Jerzy Smardzewski, Łukasz Matwiej[1]

Effects of Aging of Polyurethane Foams in the Context of Furniture Design

Učinci starenja poliuretanske pjene u kontekstu dizajna namještaja

Original scientific paper - Izvorni znanstveni rad
Received – prispjelo: 14. 8. 2012.
Accepted – prihvaćeno: 21. 6. 2013.
*UDK: 630*836.1; 674.23*
doi:10.5552/drind.2013.1241

ABSTRACT • *An ergonomic seat or bed must be capable of supporting optimally and evenly the user's body for sustained periods of time. The objective of the performed investigations was to ascertain the impact of natural aging on the stiffness of polyurethane foams in dwelling apartment conditions and, additionally, to determine regression equations describing this dependence. Seven types of furniture foams, differing with respect to their apparent density and stiffness, were selected for the experiment. Experimental foams were exposed to aging for the period of 730 days (two years) in climatic conditions typical for dwelling facilities. Foam stiffness was determined in a uniaxial compression test determining strain characteristics in the function of deformations. The performed experiments made it possible to establish percentage changes of stiffness of some foams as well as the time required for those changes to assume a significant character.*

Key words: *aging, polyurethane foam, stiffness*

SAŽETAK • *Ergonomsko sjedalo ili ležaj mora biti sposobno optimalno i ravnomjerno podržavati korisnikovo tijelo dovoljno dugo vrijeme. Cilj provedenih istraživanja bio je utvrditi utjecaj prirodnog starenja na čvrstoću poliuretanske pjene u stambenim uvjetima, a osim toga, i utvrditi regresijske jednadžbe koje opisuju tu ovisnost. Za eksperiment je odabrano sedam vrsta pjene za namještaj različite gustoće i krutosti. Odabrane su pjene izložene starenju u razdoblju od 730 dana (dvije godine), u klimatskim uvjetima tipičnim za zatvorene stambene objekte. Krutost pjena utvrđena je jednoosnim kompresijskim testom određivanja ovisnosti naprezanja o deformaciji. Provedenim je eksperimentom moguće utvrditi postotak promjene krutosti neke pjene, kao i vrijeme potrebno da te promjene postanu značajne.*

Ključne riječi: *starenje, poliuretanske pjene, krutost*

1 INTRODUCTION
1. UVOD

Polyurethane foams are plastics consisting of polyetheretherketone skeleton surrounded by gaseous bubbles, most frequently of carbon dioxide. At the present time, they constitute a key constructional material applied in upholstered furniture, including wheelchairs, various vehicles or aircraft improving comfort of their use. An ergonomic seat or bed must optimally and evenly support the user's body for sustained periods of time and, hence, it is important to recognize the influence of aging of polyurethane foams used in seats and/or beds on their physical-mechanical properties. However, the available literature on the subject is dominated by articles dealing, primarily, with issues con-

[1] Authors are professor and associate professor at Poznan University of Life Sciences, Faculty of Wood Technology, Department of Furniture Design, Poland.
[1] Autori su profesor i docent Sveučilišta bioloških znanosti u Poznanu, Fakultet drvne tehnologije, Odjel za dizajn namještaja, Poljska.

nected with the selection, modeling or stiffness analysis of foams for upholstered furniture (Alderson and Alderson, 2007; Bezazi and Scarpa, 2007, 2009; Brandel and Lakes, 2001; Choi and Lakes, 1992; Chow and Odell, 1994; Chu, 2000; Ebe and Griffin, 2001; Ferrarin et al., 2000; Gonga and Kyriakidesa, 2005; Grujicic *et al*., 2009; Lakes, 1987, 1992; Linder-Ganz *et al*., 2005; Lusiak and Smardzewski, 2010; Petre *et al*., 2006; Scarpa *et al*., 2004; Schrodt *et al*., 2005; Silber *et al*., 2010; Smardzewski, 2009; Smardzewski *et al*., 2006, 2008, 2010a,b; Smardzewski and Grbac, 1998; Smardzewski and Matwiej, 2007; Smardzewski and Wiaderek, 2007; Verver *et al*., 2004; Vlaović *et al*., 2008; Wang and Lakes, 2004; Webber *et al*., 2008; Wiaderek and Smardzewski, 2008, 2010a,b). Moreover, studies have also been conducted on the impact of aging on changes in: thermal conductivity coefficient (Brandreth and Ingersoll, 1980, Herge 1985; Wilkes *et al*., 2000, 2002; Mukhopadhyaya *et al*., 2004), diffusion coefficient (Ostrogorsky *et al*., 1986) or foam cell structure (Dementyev *et al*., 1999). What is missing is a more comprehensive discussion on the effect of aging on stiffness of furniture foams. Only few articles (Garber *et al*., 1982; Noble *et al*., 1984) deal with changes in foam hardness as a result of aging.

