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Dynamic Analysis of PUR Foam Reinforced with Coconut Fibres in Various Thermal Conditions

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Abstract. The reduction of emissions and using natural materials are the current trends. One of the ways how to reduce emissions is the vehicles weight reduction. The requirement on the weight reduction is also applied to car seats cushions. Polyurethane foam is still the most often used material for cushion of car seats. The weight saving could be achieved by manufacturing and using composite polyurethane foams with lower density and improved mechanical properties provided by the fibres reinforcement. Samples of polyurethane foam with coconut fibers were made and their inner structure was scanned by means of an electron microscope (SEM). Beside the static properties for the car parts (seats) it is important to know especially the dynamic properties. Therefore, the samples were tested on the dynamic mechanical analyzer (DMA). The chosen method was compression with constant strain, sweeping frequencies and various temperatures. This way, the storage and loss modulus of the reinforced foam samples were determined. The significant dependency of those main elastic constants on the using of reinforcement and also the varying ambient temperature has been found.

Introduction

Polyurethanes were developed in 1950s. Since then has been done many researches, and polyurethane production has become a multi-billion dollar business in the world today [1]. Polyurethanes have a wide variety of commercial use. Polyurethane foams are produced in three forms as flexible, semi-rigid and rigid. Flexible foams are widely used in different applications mostly in automotive, furniture and packaging. Nowadays car manufacturers have high demands on car seat development. The main limiting factor is the constant effort to reduce weight and price while keeping or even improving the main mechanical properties. One way to achieve a reduction of price of car seat cushion is using cheap natural material as a filler in polyurethane foam. Important features for seat evaluation are comfort and vibration isolation. In order for these parameters to be met, it is necessary to check the replacement material by a number of mechanical tests. Many studies describe the possibility of using natural fibers as reinforcement in polyurethane foams. Gu [2] describes the effect of adding wood fibers as a filler into several rigid and flexible polyurethane foams. The addition of fibers resulted in an increase in tensile and compressive strength of the rigid foam and increased stiffness of flexible foam. Banik [3] determined the effects of different cellulosic fibrous materials on the formation of the foam structure. The addition of few percent of fibers had a significant effect on the structure and the resulting properties of the polyurethane foam.

Combining coconut fibers with polyurethane foam could also possitively affects the damping of arising vibration. After the addition of 2.5% coconut fibers to the flexible polyurethane foam, an increase in the damping properties of the polyurethane foam was found and the resonance frequency was shifted to higher values compared to pure foam [4]. The dynamic properties of car seat cushions are very important in terms of long-term seating comfort [5]. Long-term exposure of human body to low frequency vibration is associated with health problems, especially, lower back pain. The vertical vibrations with frequency around 3 Hz increases fatigue and drowsiness [6]. A dynamical mechanical analyzer is a useful tool for measuring the mechanical properties of different materials [7].

Materials

For this study foam samples with 5 % of coconut fibers were created. In Fig. 1_a the microscopic photo of a wad of coconut fibers could be seen. There it is possible to see the varying diameters of the individual fibers. Fig. 1_b shows the SEM photo of one fiber in polyurethane foam, there can be seen the damage of the fiber where the part of its surface is torn off. On the torn off layer good coupling polyurethane with fiber is evident. That means the suitable composite material has been created. In addition, improvement of mechanical properties of this way prepared composite foam compared to the pure polyurethane foam could be expected.

