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Study And Analysis Of Transmissibility Of Car Seat With Non Polyurethane Material

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Abstract: Trend and effort of the current car seat development is a weight reduction of the individual parts. The development is also focused on the low energy usage, especially recycled materials. The emphasis is placed mainly on the compensation of the comfort layers, which are usually made of polyurethane foam (PUF). The PUF is mostly produced from the oil. Therefore its replacement with suitable material can secure not only weight and energy reduction, but it can also bring an improvement of some mechanical parameters and passenger security. Systematic research led to the testing and comparison of the selected samples from non polyurethane material (NPU) and PU foam for determination of the dissipated mechanical energy which is equal to the area between loading and unloading strain-stress curves. From the measurement results the suitable material for the construction of comfort layer was chosen. This material was textile with horizontally laid fibers. For a comparison of dynamic characteristics, especially transmissibility, an experimental device for testing of complete car seats was developed. Also the virtual models of car seats in finite element method were assembled for achieving of non-measureable properties. The cushion made of the NPU has improved damping and significantly lowered the dependence of the damping factor on the frequency change and the strain rate, when compared to PUF. It is very important for the safety during the car crash, because then the stiffness does not increase significantly.

Keywords: Non-polyurethane, recycled material, car seat, FEM, transmissibility, strain rate

1. Introduction

Study and analysis of the mechanical properties of comfort stuff material of car seat is very important for the optimization of safety and seating comfort [1]. Safety of seats depends on the current position and geometry of the human body, and also significantly depends on the material for the comfort stuff of the seat [2]. Comprehensive research of seating quality is very complicated, because it is cost and time consuming due to the necessary number of measurements and analyzes of all mechanical parameters [3]. For a more detailed understanding of the problem: the term "seating comfort" is not only a sense during the seating

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influenced primarily by human anatomy (constitution of the body), but it is also the ergonomics associated with the space, which is important for easy accessibility of controls inside the car. The body weight and constitution influences its interaction with the car seat [4]. The interaction of the human body and seats also significantly affects the size and distribution of a contact pressure that depends on the geometric shape and size of contact areas. The parameter optimizing mentioned above is very important for people who are in long-term interaction with a comfortable cushion layer, such as professional drivers or operators of industrial machines. Currently, the problem of optimizing of these parameters is increased due to requirements of lower weight, prices and energy. Systematic research led to the testing and comparison of the selected samples from NPU material and PU foam for determination of the dissipated mechanical energy which is equal to the area between loading and unloading strain-stress curves [2]. This paper deals with studies of the mechanical properties of NPU material samples and PU foam. From NPU material the functional sample of the seat stuff was made, and the obtained transmissibility function was compared with the transmissibility of stuff of currently produced car seats. In this case the term transmissibility [-] is square root of the ratio of a power spectra (periodogram) of excited and excitation signals obtained from the values of acceleration. A distribution of principal stresses of dynamically loaded car seat comfort stuff were obtained using model simulations in the FEM program PAM-CRASH. Experimentally obtained properties of analyzed samples with viscoelastic behavior are used as input of material models in the simulation. FEM simulations are currently a very useful tool for engineering and biomechanical applications and also for a determination of the parameters that are difficult to measure [1, 2]. This allows a good approximation of strongly nonlinear behavior of materials. The geometry and material properties of seat cushions can be optimized using FEM simulations.

2. Materials and methods

2.1. Experimental samples

Based on a study and comparison of mechanical properties of polyurethane foams and NPU material under static and dynamic compression loading of measured strengths of the samples was selected material with appropriate properties - fibrous material with the horizontally laid structure. These samples have significantly nonlinear visco-elastic properties manifested by hysteresis during compression loading and unloading. Through this the energy absorption (damping), which can be described by the relation (1) can be compared. Nonlinear viscoelastic properties can be mathematically described including rheological models [1]. The structure may be one species, or it can be a combination of more types of structures (for example: anisotropic or quasi-isotropic particle composite). This behavior during the compression loading is very difficult for a mathematic formulation, because the set up of appropriate rheological model for this behavior requires lots of measuring and comparisons. From that a value of pressure can be obtained. The pressure depends on parameters of fibers and packing density of applied structure [5].

$$\sum_{i=1}^{n}\left(W_{comp}-W_{unload}\right)_i=\sum_{i=1}^{n}\oint\left(F_{comp}(\tau_1)-F_{unload}(\tau_2)\right)_i dl=\Theta(\rho,t,\delta) \qquad (1)$$

where Θ [J] represents the dissipation of energy absorbed by PU, W_{comp} and W_{unload} is deformation work (loading, unloading), $F_{comp}(\tau_1)$ [N] represents the total loading force in time $\tau_1 < t$ [s], $F_{load}(\tau_2)$ [N] describes unloading force at the time $\tau_2 < t$, which is a different during the hysteresis $\tau_1 \neq \tau_2$.
The comparison of sample structures of PU foams and NPU fibrous material in the cross-section is shown in Figure 1 and 2. Their characteristics are written in Table 1.