The aim of this study was to determine the impact of natural aging on the stiffness of polyurethane foams in dwelling conditions and, additionally, to elaborate the regression equation describing this dependence.

2 METHODS AND MATERIALS
2. METODE I MATERIJALI

Seven types of polyurethane foams commonly used in furniture design were selected for the presented investigations. The experimental foams differed from one another in their density and stiffness. Major technical properties of these foams provided by the Polish manufacturer are given in Table 1. In the designation of foam types, the first two digits give information about the mean apparent density of a foam expressed in kg/m^3 and the second two digits give information about foam mean stiffness expressed in 10^{-1} kPa at the deformation of ε=0.4. Ten cubical samples were prepared for each type of experimental foams with the side of H=100 mm obtained from different places of a commercial block measuring 1.2 x 1.2 x 2 m, as shown in Figure 1

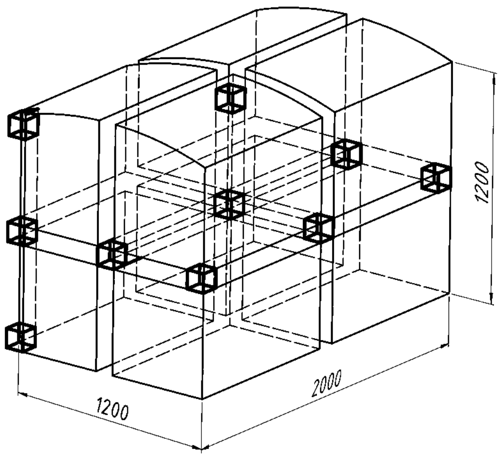

Figure 1 Commercial block of foam and places of sample collection (cm)
Slika 1. Komercijalni blok pjene s označenim mjestima uzimanja uzoraka (cm)

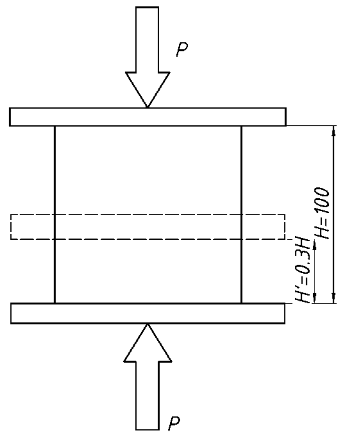

Figure 2 Diagram of uniaxial sample compression
Slika 2. Dijagram jednoosnoga kompresijskog testa

Table 1 Technical properties of selected foams (according to manufacturer's data)
Tablica 1. Tehnička obilježja odabranih pjena (prema podacima proizvođača)

Foam type *Vrsta pjene*	**Apparent density** *Prividna gustoća* PN-EN ISO 845:2000 kg/m^3	**Stiffness at ε=0.4** *Krutost pri ε=0,4* PN-EN ISO 3386-1:2000 kPa	**Resilience (min.)** *Elastičnost (min.)* PN-EN ISO 8307:2008 %	**Water content (max)** *Sadržaj vode (maks.)* %
T1823	15.5 - 18.5	1.8 - 2.5	40	1
T1830	15.5 - 18.5	2.8 - 3.5	40	1
T2315	20.5 - 23.5	1.3 - 2.0	40	1
T2538	22.5 - 25.5	3.3 - 4.3	40	1
T3037	27.5 - 30.5	3.3 - 4.3	45	1
T3538	32.5 - 35.5	3.3 - 4.3	45	1
T3546	32.5 - 35.5	4.0 - 5.0	50	1

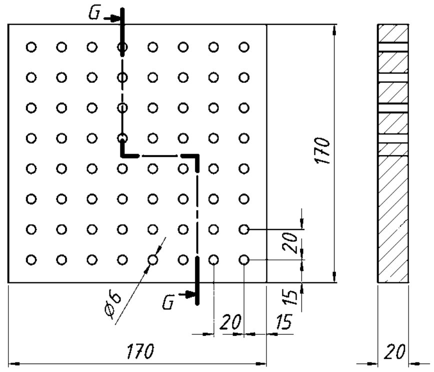

Figure 3 Pressing plates used in uniaxial compression test (mm)
Slika 3. Pritisne ploče koje se primjenjuju pri jednoosnom kompresijskom testu (mm)

