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The effect of the ageing process on physical properties of selected composite materials used in upholstery systems

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Abstract. *The effect of the ageing process on physical properties of selected composite materials used in upholstery systems.* The aim of this study was to determine the effect of ageing processes on selected physical properties of composite materials used in upholstery systems. The authors conducted tests using accelerated ageing methods, which facilitated continuous monitoring of process conditions and simulation of long-term ageing of materials. Tests were conducted on low-resilience (viscoelastic) polyurethanes and reference polyether materials. Tests showed considerable susceptibility to ageing factors in many key properties of low-resilience systems such as rigidity or Poisson's ratio. Moreover, the analyses confirmed the practicality of applied accelerated testing methods, both in comparative analyses and their implementation in industrial practice.

Keywords: low elasticity, foams, accelerated ageing, polyurethanes

INTRODUCTION

Upholstery systems in most upholstered sitting and sleeping furniture are typical examples of structural composites. They include continuous structures of structural components, the so-called layers. Layers may be composed of various materials, while most typically they are polyurethane foams. While elastic polyurethane foams may be divided according to several criteria, one of the most important divisions is in terms of their elasticity. According to this classification we may distinguish high-resilience foams (HR), products with standard elasticity and products with low elasticity, i.e. low elastic (viscoelastic – VE) foams, commonly called memory foams or thermoelastic foams (Rojek, Pawlik, Prociak 2010).

Low-resilience foams are used mainly as the elastic layer in mattresses and pillows in medical uses and as top layers of subassemblies of high standard upholstered furniture to improve user comfort (Rojek, Pawlik, Prociak 2010). The production technology of these foams was developed by NASA and used in cushioning aircraft seats to enhance the comfort at launch of aircraft. In present times this futuristic technology, thanks to its applications in mattresses and anatomical pillows, is found in many homes worldwide.

It needs to be mentioned here that low-resilience foams are highly sensitive to changes in humidity and air temperature. This phenomenon is of great importance both for the performance of products containing these foams and during experimental tests. During cooling these foams start to exhibit mechanical parameters comparable to certain wood species, preventing their use and workability. In turn, at elevated temperatures over 50°C they lose their original properties, becoming similar to high-resilience foams.

Ageing is a process consisting in changes in performance properties of a given material progressing with time. In the case of foam materials their manufacturing technology requires them to be produced in the form of blocks, later warehoused for further processing (changing their dimensions for further uses). This process inevitable leads to foam exposure to the action of certain external factors (Wirpsza 1991). Degradation may be caused by many factors, particularly heat – high or labile temperature, as well as electromagnetic radiation (Pączkowski 2003).

Recently published literature sources concerning parameters of polyurethane materials contained in composite layers of upholstered furniture focus primarily on modelling and determination of their properties during short-term tests, as confirmed by publications by Lusiak and Smardzewski (2010), Smardzewski and Grbac (1998), Wiaderek and Smardzewski (2008), Wiaderek and Smardzewski (2010). This problem was stressed in their study by Smardzewski and Matwiej (2013). Those authors indicated a lack of comprehensive analyses concerning the effect of ageing processes on properties of polyurethane foams and their variability in time.

The primary aim of this study was to determine the effect of the ageing process on physical properties of low-resilience foams as components of upholstery systems.

The objective connected with pure science was to determine selected properties such as density, rigidity, permanent deformation, rebound resilience and Poisson's ratio, as well variability of selected parameters in foams under the influence of ageing processes.

The practical objective was to determine the significance of the effect of ageing processes on changes in selected properties of low-resilience foams.

MATERIALS

It was decided to select two types of components – low-resilience foams and polyurethane foams as reference material. Basic physical properties, i.e. apparent density of foams, resilience and permanent deformation of tested foams are presented in Table 1, based on information given in the material specifications supplied by the manufacturer (Organika 2012).

Table 1. Foams characteristics

No.	Foam type	Relative density [kg/m^3]	Elasticity (min) [%]	Deformation 50% (max) [%]
1	T28150N	26.6-30.8	40	7.0
2	V5060N	47.5-55.0	5	7.0
3	V5030	47.5-55.0	3	5.0

Density was determined based on the PN-EN ISO 845 standard. Cellular plastics and rubbers.