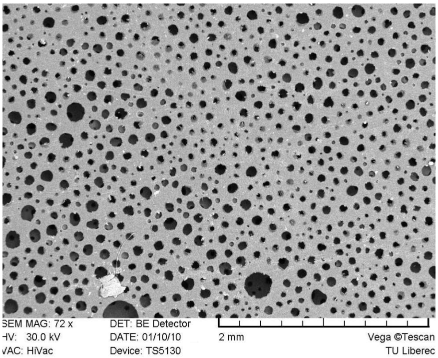

Fig. 1. Cell structure of PU foam

Fig. 2. Fibrous structure of NPU material

Table 1. Selected properties of samples

Material	*Density [kg.m^{-3}]*	*Surface mass [kg.m^{-2}]*	*Volume of air [%]*	[a] ψ [-]	[a] ζ [-]
PU foam	50 ±0,2	2003±3	96,6±0,6	0.033	-
NPU material	46±0,16	773±2	97,1±0,1	-	0.97

[a] is parameter of packing density of PU foam $\left(\psi=\frac{V_{polymer}}{V_{air}}\right)$

[b] is structure porosity $\left(\zeta=1-\frac{V_{fibers}}{V_{total}}\right)$

2.2. FEM model

For the analysis and experimental comparison the sample of seat stuff from NPU material with same geometry as the current car seat stuff of polyurethane foam was made (Fig. 3). For a comprehensive study of the mechanical behavior of the seat stuff loaded by specially shaped body was assembled virtual model in the FEM program PAM CRASH (Fig. 4). This model had the same initial and boundary conditions as in the experiment. Input material properties of the computational model have been already published in [1,2].

Fig. 3. Sample of NPU seat stuff (left), stuff from PU foam (right)

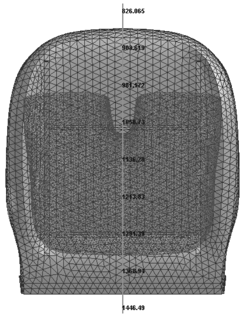

Fig. 4. FEM model

2.3. Experimental measurement of car seat

For the measurement of the static and dynamic properties of complete car seats, an experimental device was built according to own design in hydrodynamic laboratory of TUL. The device consists of a jig to fixation of a seat on hydraulic cylinder and from the horizontal frame for loading of seat and fixation of specially shaped body with weights. The device is shown in Figure 5.

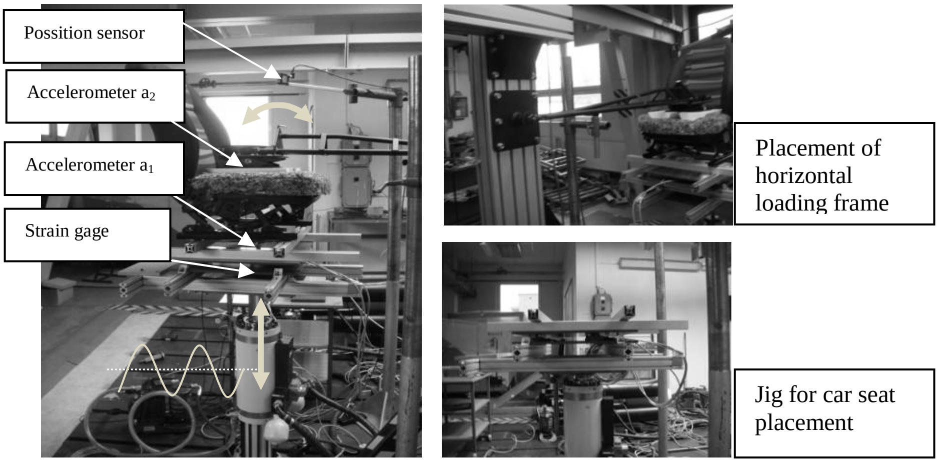

Fig. 5. Realisation of the experimental device for measuring of car seats

Measurements were performed using the generated harmonic sinusoidal signals with frequencies in a single composite input file (one measurement with a gradual change of the frequency and amplitude). This signal was used for an excitation of hydraulic cylinder. Generated input file containing the data put in Table 2. The total time of one measurement took 270 s. Five measurements were performed for different loads (22, 32, 42, 52 and 62kg). These loads were chosen to correspond to different human bodies while human body loads the car seat with approx. 60% of total weight. Individual measurements were repeated three times.