As mentioned in the Introduction, in furniture design practice, stiffness is the most important criterion for selecting the foams. In accordance with the PN-EN ISO 3386-1:2000 standard, this stiffness is determined during the uniaxial compression test (Fig. 2) applying pressure beams in the form of drilled plates (Fig. 3). Individual experimental foams were compressed on a ZWICK 1445 testing machine recording force P with 0.01 N accuracy and dH displacements with 0.02 mm accuracy. The loading was terminated once the compressed sampled achieved the height of *H'* = 0.3 H. The course of compression was illustrated in the form of the σ=f(ε) dependence assuming that: $\sigma=P/H^2$, ε=d*H*/*H* and d*H*=*H*-*H'*. The stiffness of individual foams was determined on the basis of the σ=f(ε) dependence as the value of strain in kPa at the deformation of ε=0.4. Following the first stiffness evaluation of samples conducted on the 20th of August 2009, they were exposed to climatic conditions natural for dwelling facilities. Stiffness tests of experimental foams were carried out at quarterly and annual intervals, namely: after 123 days (2009. 12. 20), 244 days (2010. 04. 20), 366 days (2010. 08. 20) and 730 days (2011.08.20). Throughout this period, the values of relative humidity and air temperatures were recorded. The above parameters were recorded with the assistance of a Datalogger AZ 8829 Bacto Laboratories Pty Ltd taking measurements with up to 0.1 °C and 0.1 % accuracy. The results of measurements were collected and presented on a single diagram indicating days on which investigations of the selected foams were carried out. The significance of the impact of aging on foam stiffness was evaluated by the *t*-test for dependent samples using the Statistica 9.1 StatSoft. Inc. statistical package.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Figure 4 presents the changes in relative humidity and air temperature during the period of 730 days. On the day of the first measurement (Aug. 20, 2009), the recorded air temperature reached 27.9 °C, and relative air humidity – 37.1 %. During autumn (until Dec. 12, 2009), air temperature dropped from 27.9 °C to 17.0 °C, while air humidity ranged between 55.5 % and 15.9 %. During winter, i.e. until April 20, 2010, as a result of the operation of the central heating system, air temperature ranged between 17.0 °C and 23.0 °C, while air humidity increased from 9.3 % to 28 %. During summer, i.e. until Aug. 20, 2010, the temperature increased significantly and ranged between 22.7 and 33.8 °C and air humidity increased from 32.5 % to 57.8 %. In the following year, until Aug. 20, 2001, the measured values were slightly different, but their trends were similar to the trends in humidity and temperature changes from the previous year. Changes in the stiffness of the selected foams were observed against this background. On the first day of investigation, a σ=f(ε) dependence was determined for each experimental foam as shown in Figure 5.

As evident from Figure 5, the dependence of strain on deformation for all the tested types of foam is of non-linear nature. During the initial stage of com-

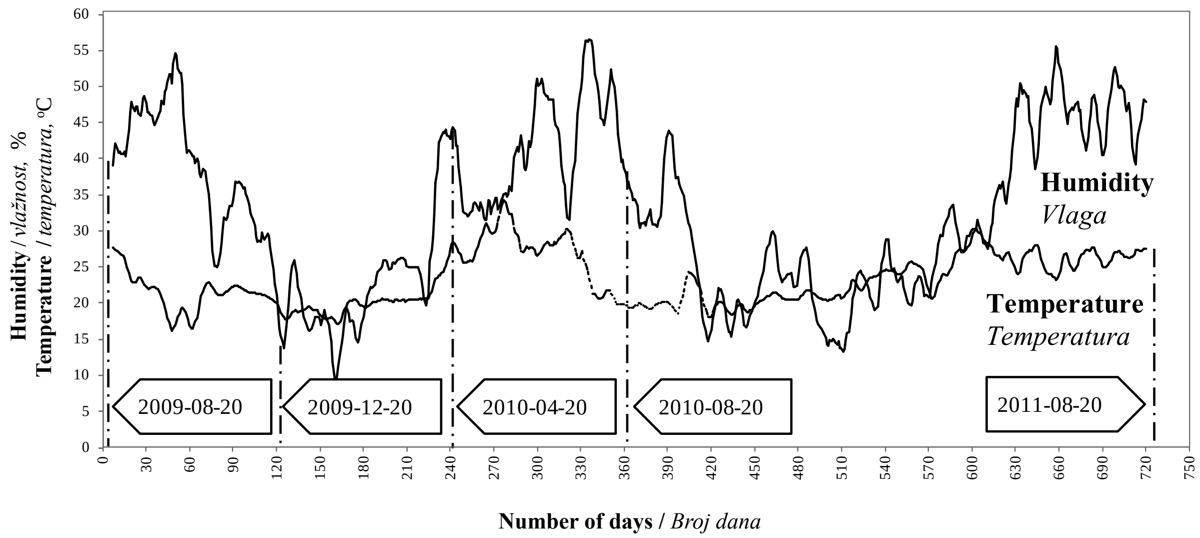

Figure 4 Changes in runs of temperature and relative air humidity in the laboratory facility
Slika 4. Promjene temperature i relativne važnosti zraka u laboratoriju