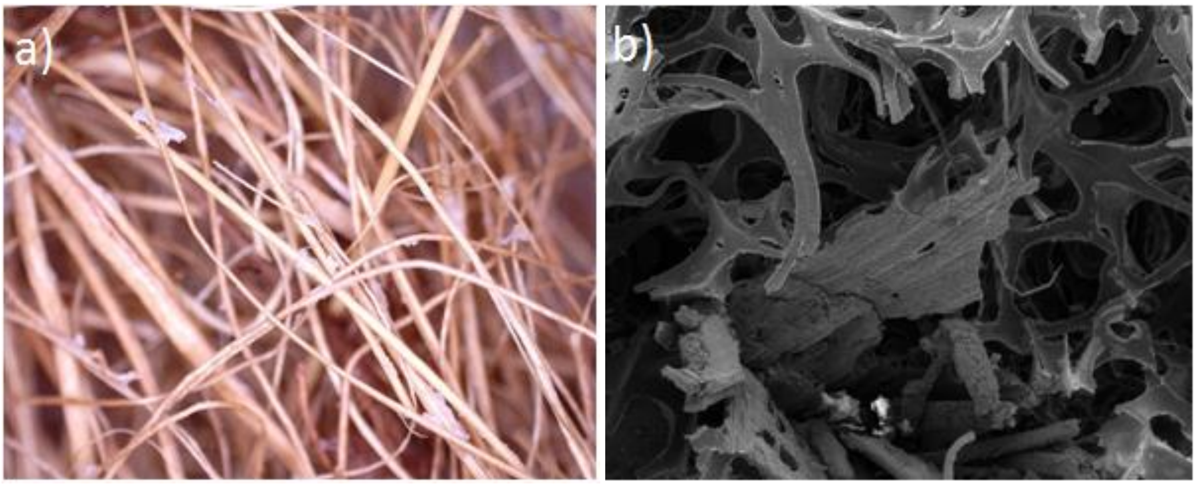

Fig 1. a) wad of coconut fibers b) SEM photo of one fiber in polyurethane foam

Fig. 2 Samples for DMA compression testing

Experiment

The aim of the carried experiment was to compare elastic behavior of the neat polyurethane foam samples and the reinforced one by means of the dynamic mechanical analyzer (DMA) as is schematically illustrated in the Fig 3. DMA compression is used to measure the properties of low and medium tough materials, including gels and weak elastomers [8]. The sample must support a static preload force during testing. The sample should have the ratio between the thickness and diameter as high as is possible, depending on the sample preparation and instrument limits. The carried experiment consists in various frequency with constant strain amplitude. Because the properties of the polymer material are temperature dependent, the measurements were carried out for different temperatures. A frequency sweep may be performed to evaluate the viscoelastic response of a material by the observed changes in the storage and loss moduli and tan δ. The loss tangent is the ratio of loss modulus and storage modulus, which indicate the viscosity and elastic properties of material, respectively. According to [8] is recommended to use logarithmically space frequencies (e.g. 10, 5, 2, 1) rather than linearly spaced for composite samples.

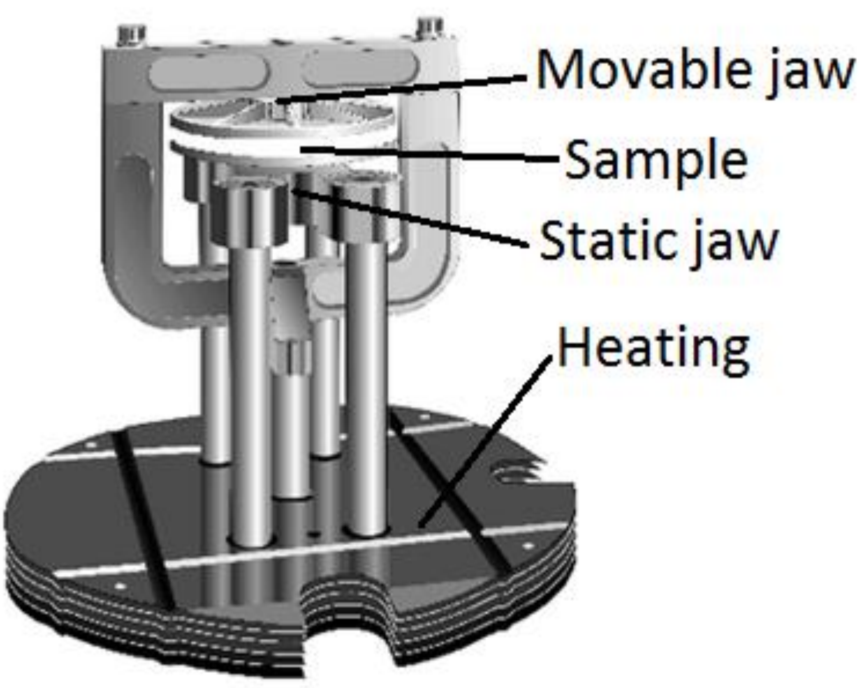

Fig. 3 The experimental DMA device

Before the main testing, it is appropriate to set the value of the geometry factor. For the compression clams it is possible to determine the optimal sample size according to (1)

$$\mathbf{GF} = \mathbf{Fe}\ \frac{\mathbf{T}}{\mathbf{A}} \tag{1}$$

where T is sample thickness [mm], A is sample cross sectional area [mm^2], Fe is sample shear factor. This factor is a strong function of Poisson’s ratio and the thickness of range 0.1 to 1. The value was determined from table in device manual [8]. Tab. 1 summarizes sample values and measurement settings.

