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# Test for the auxetization of chosen polyurethane foams used in the production of seat bases for upholstered furniture

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**Abstract:** *Test for the auxetization of chosen polyurethane foams used in the production of seat bases for upholstered furniture.*

The main purpose of the thesis was to perform an attempt of auxetic process of the foams and to determine the level of susceptibility of the selected foams to thermal modification of resilient properties.

The research has been conducted on the basis of methodology consisting in:
– selecting materials for the research,
– measuring the Poisson's ratio,
– performing an attempt of the auxetic process of the selected polyurethane foams.

The research has been carried out with the use of numerically controlled testing machine Zwick 1445, DIC system for digital image correlation, Pc54k furnace by WARMA, special form for the auxetic process of foams and by means of the mFlex sensor mat for measuring and reading contact stresses.

On the basis of the performed research, an analysis of the obtained results have been conducted and conclusions have been drawn up.

It has been found that thermal modification in connection with a uniaxial compression of material has not led to the auxetic process of foams.

It has been found that the selected type of polyurethane foams is not susceptible to the auxetic process.

*Keywords*: auxetic process, foam, Poisson's ratio

## INTRODUCTION

Polyurethane foam is a considerably universal material - soft, durable and able to sustain its shape for longer periods of time. Therefore, it is frequently used in the production of upholstered furniture and its components, such as seat bases and backrests of chairs and armchairs.

It has been known since long that that sedentary lifestyle is harmful to health. It is estimated that 70% of active employees work in a sitting position. At the same time, 60-80% of workers seek medical help due to pain experienced in the lower area of the spine. These pains are most frequent among people who perform sedentary jobs, seemingly the easiest of all. Back pains are the cause of 20% of sickness absenteeism cases, thus being the second most frequent reason after the common cold (www.zdrowie.med.pl).

50% of premature retirements are caused by pathological changes in the spine. This forces the producers to design and introduce materials, including foams with greater parameters, modifying the structure of the conventional foam. Through the modification of conventional foams, it is possible to develop auxetic foam. Due to the negative Poisson's ratio, auxetic materials increase their dimensions in a direction transverse to the stretching direction and reduce their dimensions in a direction transverse to the stretching direction. Such behavior of the material is beneficial for the feeling of comfort in the furniture's usage (including seating furniture). Traditional foams have a 0,1 to 0,4 Poisson's ratio, while auxetic foams have a negative –0,1 to –0,7 ratio (Lisiecki et al. 2010). Open-pore polyurethane foam is made of convex polyhedrons that create a three-dimensional web of contextures and ribs. Auxetics, on the other hand, have curved, knee-shaped ribs. Through thermal compression, polyurethane foam can be turned into an auxetic. In total, three methods of producing auxetic foam can be distinguished:

– triaxial thermocompression (Chan, Evans 1999),
– biaxial thermocompression (Lisiecki et al. 2010),
– mult-stage triaxial thermocompression (Chan, Evans 1997).

Multiple research centres inside and outside of Poland attempt to study the auxetics. Reference works suggest that only small-sized samples were subjected to auxetization testing. Auxetization of full-scale seat-bases has not been tackled so far.

The aim of the study was to conduct a test for the auxetization of chosen polytherane foams and to evaluate the susceptibility of the chosen foams to thermal modification of their elastic properties.

MATERIALS

The subject of the study were forms of chosen polyutherane foams: ployester and polyether types, most frequently used as the material for the resilient layer of furniture developed for work and leisure.

**The choice of study material**

Polyurethane foams belong to a wide group of polyurethanes (PUR) which are characterized by high durability and both great chemical and physical resistance, as well as scrub resistance. According to Sah et al. (2005) these qualities mostly depend on:
– structure: size, shape and texture of cells,
– density,
– material constants.

In upholstered furniture most commonly used are foams with density from 14,5 to 65,0 kg/m$^3$, stiffness from 1,0 to approx. 7,0 kPa, deformability from 4 to 20%, and resilience from 37 to 80% (Matwiej 2011). Most commonly used types of foams are:
– classic polyether (standard),
– classic fire-retardant,
– high-flexible polyester,
– high-flexible high-resilienc,
– high-flexible fire-retardant,
– low-elastic (thermoelastic).