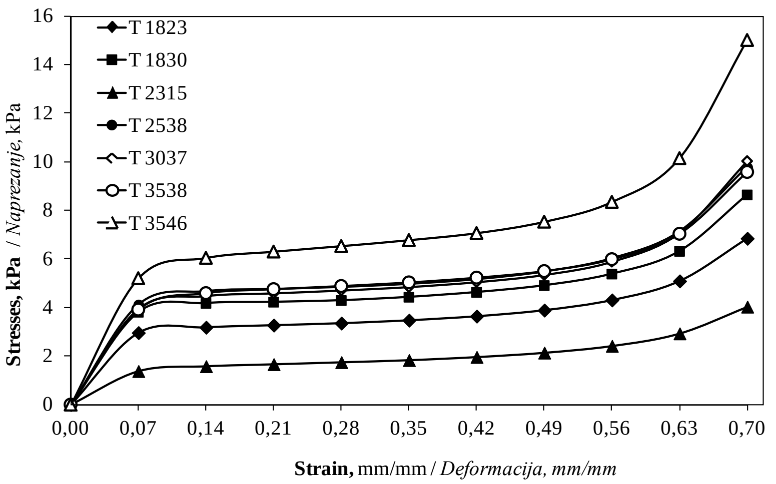

Figure 5 Dependence of strain on deformation for the tested types of foam
Slika 5. Ovisnost naprezanja o deformaciji za ispitivane vrste pjena

pression, for $0<\varepsilon\leq0.07$, foam stiffness increased distinctly because the polyurethane skeleton transferred all the external loads. Within the range of deformations from $0.07<\varepsilon\leq0.63$, cell walls lost their stability and allowed large displacements under the influence of even small loads. Another increase of foam stiffness occurred for $\varepsilon>0.63$, i.e. after the concentration of the matter and crushing of cell walls. Furthermore, this drawing clearly shows that foam stiffness did not always depend on its density. For further analyses, Figure 6 collates foam stiffnesses determined at deformations of $\varepsilon=0.4$ at five consecutive measuring periods. It can be clearly seen that in the observed periods, individual foams differed considerably among themselves with respect to their stiffness. It is worth stressing that foam stiffnesses established on the first day of testing exceeded considerably maximum values given by the manufacturers in the product card. These differences are collated in Table 2. It is evident that stiffness of the manufactured foams exceeded by 110 to 217 % catalogue values provided by manufacturers. Simultaneously, it can also be noted from Table 2 that small values of standard deviations (0.08 to 1.00 kPa) as well as of coefficients of variability (1.31-13.78 %) confirmed high uniformity of each group. Therefore, the applied number of samples, 10 for each type of foam, was adequate to obtain reliable research results. Figure 6 also illustrates that quality relationship between foam stiffnesses was maintained stable during the period of aging of 730 days. However, the process of foam natural aging caused stiffness depreciation meaning that stiffness of some of the tested foams was reduced to values comparable to the initial stiffness of other foams. This occurred in the case of T2538 and T3538 foams, which reached stiffness comparable or lower to the stiffness of the T1830 foam determined on the first day of testing after 366 and 730 days of aging.