Tab. 1 Sample values and measurement settings

	Neat PU foam	Composite foam
Sample thickness T [mm]	7.8	8.1
Sample diameter D [mm]	12.8	12.7
Clamping factor Fe [-]	0.61	0.61
Geometry factor [1/mm]	0.0369	0.039
Amplitude [mm]	0.5	
Preload [N]	0.6	
Force track [%]	125 %	
Frequency range [Hz]	1 - 50	
Temperature range [°C]	30 - 60	

Results

In the following figures are the results of dynamic compression. It is possible to see the comparison of the neat polyurethane foam Fig. 4 and composite foam with coconut fibers Fig. 5 in dependency on the loading frequency in the range of 1 – 50 Hz.

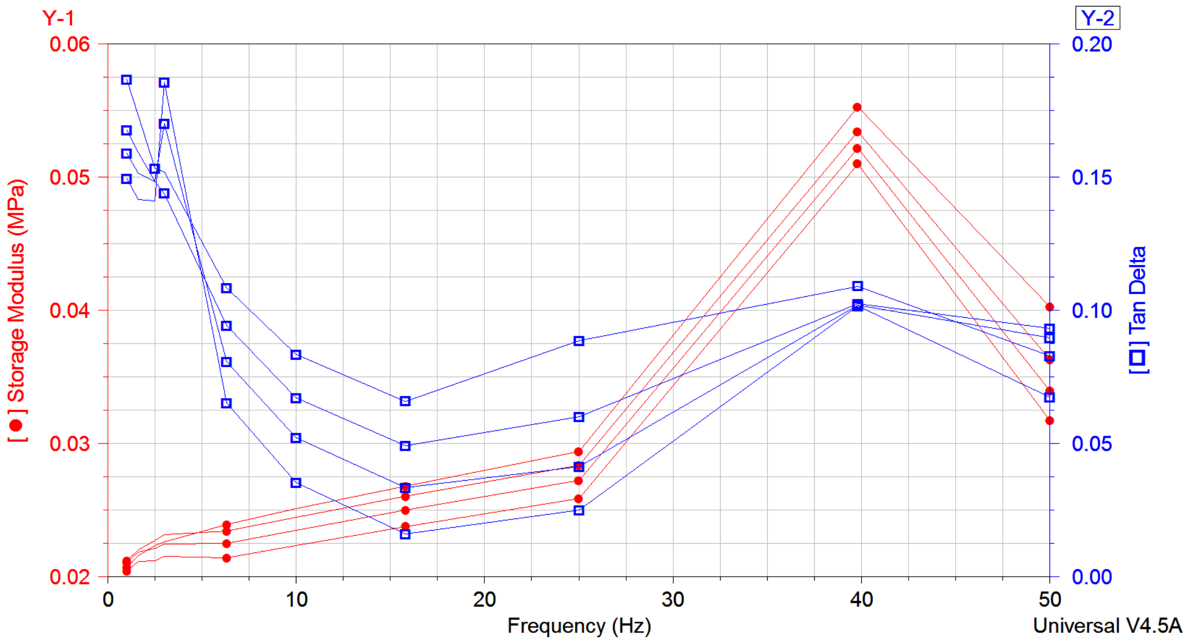

Fig. 4 Experimental results of the modulus in dependency on frequency of neat foam

