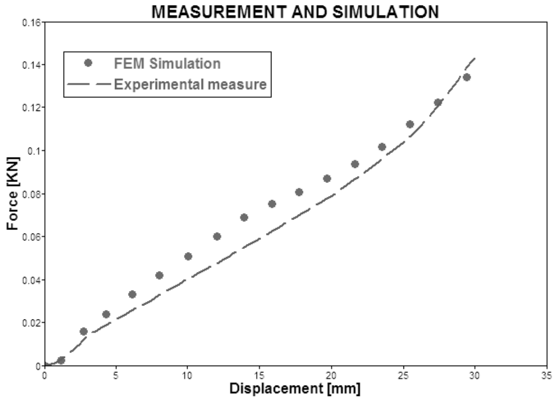


Fig. 17 Dependence force – displacement of PU foam sample

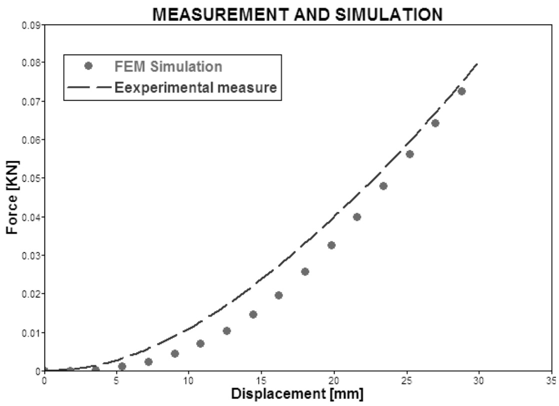


Fig. 18 Dependence force – displacement of Struto sample

5 Conclusion

The article has shown the simulation of mechanical properties in FEM environment. The main aim was to create FEM models of polyurethane foam and bulky nonwoven with nonlinear behaviour and properties of real samples. The very important was the evaluation of contact pressures between the modeled material and indenter. These contact pressures were compared with contact pressures of real samples. The results are in close agreement with each other (see fig. 13-16). Also strain-stress curves of experimental and modeled materials are very close (fig. 17-18). Thus it can be concluded that the FEM simulations are useful tool for the optimizing and testing of new materials, because they reduce time and the cost of very expensive experimental measurements.

Literature

[1] NOVAK,O.; PETRŮ, M.: *SIMULATION OF MATTRESSES FOR IMMOBILE PATIENTS,* Autex 2009 World Textile Conference, ISBN 978-975-483-787-2, Izmir Turkey.
[2] NOVAK,O.; PETRŮ, M.: *SIMULATION OF NONLINEAR MATERIAL PROPERTIES OF UPHOLSTERY FABRICS,* 16th ^{i}nternational conference Strutex, ISBN 978-80-7372-542-6, Liberec, Czech republic.
[3] PETŘÍK, J.; PETRŮ,M.: *SIMULATION OF THE TRANSMISSIBILITY OF THE NON-LINEAR MATERIALS*, In: VIBROENGINEERING 2009, Proceedings of the 8th International Conference, Klaipeda, Lithuania, ISSN 1822-1622.
[4] PETRŮ,M.; PETŘÍK,J.: *SYSTEMS TO OPTIMIZE COMFORT AND DEVELOPMENTS OF CAR SEATS,* ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering, ANNALS of Faculty Engineering Hunedoara, Romania, International Journal of Engineering – fascicule 4, ISSN 1584-2665.
[5] PETŘÍK,J.; PETRŮ,M.: *OPTIMALIZATION OF THE SEAT CUSHION COMFORT LAYER,* 50. Conference of Departments of Parts and Mechanism of Machines, Zilinska univerzita, Slovensko*,* ISBN 978-80-554-0080-8.
[6] PAM-CRASH/SAFE, *Reference And Solver Notes Manuals*, Version 2005.
[7] ALTAIR HYPERMESH 9.0, *www.altair.com/software/hw_hm.htm*.
[8] BELYTSCHKO,T. ; LIU,W.K. ; MORAN, B.: Nonlinear Finite Elements for Continua and Structures. John Wiley, Chichester, 2000.