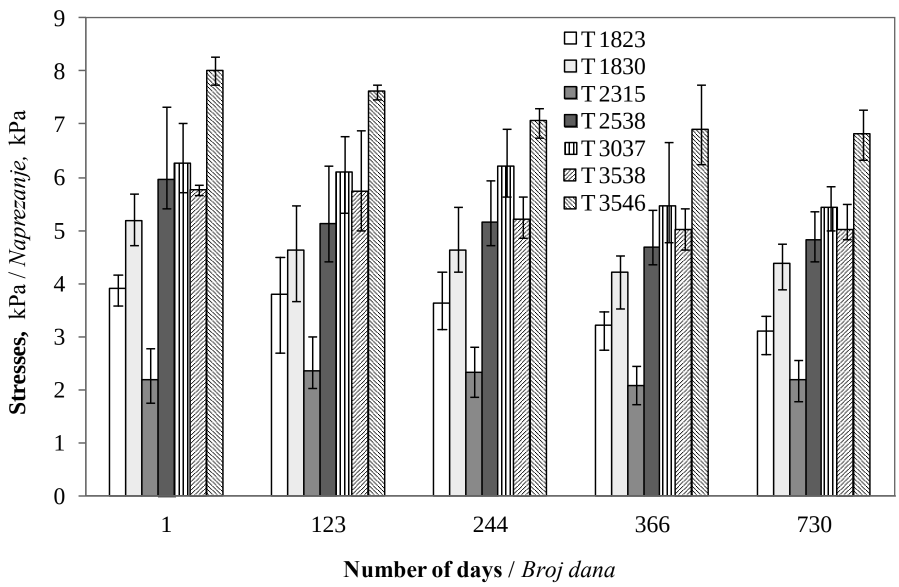

Figure 6 Stiffness of foams in individual periods of observation
Slika 6. Krutost pjena u pojedinim razdobljima promatranja

Table 2 Foam stiffness at ε=0.4 according to data provided by the manufacturer and obtained in the course of experimental studies
Tablica 2. Krutosti pjena pri ε=0,4 prema podacima proizvođača i podacima dobivenim u ovom istraživanju

Foam type *Vrsta pjene*	**Stiffness at ε=0.4, kPa** / *Krutost pri ε=0.4, kPa*				**Stiffness, kPa** *Krutost, kPa*
	Manufacturer's data *Podaci proizvođača*	**Investigations results**/ *Rezultati istraživanja*			
		Mean *Srednja vrijednost*	Standard deviation, kPa *Standardna devijacija, kPa*	Coefficient of variability, % *Koeficijent varijabilnosti, %*	F=C-A
A	B	C	D	E	
T1823	1.8 - 2.5	3.90	0.18	4.57	1.40 - 2.10
T1830	2.8 - 3.5	5.19	0.37	7.11	1.69 - 2.39
T2315	1.3 - 2.0	2.19	0.30	13.78	0.18 - 0.89
T2538	3.3 - 4.3	5.97	0.58	9.75	1.67 - 2.67
T3037	3.3 - 4.3	6.27	0.54	8.59	1.97 - 2.97
T3538	3.3 - 4.3	5.76	0.08	1.31	1.46 - 2.46
T3546	4.0 - 5.0	8.05	1.00	12.48	3.05 - 4.05

Table 3 Results of the *t*-test for dependent samples indicating lack of significance of differences between foam stiffnesses (an example for the T1823 foam)
Tablica 3. Rezultati *t*-testa za zavisne uzorke koji pokazuju nesignifikanost razlika među krutostima pjena (primjer za pjenu T1823)

Type of foam *Vrsta pjene*	Number of days *Broj dana*	***t*-test for dependent samples** / *t-test za zavisne uzorke* **Marked differences are not significant at *p* <0.05** / *Označene razlike nisu značajne pri p <0,05*							
		Average *Prosjek* kPa	Std. *St. dev.* kPa	Difference *Razlika* kPa	Std. Difference *St. dev. razlike* kPa	*t*	*p*	Confidence *Pouzdanost* -95 %	Confidence *Pouzdanost* +95 %
T1823	1	3.90	0.18						
	123	3.80	0.57	0.10	0.61	0.51	0.624	-0.363	0.569
T2315	1	2.20	0.30						
	123	2.35	0.34	-0.15	0.39	-1.19	0.268	-0.454	0.145
	1	2.20	0.30						
	244	2.33	0.35	-0.13	0.46	-0.87	0.407	-0.488	0.220
	1	2.20	0.30						
	366	2.08	0.24	0.12	0.35	1.01	0.341	-0.150	0.385
	1	2.20	0.30						
	730	2.19	0.26	0.01	0.24	0.12	0.904	-0.172	0.192
T3037	1	6.27	0.54						
	123	6.09	0.59	0.18	0.73	0.54	0.617	-0.733	1.088
	1	6.27	0.54						
	244	6.22	0.53	0.05	0.53	0.21	0.840	-0.611	0.713
T3538	1	5.76	0.08						
	123	5.75	0.94	0.01	0.99	0.02	0.986	-1.216	1.232
T3546	1	8.00	0.28						
	366	6.91	0.77	1.09	0.61	3.11	0.090	-0.420	2.607
	1	8.00	0.28						
	730	7.26	0.59	0.74	0.51	2.55	0.126	-0.512	2.000

Table 3 presents the results of the t Test (p<0.05) for dependent samples indicating high probability of the lack of significance of differences between stiffnesses of some foams subjected to aging. It is evident that only the T2315 foam turned out to be completely insensitive to a change in its stiffness as shown by the result of aging. The stiffness of T 1823 and T3538 foams did not change during the first 123 days (4 months) of aging, the T3037 foam exhibited resistance to aging during the first 244 days (8 months) of this process, whereas the T3546 foam returned to its original stiffness after 366 and, then, after 730 days of aging. For the remaining foams, there is high probability of a significant impact of aging on their stiffness. This impact is shown in Figure 7-9.