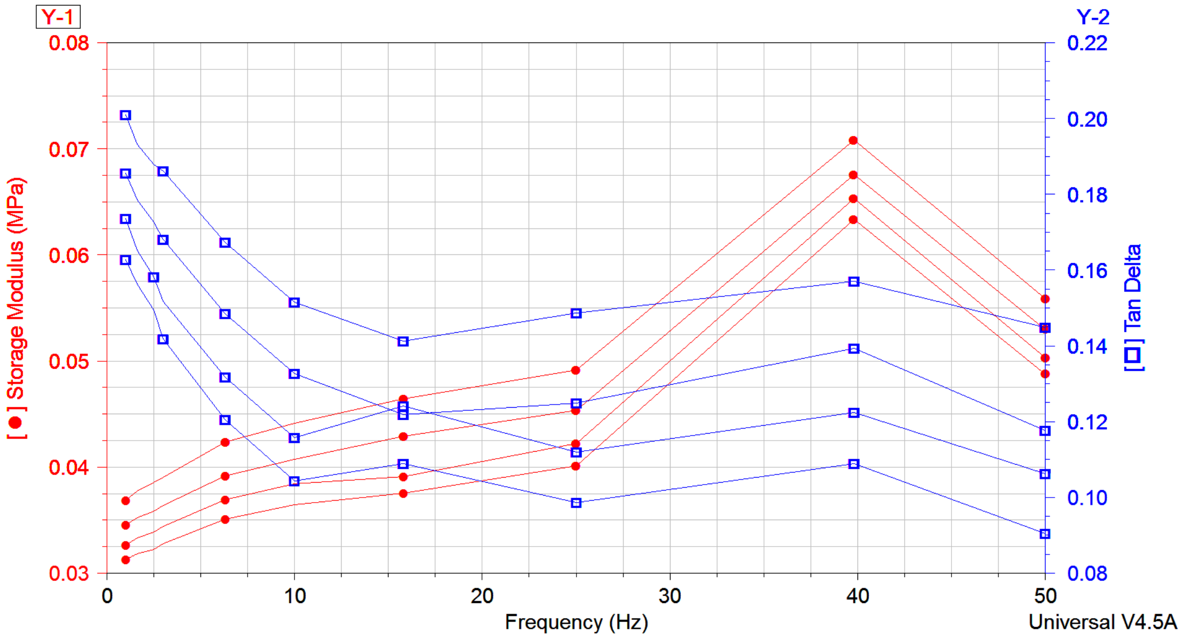

Fig. 5 Experimental results of the modulus in dependency on frequency of composite foam

Because the temperature in car could achieve relatively high values, it is appropriate asses the dependency of properties also with various ambient temperatures. The result of dynamic compression in dependency on the temperature could be seen in the following figures. It is possible to see the comparison of the neat polyurethane foam Fig. 6 and composite foam with coconut fibers Fig. 7 in dependency on the temperature in the range 30 – 60°C.