Ing. Michal Petrů
Ing. Ondřej Novák

MĚŘENÍ A POROVNÁNÍ MECHANICKÝCH VLASTNOSTÍ NÁHRADY POLYURETANOVÉ PĚNY.

V současné době je kladen velký důraz na zvyšování a optimalizaci komfortu sezení (automobilové sedačky, bytové sedačky, nemocniční matrace, …). S komfortem ale souvisí také bezpečnost, kvalita, prodyšnost a v neposlední řadě odpovídající ergonomické parametry mechanických vlastností komfortního materiálu. Polyuretanové pěny (PU) jsou nejvíce používaným materiálem pro komfortní vrstvu. Spolu s potahovou látkou tvoří kompletní komfortní vrstvu. S rychlým úbytkem ropy a zvyšující se cenou PU pěny souvisí velká snaha odborníků nalézt nové řešení v náhradě PU pěny pomocí jiných, nejlépe recyklovatelných materiálů. Experimentálním kvazi statickým měřením při stlačování indentoru do vzorku PU pěny a stejného vzorku textilního materiálu získáváme porovnávací výsledky. Experimentální data jsou podkladem pro virtuální simulace v MKP. Kritériem je především vyhodnocování kontaktních tlaků mezi zkušebním indentorem a zkušebním vzorkem.

MESSEN UND BEWERTEN DER EIGENSCHAFTEN VON ERSATZSTOFFEN FÜR POLYURETANSCHAUM

Gegenwärtig liegt viel Gewicht auf der Erhöhung und Optimierung des Sitzkomforts (Autositze, Sitzgelegenheiten in Wohnungen, Krankenhausmatratzen ….). Eng mit Komfort verknüpft sind auch Sicherheit, Qualität, Luftdurchlässigkeit und nicht zuletzt die entsprechenden ergonomischen Parameter der mechanischen Eigenschaften des Komfortmaterials. Polyuretanschäume (PU) sind das meist benutzte Material für die Komfortschicht. Zusammen mit dem Bezugsstoff bildet es eine komplette Komfortschicht. Mit dem schnellen Rückgang von Rohöl und dem steigenden Preis für PU-Schaum wird große Anstrengung darauf verwendet, eine neue Lösung für den Ersatz von PU-Schaum mit Hilfe anderer gut recyclebarer Materialien zu finden. Durch experimentelle, statische Messung bei der Kompression des Indentors in die Formel des PU-Schaums und in die gleiche Formel von Textilmaterial erhalten wir Vergleichsergebnisse. Die experimentellen Daten sind die Grundlage für die virtuelle Simulation im MKP. Kriterium ist vor allem die Auswertung der Kontaktdrücke zwischen dem Versuchsindentor und der Versuchsformel.

MIERZENIE I PORÓWNANIE MECHANICZNYCH WŁAŚCIWOŚCI SUBSTYTUTU PIANKI POLIURETANOWEJ

Obecnie kładziony jest duży nacisk na podnoszenie i optymalizowanie komfortu siedzenia (siedziska samochodowe, wersalki, materace szpitalne,...). Z komfortem związane jest jednak również bezpieczeństwo, jakość, przewiewność oraz odpowiednie parametry ergonomiczne mechanicznych właściwości komfortowego materiału. Pianki poliuretanowe (PU) są najczęściej stosowanym materiałem w warstwach komfortowych. Wraz z tkaniną obiciową stanowią kompletną warstwę komfortową. W związku z malejącą ilością ropy oraz rosnącą ceną pianki PU podejmowane są duże starania, mające na celu znalezienie nowych rozwiązań w zakresie substytutów pianki PU, wykorzystujących inne materiały dobrze podlegające recyklingowi. Stosując eksperymentalne quasi statyczne pomiary przy wtłaczaniu indentora do próbki pianki PU i takiej samej próbki materiału tekstylnego uzyskujemy porównywalne wyniki. Dane eksperymentalne stanowią podstawę do wirtualnej symulacji w MKP. Kryterium stanowi przede wszystkim ocena ciśnień kontaktowych pomiędzy indentorem próbnym i próbką eksperymentalną.