Tests were conducted on 10 samples of each foam type. Linear dimensions were measured using a rule accurate to 1 mm, in accordance with the PN-EN ISO 1923 standard. Measurements of each sample were taken three times and next the value was averaged and sample volume was calculated. Sample mass was measured using a laboratory balance accurate to 0.01 g. Density was calculated according to the formula (1):

$$\rho = m/v \quad (1)$$

where:

- ρ – density [kg/m^3],
- m – mass [kg],
- v – volume [m^3].

In order to determine rigidity characteristics of foams uniaxial compression tests were conducted. For each foam type 10 cuboid samples of 100 x 100 x 50 mm were tested.

Analyses of elastic properties of low-resilience foams and reference polyether foams were conducted based on the PN - EN ISO 3386-1 standard. Tests were conducted using a numerically controlled Zwick 1445 strength testing machine and a BASLER A102K digital camera (Fig. 1).

The stress cycle lasted until compression H' = 0.3 H was reached.
Characteristics of the dependence of stress on strain were established based on the equation (2):

$$\sigma = F / A \quad (2)$$

where:

- σ – compressive stress [MPa],
- F – force [N],
- A – area of compressed sample [mm^2].

Characteristics of the dependence of stress on strain were plotted at known values of force recorded during tests and the calculated area.

Figure 1. Zwick 1445 with photo camera BASLER A102K

Poisson's ratio was determined based on the ratio of transverse strains to longitudinal strains at the axial state of stress in the tested material applying the dependence (3-5):

$$v = \Delta x / \Delta l \quad (3)$$

$$\Delta l = l_1 - l \quad (4)$$

$$\Delta x = x - x_1 \quad (5)$$

where:

- ν – Poissons ratio [mm/mm],
- Δx – transverse strain [mm],
- Δl – longitudinal strain [mm],
- x – width of sample before loading [mm],
- x_1 – width of sample after loading [mm],
- l – height of sample before loading [mm],
- l_1 – height of sample after loading [mm] (Fig. 2).

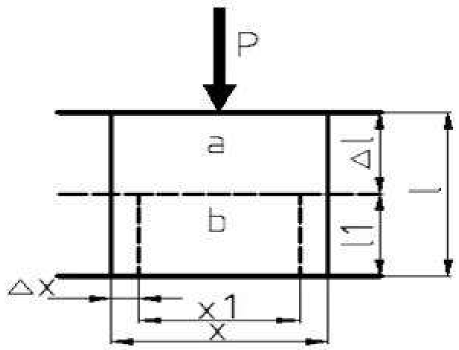

Figure 2. Diagram of load and deflection of the samples: a – the sample before compression height of the initial l=50 mm, b – the sample after the final compression height l_1=15 mm

Strains in selected samples measured using digital image analysis were calculated from the difference in the position of specific points (markers) on the observed gridded plane. For this purpose recorded series of two successive photographs (taken at sample heights H = 50 mm and H' = 15 mm) were used. Values of marker translocation were measured in the IMAQ™ Vision Builder by National Instruments, using detection of characteristic points in selected zones of foams. The points of measurements are shown in Fig. 3.

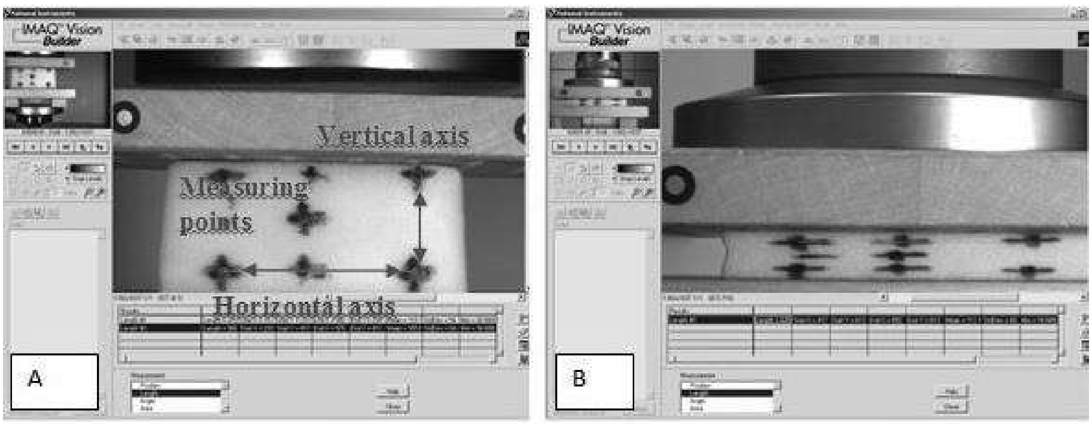

Figure 3. Method of determining measuring points: A – the image of the surface the foam before load, B – image of the surface of the foam after load

The value of permanent deformation was determined in accordance with the PN-EN ISO 1856 and the PN-EN ISO 1856/A1 standard Elastic porous plastics.