Table 2. Input frequency of excitation signal

Frequency [Hz]	Amplitude [mm]
0,5	99,5
1	24,87
1,25	15,92
1,6	9,72
2	6,22
2,5	3,98
3,15	2,51
4	1,55
5	0,99
6,3	0,63
8	0,39
10	0,25
12,5	0,16

3. Results

Experimental data were recorded to program DEWESoft 7.0 (Fig. 6). The data processing was in program Matlab, where the data are filtered and modified using *pwelch* function. The calculation algorithm is based on Welch's method. The results of transmissibility are in fig. 7. The phase shift is shown in Figure 8. The distribution of contact pressures on seat cushion from PU foam and NPU material is shown in Fig. 9 and 10.

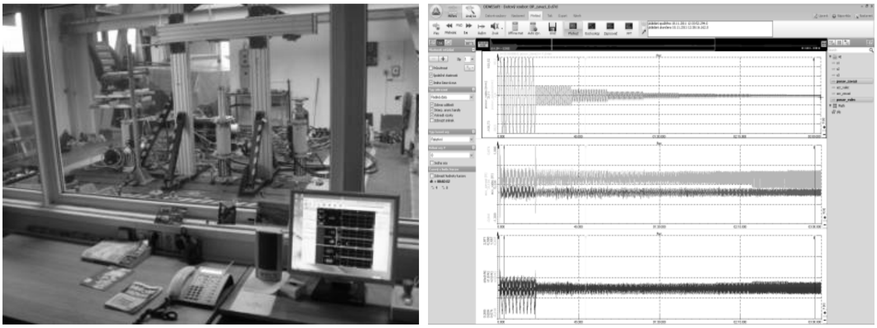

Fig. 6. Data were recorded to program DEWEsoft 7.0

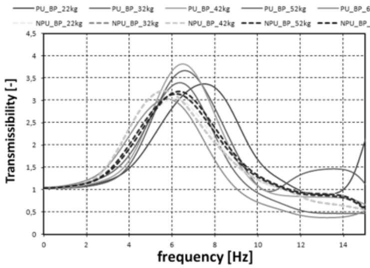

Fig. 7. Frequency analysis

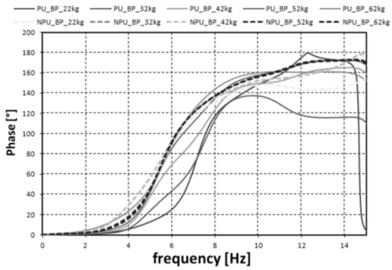

Fig. 8. Phase analysis

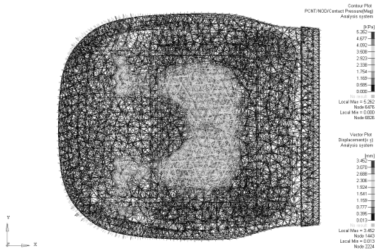

Fig. 9. Distribution of contact pressure (PU foam)

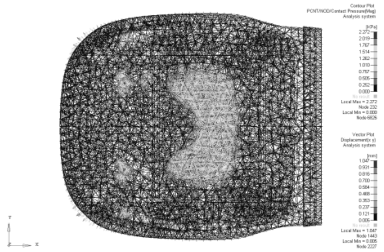

Fig. 10. Distribution of contact pressure (NPU material)

4. Conclusions

The comparison of the transmissibility showed a different behavior between the functional model with NPU material and seat currently produced from PU foam in frequency range of 0 – 12 Hz. The functional model for each load exhibits almost identical course of transmissibility and phase delay, which characterizes the independence on the value of the load. In contrast the seat with PU foam shows different transmissibility for each loads (Fig. 7 and 8). This fact is very important in the terms of the easier NPU material properties optimization, because then the material can be optimized only for one selected mass. Also, the contact pressure peaks of the seat comfortable stuff under load indicates, according to the FEM simulation, 2.5 higher values in the case of PU foam when compared to NPU material (Fig. 9 and 10). It is very suitable, because a reduction of the contact pressure improves the seating comfort.

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