Due to the widespread use of some of the aforementioned types in seating and leisure furniture production, polyether foams (labelled with T) and polyester foams (labelled with HR and S) were specifically chosen for the study. Basic physical-mechanical parameters, such as: apparent density of the foams, elasticity, and deformability of base foams is presented in table 1, based on the data from the producer.

**Table 1.** Basic physical-mechanical parameters of chosen polyurethane foams.

| No. | Foam type | Apparent density* [kg/m$^3$] | Elasticity* (min) [%] | Deformability 50% *(max) |
|---|---|---|---|---|
| 1 | T-3538 | 32,0-34,5 | 50 | 6 |
| 2 | HR-3533 | 32,0-34,5 | 60 | 6 |
| 3 | S-30SG | 35,0-38,0 | 25 | 10 |

*according to www.restpur.pl

**Method of determining the Poisson's rate**

In the study, tests of single-axis compression were necessary in order to determine the Poisson's rate as the qutient of lateral and longitudinal deformation, with the axial state of stress in the studied material.

10 samples of each foam types (cubical shape with side H = 100 mm) were chosen for the research.

To record the deformation and measure the shift of foams through digital video analysis system, a web of dark spots was applied to each sample, creating a stitch sized 10 x 10 mm.

The study was conducted with the use of a numerically controlled testing machine Zwick 1445. A BASLER A102K digital camera with high resolution CCD converter (1392 x 1037 pixels and a max. 10-bit grayscale) was used at the purpose-built test site.

Throughout the study, image acquisition with 8 bit per pixel accuracy was being made due to expected changes in the luminous intensity gradient (a necessity to detect often jagged edges). Two 40 W reflector lamps (illuminating the studied object) and one 75 W light bulb (illuminating the reflective screen) served as the lighting source. The images were transmitted to the computer through a National Instruments 1428 image acquisition card. The tests were conducted until reaching a H' = 0,5 H compression. The velocity of pressure movement during the axial compression of the samples was 100 mm/min.

During the tests, photographic recordings were being made for the H and 0,5 H deformation samples. The ratio of the lateral deformation to the longitudinal deformation with the axial state of stress of the studied material (Poisson's ratio) was based on a correlation:

$$\nu = \frac{\Delta x}{\Delta l} \quad [\frac{mm}{mm}]$$

$$\Delta l = l_1 - l$$

$$\Delta x = x - x_1$$

where:

ν – Poisson's rate,

Δx – lateral deformation [mm],

Δy – longitudinal deformation [mm],

x – the width of the sample before load [mm],

x1 – the width of the sample after load [mm],

l – the height of the sample before load [mm],

l1 – the height of the sample after load [mm] (fig. 1).

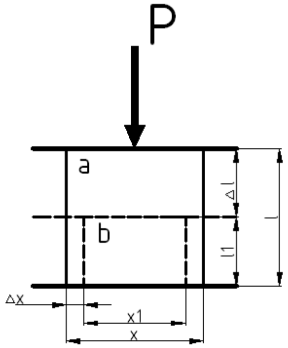



**Fig 1.** Outline for load and sample deflection during the study: a) sample before compression with initial height l = 100 mm and initial width x = 100 mm, b) sample after compression with final height l1 = 50 mm and final width x1.

The measurements of the samples' deformation were made with the use of digital image analysis by calculating the positional difference of spots on the observed surface, recorded on two subsequently taken photos. The value was measured through the detection of points located in the characteristic spots of the foam. It was made in the environment of IMAQ™ Vision Builder software developed by National Instruments. Places of measuring are specified on figures 2 i 3.

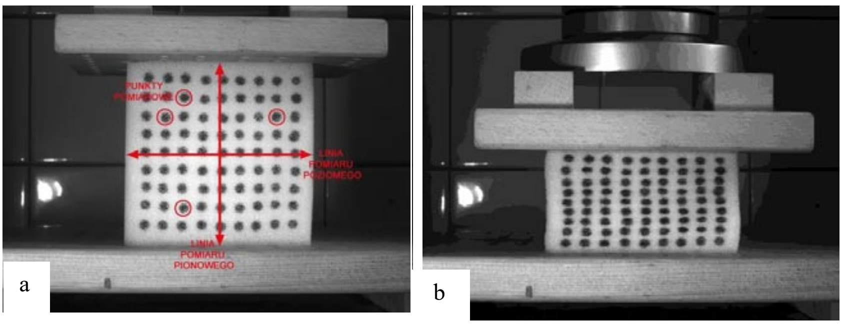



**Fig. 2.** Method of determining places of measuring on the samples prior to the auxetization test: a –image of the foam's surface before compression b – image of the foam's surface after compression.