First thickness of foam samples was measured and next the samples were compressed to 50% thickness (12.5 mm) for 72 h. At 10 min after sample unloading to provide elastic recovery of material sample their thickness was again measured. The value of permanent deformation was calculated from the formula (6):

s.c. = [(d0-dr)/d0]*100% (6)

where:

- s.c. – permanent deformation [%],
- d0 – initial thickness of tested sample [mm],
- dr – thickness of tested sample after elastic recovery [mm].

Resilience of foams was tested based on the PN-EN ISO 8307 standard. Elastic porous plastics.

Foam elasticity (i.e. rebound resilience) was determined using a special apparatus, with the procedure consisting in dropping a steel ball – a marker with dimensions and mass specified in the standard - on sample surface. A measure of foam resilience is the value of maximum rebound of the ball in percent, with the reading recorded from the scale.

The author adopted the method consistent with standards of accelerated ageing used for artificial ageing chambers equipped with lamps, prepared based on: ISO 3696 Water for analytical use - Specifications and test methods, EN ISO 4892-1 Methods of exposure to laboratory light sources. Part 1: General Guidance, EN ISO 4892-2 Plastics. Methods of exposure to laboratory light sources. Part 2: Xenonarc Sources, EN ISO 4892-3 Plastics. Methods of exposure to laboratory light sources. Part 3: Fluorescent UV lamps.

The process was run in a conditioning xenon testing chamber, which facilitated simultaneous exposure to light, oxygen and recycling moisture, which reflected the daily cycle of use and confectioning of products made from polyurethane foam. Tests for assumed parameters of radiation intensity, length of the lighting cycle, the number of cycles and the values of the irradiation and wetting cycle were adjusted to simulate the conditions of the temperate climatic zone, as the standard for the author.

The ageing process was run in a Klimatest Atlas UV Test conditioning chamber (Fig. 4, Fig. 5).

Figure 4. Climate chamber type Atlas Klimatest UV test

Figure 5. Mounting of the samples in a climate chamber

In selection of adequate ageing cycle parameters the manufacturer's recommendations were applied, who based on the EOTA Exposure procedure for artificial weathering (European Organisation for Technical Approvals Exposure procedure for artificial weathering 2004) indicates the 83-h UV irradiation period as an equivalent of a 30-day (monthly) ageing – these values were determined for UVA lamps with the emitted wavelength of 340 nm at 60±3°C and irradiance of 55 W/m^2.

Since during sleep the human body excretes approx. 0.5-0.75 l water, this causes a significant increase in water vapour content inside the mattress (Grbac 2006). Tests conducted by Cunningham (1999) indicate that relative moisture content of the mattress core may even increase above 70%. For this reason, in order to ensure the ageing process closely resembling actual ageing, a cycle of condensations run at 50±3°C was implemented, which length corresponded to 1/3 total duration of a single ageing phase. This procedure aimed at the simulation of the effect of human sweat on the tested object. In accordance with this rule, when simulating 30 days of actual ageing, the tested material was kept in the chamber for 123 h, with the period for one complete 12-h cycle divided into 8 h irradiation and 4 h condensation. Such a cycle was repeated ten times and completed with an incomplete irradiation cycle of 3 hours. The author assumed 180 days as the maximum simulation period, dividing the testing periods into 30-day intervals.

RESULTS

Conducted analyses showed that the mean density of low-resilience foams for samples not subjected to the ageing proess was within the range of 47.3 – 48.0 kg/m^3, while for the reference foam it was 27.6 kg/m^3. Density determined after the complete ageing period amounted to 50.0 - 502 kg/m^3 for low-resilience foams, while for the reference foam it increased to 28.9 kg/m^3. Specific values of density are given in Table 2.