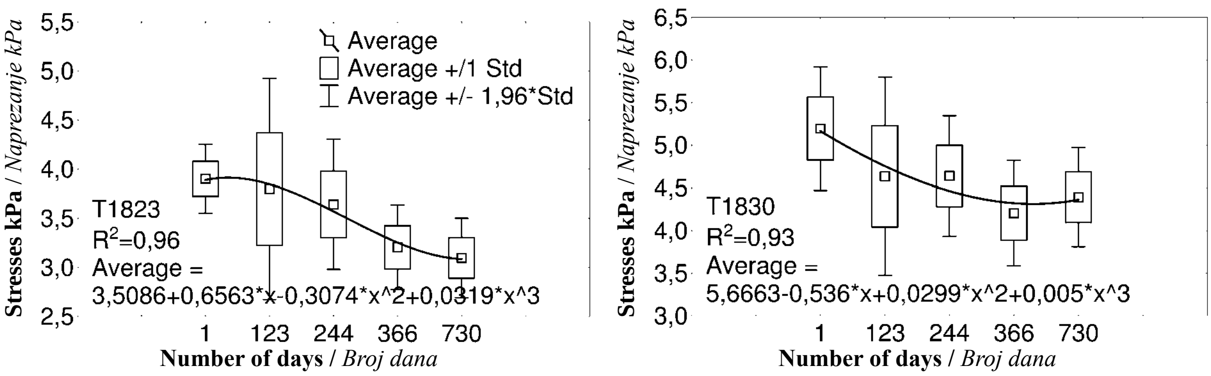

Figure 7 Impact of aging on stiffness of foams of 18 kg/m^3 density
Slika 7. Utjecaj starenja na krutosti pjena gustoće 18 kg/m^3

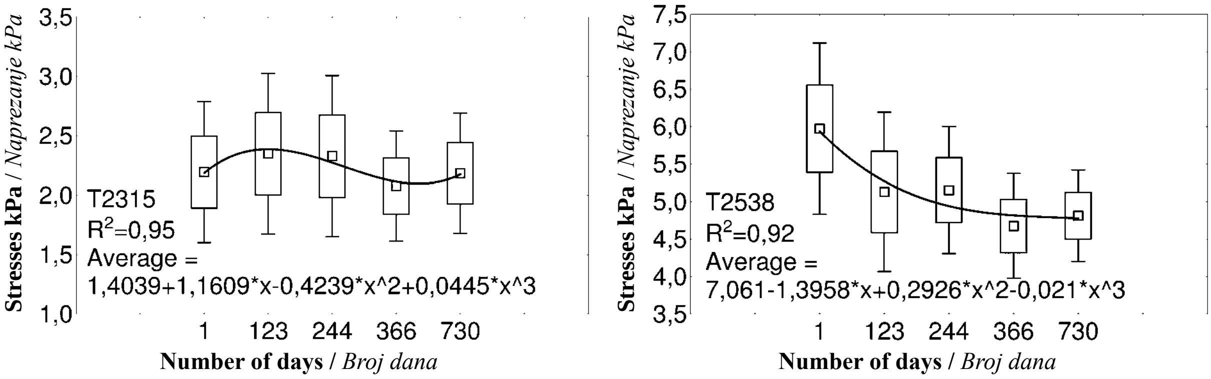

Figure 8 Impact of aging on stiffness of foams of 23 and 25 kg/m^3 density
Slika 8. Utjecaj starenja na krutosti pjena gustoće 23 i 25 kg/m^3