Similar analysis was made after the foams' auxetization test. Samples of modified, full-scale seat-base foams were used in the study (fig. 3).

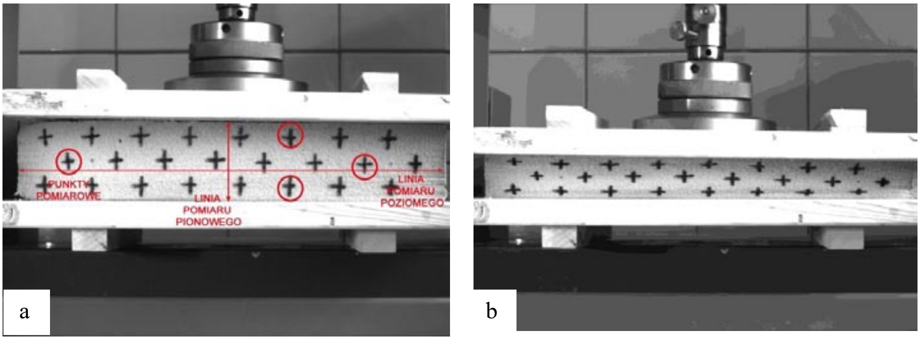
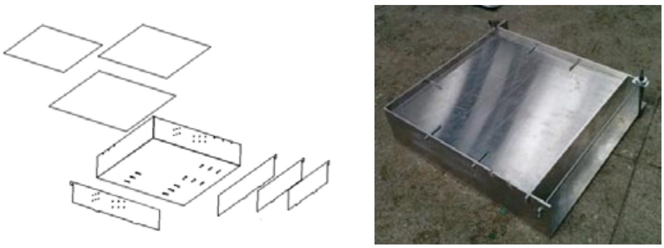



**Fig. 3.** Method of determining places of measuring on the samples after the auxetization test: a –image of the foam's surface before compression, b – image of the foam's surface after compression.

## Method of conducting an auxetization test of chosen foams

To attempt a modification of the elastic properties, a method of biaxial compression with heating was chosen. The heating was conducted with the use of a WARMA Pc54k oven. Cuboid-shaped polyurethane foams (sized 500 x 500 x 100 mm) were placed in an aluminium form (fig. 4).



a b

**Fig. 4.** A form for the thermal auxetization of foams: a – an outline of form's components, b – image of the form after assembling.

The modification was completed following the instructions described in literature (www.auxetic.info):

- placing the foam in the form,
- heating in the oven (temp. 200°C) for 10 minutes (at 1 deformation),
- removal of the foam from the form and stretching,
- heating in the oven (temp. 200°C) for 10 minutes (at 2 deformation),
- removal of the foam from the form and stretching,
- heating in the oven (temp. 200°C) for 10 minutes (at 2 deformation),
- removal of the foam from the form and stretching,
- placing in the form and cooling down to room temperature,
- heating in the oven (temp. 100°C) for 1 hour.

During the study, TES 1310 TYP K thermometer was used for the control measurement. Temperature measurements were made inside and outside the foam. The entire procedure was repeated three times, due to the usage of three different types of foams, varying in density.

## RESULTS

The measurement of the samples' deformations through the detection of characteristic points has enabled determination of Poisson's ratio before and after the auxetization test of the foams. Specified values are presented in tables 2-3.

**Table 2.** Poisson's ratio before modification.

| Sample | Sample size | | Poisson's ratio | Measurement between the points | | Poisson's ratio |
|---|---|---|---|---|---|---|
| | Vertical | Horizontal | | Vertical | Horizontal | |
| H0000 | 622 | 639 | 0,01 | 121 | 130 | -0,03 |
| H0001 | 335 | 641 | | 63 | 128 | |
| S0000 | 610 | 640 | 0,11 | 122 | 130 | 0,75 |
| S0001 | 340 | 670 | | 118 | 133 | |
| T0000 | 612 | 620 | -0,05 | 124 | 127 | -0,02 |
| T0001 | 336 | 605 | | 41 | 125 | |

Foams with greater density (H, T) are characterized by a negative or near-zero Poisson's ratio. Foams with lower density levels (type S foam) have a positive Poisson's ratio. Values in the table indicate that the Poisson's ratio on the outer edges and inside the foam of the same type is varied. According to the analysis of the results, it is again possible to deduce that the foams were of the same structure.