Table 2. Variability of the density of the tested materials for selected types of foam

Foam type	Simulated aging period	Average density [kg/m^3]	Change [%]
T28150N	1 day	27.6	4.7
	180 days	28.9	
V5060N	1 day	47.3	6.1
	180 days	50.2	
V5030	1 day	48.0	4.2
	180 days	50.0	

Conducted tests indicate that the density of samples subjected to ageing increases – this regularity was confirmed by the values recorded for the reference sample, as for samples of low-resilience foams the increase amounted to 4.2 – 6.1%, while for the reference sample it was 4.7%. The increase in density is caused by the disproportional change in linear dimensions and the resulting change in volume in relation to the mass of tested samples. Progress of this process results from crumbling as a consequence of penetration by ageing factors.

The test conducted in the strength testing machine made it possible to collect indirect results in the tabular form and to plot graphs for the dependence of stress on strain. For the conducted measurements Student's t-test was performed for dependent samples, indicating significance of differences at $p<0.05$ for rigidity of tested materials. Based on the analysis the following characteristics of strain depending on stress were determined for the simulated ageing periods (Figures 6-8).

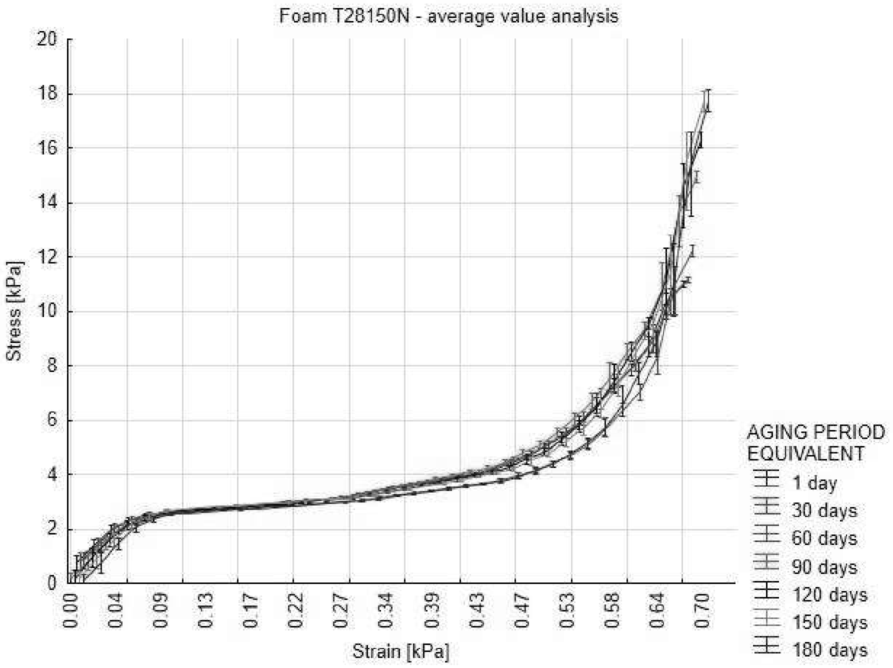

Figure 6. Stress - strain foam T28150N for selected periods

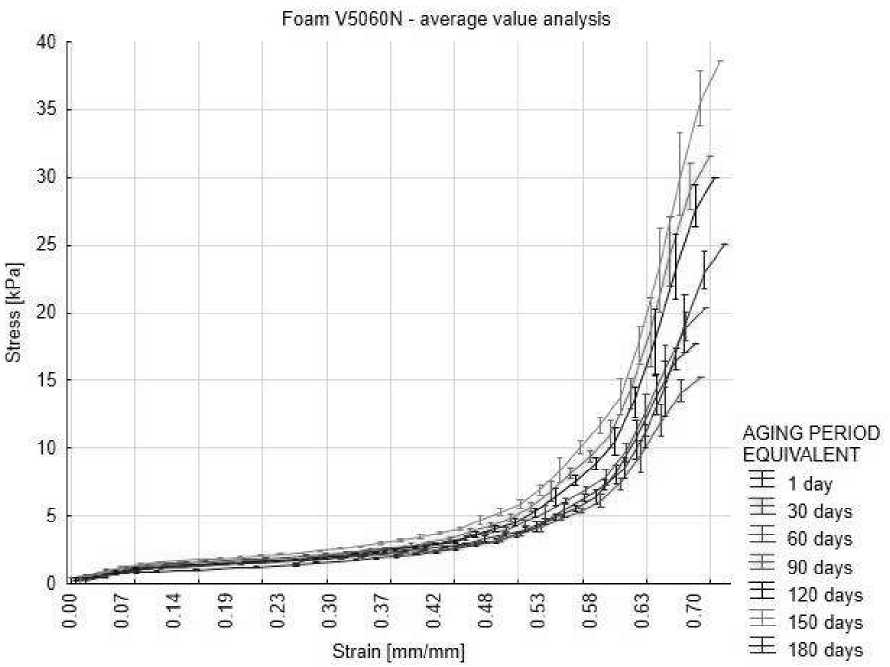

Figure 7. Stress - strain foam V5060N for selected periods

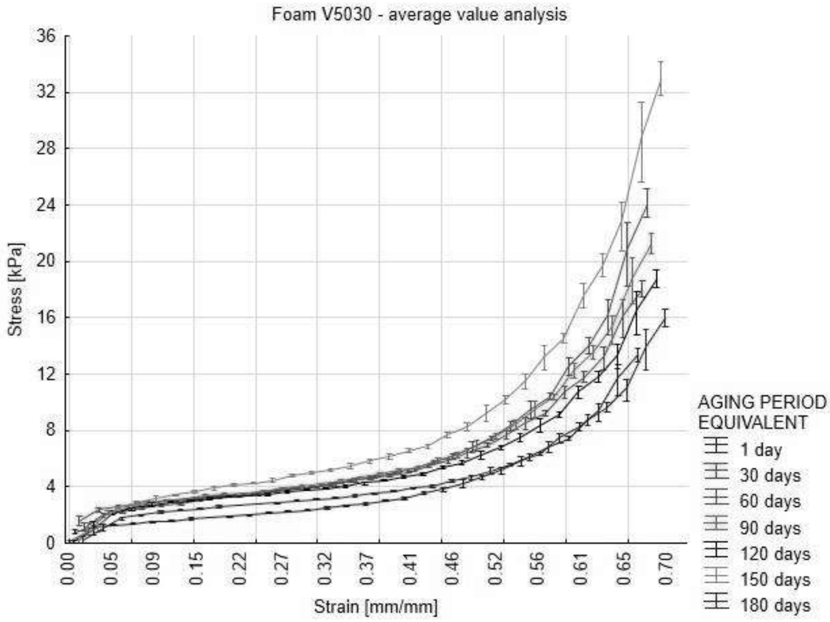

Figure 8. Stress - strain foam V5030 for selected periods

Additionally, the characteristics of variation in rigidity were determined for the tested foams for individual ageing periods, which is shown in Figure 9.

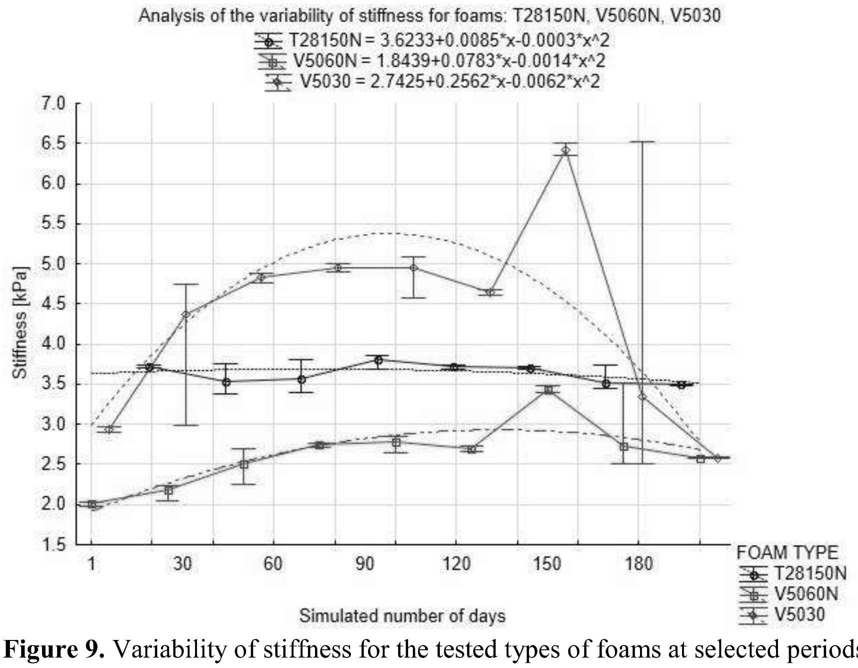

Figure 9. Variability of stiffness for the tested types of foams at selected periods

Values of rigidity for individual testing periods are given in Table 3.