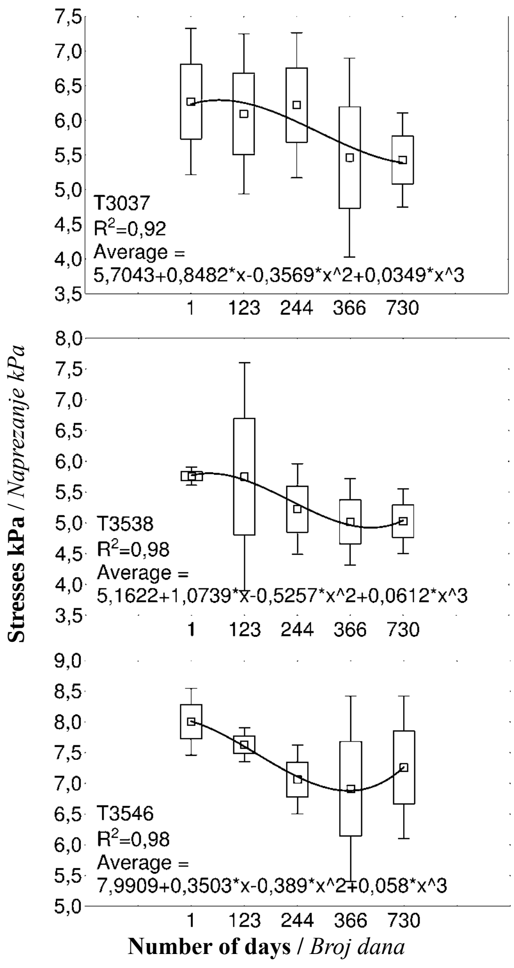

Figure 9 Impact of aging on stiffness of foams of 30 and 35 kg/m^3 density
Slika 9. Utjecaj starenja na krutosti pjena gustoće 30 i 35 kg/m^3

Figure 7 presents the influence of aging on the stiffness of foams of 18 kg/m^3 density. As shown in Table 3, the T1823 foam was not sensitive to aging only during the first 123 days. After 730 days, the stiffness of this foam decreased with respect to the initial value by 26 %. The T1823 foam distinctly reduced its stiffness during the entire period of aging. The greatest decline of stiffness (23 %) occurred after 366 days of aging. After another year passed (730 days in total), foam stiffness increased slightly (by 4.5 %) and this difference was statistically significant.

The influence of aging on changes in the foam stiffness of 23 and 25 kg/m^3 apparent density is shown in Figure 8. This Figure corroborates information from Table 3 that the T2315 foam did not undergo statistically significant changes in its stiffness as a result of aging. On the other hand, the T2538 foam of only slightly higher density lost stiffness as a result of aging. After 366 days, the loss of stiffness in relation to the initial value amounted to 27 %. After the following 364 days of aging, the stiffness of this foam increased by 2.9 %, and however at $p<0.05$, this difference was not statistically significant.

In the case of the foam characterized by 30 kg/m^3 apparent density, statistically significant differences in their stiffness only took place after 366 days of aging and more (Fig. 9). This drop amounted to 14 % in relation to the initial stiffness. Continued aging lasting up to 730 days did not cause further changes in the foam stiffness, which remained at the same level of 5.4 kPa. A similar tendency was observed in the case of the

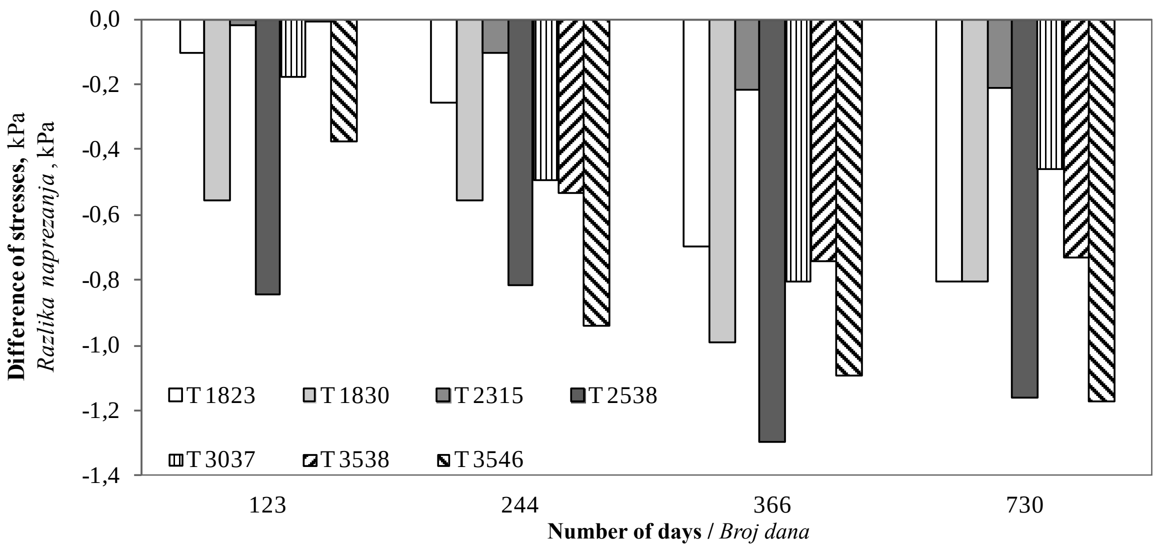

Figure 10 Differences in foam stiffness in individual periods of observation
Slika 10. Razlike u krutosti pjena za pojedina razdoblja promatranja