**Table 3.** Value of the Poisson's ratio after the modification of the foams.

| Sample | Sample size | | Poisson's ratio | Measurement between the points | | | | Poisson's ratio |
|---|---|---|---|---|---|---|---|---|
| | Vertical | Horizontal | | Vertical left | Vertical right | Horizontal up | Horizontal down | |
| H*0 | 251 | 1332 | 0,13 | 148 | 150 | 159 | 157 | 0,00 |
| H1 | 131 | 1347 | | 86 | 87 | 159 | 157 | |
| Hp**0 | 237 | 1223 | 0,14 | 140 | 140 | 141 | 142 | -0,01 |
| Hp1 | 119 | 1240 | | 64 | 61 | 138 | 143 | |
| S0 | 268 | 1237 | -0,02 | 145 | 148 | 160 | 162 | 0,03 |
| S1 | 147 | 1235 | | 70 | 76 | 165 | 162 | |
| Sp0 | 265 | 1279 | 0,11 | 140 | 142 | 143 | 145 | -0,10 |
| Sp1 | 142 | 1293 | | 59 | 68 | 139 | 133 | |
| T0 | 269 | 1079 | 0,07 | 152 | 153 | 155 | 157 | -0,01 |
| T1 | 129 | 1089 | | 62 | 57 | 152 | 158 | |
| Tp0 | 241 | 1223 | 0,02 | 143 | 136 | 139 | 141 | 0,01 |
| Tp1 | 118 | 1225 | | 65 | 66 | 140 | 141 | |

Attention: *a single letter signifies a measurement on the outer structure of the foam. Number 0 signifies a sample of the foam prior to deformation, number 1 signifies a sample of the foam after approx. 50% deformation

**a two-letter symbol signifies a cross-section of the foam.

The above table indicates that the Poisson's ratios which were determined through the detection of points on the outer edges are radically different to values determined through the detection of points inside the foam. In case of the H-type foam the Poisson's ratio on the outer edges was respectively $\nu$ = 0,13 and $\nu$ = 0,14, while the value determined through the detection of points inside the foam was $\nu$ = 0,00 and $\nu$ = -0,01. Similar behaviour can be seen in foams of S and T types. The analysis of the above values shows that the structure of foams is not homogeneous.

## CONCLUSIONS

1. Modification of chosen polyurethane foams intended for the production of seat-bases for upholstered furniture attempted through a biaxial compression with heating has not lead to a significant change in the elastic properties of this material. Specifically, no prominent changes in the Poisson's ratio were observed.
2. The material chosen for the study did not submit to the auxetization test. The reason could be its high heterogenity, stated in the studies above.
3. During the conducted study, significant issues regarding the uneven velocity of heating of the insides of the sampled foams were observed. It is probable that it had an influence on the failure of the foam's auxetization.

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**Streszczenie**: *Próba auksetyzacji wybranych pianek poliuretanowych stosowanych w produkcji siedzisk mebli tapicerowanych*.

Głównym celem pracy było przeprowadzenie próby auksetyzacji pianek oraz określenie stopnia podatności wybranych pianek na termiczną modyfikację właściwości sprężystych.

Badania przeprowadzono w oparciu o metodykę, na którą składały się:

– dobór materiału do badań,
– pomiar współczynnika Poissona,
– przeprowadzenie próby auksetyzacji wybranych pianek poliuretanowych.

Badania przeprowadzono przy użyciu numerycznie sterowanej maszyny wytrzymałościowej Zwick 1445, systemu DIC do cyfrowej analizy obrazu, pieca Pc54k firmy WARMA, specjalnej formy do auksetyzacji pianek oraz przy pomocy maty sensorycznej mFlex do pomiaru i odczytu naprężeń kontaktowych.

Na podstawie przeprowadzonych badań dokonano analizy otrzymanych wyników oraz sformułowano wnioski. Stwierdzono, iż termiczna modyfikacja połączona z trójosiową kompresją materiału nie doprowadziła do auksetyzacji pianek. Stwierdzono, iż wybrany typ pianek poliuretanowych nie jest podatny na auksetyzację.

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