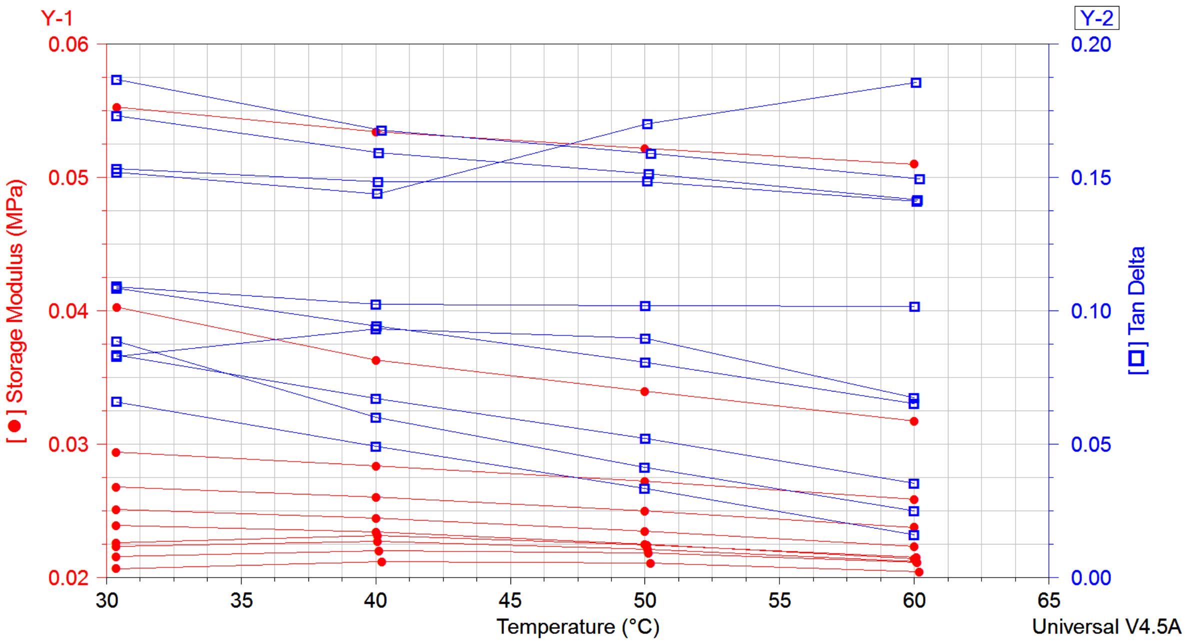

Fig. 6 Experimental results of the modulus in dependency on temperature of neat foam

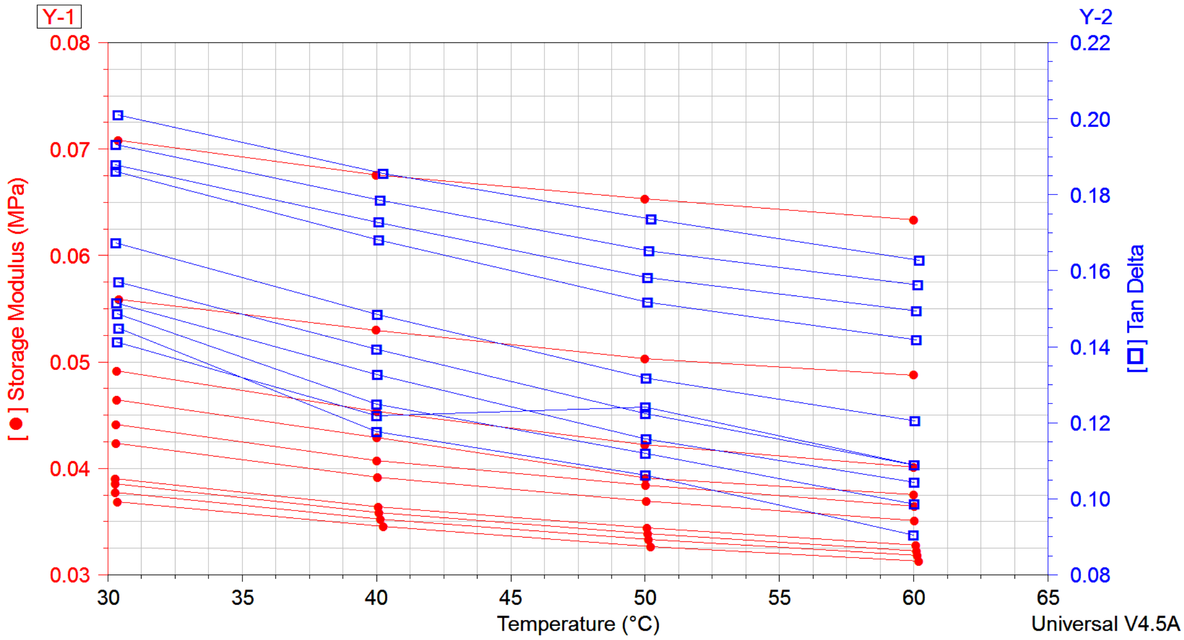

Fig. 7 Experimental results of the modulus in dependency on temperature of composite foam

Conclusions

Composite PU foam reinforced by coconut fibres was created. Mechanical properties of neat foam and composite foam were compared using the dynamic mechanical analyzer. It has been found that the resultant modulus of elasticity of composite polyurethane foam with coconut fibres is higher compared to neat polyurethane foam. Highest storage modulus was found at frequency of 40 Hz for both neat foam and composite foam. With increasing temperature storage modulus drops slightly in neat foam, for composite foam is this drop more pronounced. The results have shown that polyurethane foam with coconut fibers can be used for a car seat cushion. The further aim of the research should be targeted in order to find out the optimal volume ration of the fibre reinforcement and the best disposition.

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