Table 3. Stiffness foams for selected periods

Foam type	Days simulated	Stiffness [kPa] for ε=0.4	Standard devation [kPa]	Max difference [%]	Total change [%]
T28150N	1	3.68	0.022	4.1	-5.7
	30	3.73	0.021		
	60	3.40	0.015		
	90	3.83	0.025		
	120	3.71	0.024		
	150	3.70	0.019		
	180	3.47	0.020		
V5030	1	2,94	0.030	119.4	-13.3
	30	4.74	0.041		
	60	4.89	0.046		
	90	5.03	0.039		
	120	4.63	0.038		
	150	6.45	0.065		
	180	2.55	0.027		
V5060N	1	2.02	0.023	70.8	26.2
	30	2.23	0.020		
	60	2.70	0.026		
	90	2.80	0.034		
	120	2.68	0.034		
	150	3.45	0.046		
	180	2.55	0.027		

The analysis indicates high variability of rigidity in the function of passing time for low-resilience foams also in comparison to the reference foam. For the reference foam the distribution of variation in rigidity was more uniform and showed a relatively limited decrease. A significant increase in rigidity was recorded for low-resilience foams after the ageing phase, which was equivalent to 150 days of natural ageing. It needs to be stressed here that in the course of the test the phenomenon of crumbling of upper layers of the material was observed, which may result in such a situation and it was recorded with different intensities for reference and low-resilience foams. For the reference sample this process progressed successively from the moment, in which it reached the equivalent of 90-day ageing. For low-resilience foams intensification of this process was observed only when they reached the equivalent of 150 days of natural ageing. The attachment to this study additionally presents detailed values for the dependence of strain on stress for all types of foams at individual stages of the tests.

Mean values of Poisson's ratio for tests on the first day ranged from -0.005 to -0.022 for low-resilience materials, while for the reference foam this ratio was 0.011. After the simulation of 180-day ageing these ratios ranged from -0.028 to 0.008 for low-resilience foams, while for the standard foam it increased to -0.005. Specific values of these ratios are presented in Table 4.

Ageing influenced changes in the character of strains in loaded foam. For the selected type of artificially aged low-resilience foam (V5060N) during loading it expanded outwards in relation to its vertical axis, instead of collapsing – as in the case of both the other type of tested foam (V5030) and the reference sample. The greatest instability in reaction to the ageing factors was found for the low-resilience foam V5060N; however, all tested materials showed a tendency towards changes in the ratio of transverse strain to longitudinal strain (i.e. changes in values of Poisson's ratio).

Table 4. Value of Poisson's ratio for the tested types of foam

Foam type	Simulated aging period	Average value [-]	Total change [%]
T28150N	1 day	-0.011	-54.5
	180 days	-0.005	
V5060N	1 day	-0.005	260.0
	180 days	0.008	
V5030	1 day	-0.022	27.0
	180 days	-0.028	

Permanent deformability was recorded on the first day and in the simulated periods of 60, 120 and 180 days. Collected results showed that deformability of low-resilience foams amounted to 3.8 – 4.1% and 6.3 – 7.9%, while deformability of the reference sample was 3.3 – 12.4%. For all tested batches it was shown that the degree of deformation increases with the time of ageing. Detailed values recorded during the tests are collected in Tables 5-7.

Table 5. Value of permanent deformation for reference foam T28150N

Foam type	Simulated aging period	Average value of the permanent deformation [%]	Total change [%]
Foam T28150N	1 day	3.3	275.8
	60 days	8.3	
	120 days	9.0	
	180 days	12.4	

Table 6. Value of permanent deformation for low elasticity foam V5060N

Foam type	Simulated aging period	Average value of the permanent deformation [%]	Total change [%]
Foam V5060N	1 day	3.8	7.9
	60 days	3.9	
	120 days	4.0	
	180 days	4.1	

Table 7. Value of permanent deformation for low elasticity foam V5030

Foam type	Simulated aging period	Average value of the permanent deformation [%]	Total change [%]
Foam V5030	1 day	6.3	25.4
	60 days	7.0	
	120 days	7.7	
	180 days	7.9	

Among low-resilience foams a greater susceptibility to ageing factors, manifested in permanent deformation, was found for foam V5030. A correlation between extension of the ageing period and the increase in this value was confirmed by the results for the reference sample.

For both types of low-resilience foams maximum values of this property amounted to 9% and after the complete ageing period they reached the minimum of 6%. For the reference sample a change was recorded within the range of 43 - 27%. Specific values are given in Tables 8-10.

Table 8. Elasticity at the rebound for reference foam T28150N

Foam type	Simulated aging period	Average value [%]	Total change [%]
Foam T28150N	1 day	41.4	-30.4
	30 days	35.6	
	60 days	34.6	
	90 days	33.6	
	120 days	33.2	
	150 days	32.0	
	180 days	28.8	

Table 9. Elasticity at the rebound for low elasticity foam V5060N

Foam type	Simulated aging period	Average value [%]	Total change [%]
Foam V5060N	1 day	8.2	-14.6
	30 days	8.0	
	60 days	7.6	
	90 days	7.6	
	120 days	7.4	
	150 days	7.0	
	180 days	7.0	

Table 10. Elasticity at the rebound for low elasticity foam V5030

Foam type	Simulated aging period	Average value [%]	Total change [%]
Foam V5030	1 day	7.8	-17.9
	30 days	7.6	
	60 days	7.2	
	90 days	7.0	
	120 days	6.8	
	150 days	6.4	
	180 days	6.4	

Both low-resilience foams showed a comparable decrease in resilience under the influence of ageing factors. The trend for the reduction of this property with time was confirmed by the results for the reference sample.

CONCLUSIONS

Based on the analysis of testing results the following conclusions were formulated:

1. Ageing had a significant effect on changes in properties of selected composite materials from the group of polyurethane low-resilience foams. Analysed changes are completely or partly analogous to those taking place in the reference sample.
2. Low-resilience foams showed a markedly greater susceptibility to ageing factors, which was shown in comparison to the reference sample. In terms of permanent deformation and rebound resilience a markedly greater sensitivity to ageing was observed for the reference foam, while among low-resilience foams it was for V5030. All the tested foam types showed variable density. The most significant change in Poisson's ratio was recorded for foam V5060N, in which the character of deformations changed.
3. The application of accelerated ageing may play a significant role in manufacturing practice thanks to a considerable (approx. 4-fold) reduction of the required testing period and the resulting economic gains.
4. The method makes it possible to conduct a comparative analysis of selected types of tested composite materials thanks to their exposure to the same penetrating agents at identical external parameters.

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LIST OF STANDARDS

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3. EN ISO 4892-3 Plastics. Methods of exposure to laboratory light sources. Part 3: Fluorescent UV lamps 1994
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5. PN - EN ISO 3386-1 Elastyczne tworzywa sztuczne porowate 2000
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7. PN-EN ISO 1856/A1 Elastyczne tworzywa sztuczne porowate. Oznaczanie odkształcenia trwałego po ściskaniu 2004/A1 2008
8. PN-EN ISO 1923 Oznaczanie wymiarów linowych 1999
9. PN-EN ISO 845 Tworzywa sztuczne porowate i gumy. Oznaczanie gęstości pozornej 2010
10. PN-EN ISO 8307 Elastyczne tworzywa sztuczne porowate. Oznaczanie sprężystości przy odbiciu 2008

Streszczenie: *Wpływ procesu starzenia na właściwości fizyczne wybranych materiałów kompozytowych stosowanych w układach tapicerskich*. Celem niniejszej pracy było oznaczenie wpływu procesów starzenia na wybrane właściwości fizyczne materiałów kompozytowych stosowanych w układach tapicerskich. Autorzy przeprowadzili badanie z wykorzystaniem metod przyspieszonego starzenia, co pozwoliło na ciągłą kontrolę warunków procesu i symulację długofalowego starzenia materiałów. Przebadano materiały z grupy poliuretanów niskosprężystych oraz referencyjnych polieterowych. W wyniku przeprowadzonych badań wykazano znaczą podatność na czynniki starzenia, wielu kluczowych właściwości układów niskosprężystych jak sztywność czy współczynnik Poissona. Badania potwierdziły ponadto praktyczny charakter wykorzystania przyspieszonych metod badawczych, zarówno w analizach porównawczych, jak i wdrożeniu do praktyki przemysłowej.

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