T3538 foam. Its stiffness decreased by 14% after 366 days of aging and remained at a constant level of 5 kPa for the consecutive 364 days. The T3546 foam turned out to be the most sensitive to aging and, after each period of aging, as well as quantitative and qualitative changes in its stiffness, changes were statistically significant at $p<0.05$. The greatest drop of stiffness of this foam amounting to 16 % occurred after 366 days of aging. After the second successive year of aging, the stiffness of this foam increased slightly so that the difference between the initial stiffness and the stiffness after 730 days of aging amounted to 10 %.

Quantitative differences in foam stiffnesses in relation to their initial stiffness are presented in Figure 10. It is evident that the greatest differences took place after 366 and 730 days of aging. In the case of foams characterized by apparent density of 18 kg/m^3, similar differences in stiffness occurred after 730 days of aging. On the other hand, in the case of foams of 35 kg/m^3 apparent density, changing differences of stiffness occurred during the entire period of aging indicating high sensitivity of this material to aging.

Contemporary offices involved in designing of daily necessities commonly apply computer engineering techniques (for example CAD or CAE), which constitute an element of rapid prototyping techniques. For simulation purposes of the impact of aging of foam materials on the functional properties of upholstered furniture, it is necessary to gain knowledge about stiffness of these materials as well as its variability under the influence of aging in dwelling conditions. The regression equations presented in Figure 7, 8 and 9, providing the correlation between foam stiffness and the number of days of the aging period, will make it possible to estimate future stiffness of foams used in dwelling facilities if climatic conditions are similar to those occurring in the described investigations.

4 CONCLUSIONS
4. ZAKLJUČAK

On the basis of the analysis of the obtained research results, the following conclusions can be drawn:

1. Aging of foams exerts a significant impact on decreasing their stiffness and, consequently, on their functional value.
2. The most significant drops of foam stiffness were observed after one year of aging. Depending on the type of foams, these drops reached values ranging from 14 % to 27 %.
3. In the second year of aging of foams, their stiffness usually remained at the same level or increased slightly in relation to the stiffness observed after one year of aging.
4. The T2315 foam turned out to be completely insensitive to aging. In such circumstances, its small density and low stiffness are favorable for use in upholstered furniture.
5. Bearing in mind the highest (27 %) decline of stiffness of the T2538 foam, it should be applied with care for sitting and lying furniture.

5 REFERENCES
5. LITERATURA

1. Alderson, A.; Alderson, K., 2007: Auxetic materials. Proc. IME G.J. Aero. Eng., 221: 565-575.
2. Bezazi, A.; Scarpa, F., 2007: Mechanical behavior of conventional and negative Poisson's ratio thermoplastic polyurethane foams under compressive cyclic loading. Int. J. Fatigue, 29: 922-930.
3. Bezazi, A.; Scarpa, F., 2009: Tensile fatigue of conventional and negative Poisson's ratio open cell PU foams. Int. J. Fatigue, 31: 488-494.
4. Brandel, B.; Lakes, R. S., 2001: Negative Poisson's ratio polyethylene foams. J. Mater. Sci., 36: 5885-5893.
5. Brandreth, D. A.; Ingersoll, H. G., 1980: Accelerated aging of rigid polyurethane foam. Journal of Cellular Plastics, 16(4): 235-238.

6. Choi, J. B.; Lakes, R. S., 1992: Nonlinear properties of polymer cellular materials with a negative Poisson's ratio. J. Mater. Sci., 27: 4678-4684.
7. Chow, W. W.; Odell, E. I., 1994: Deformations and stress in soft body tissues of sitting person. J. Biomech Eng., 100: 79-87.
8. Chu, S. J., 2000: Finite element analysis of contact stresses between a seat cushion and a human body. Science and Technology, 2000. KORUS 2000. Proceedings. The 4th Korea-Russia International Symposium, 3: 11-16.
9. Dementyev, A. G.; Dementyev, M. A.; Zinger, P. A.; Metlyakova, I. R., 1999: Effect of the cellular structure on thermal conductivity of rigid closed-cell foam polymers during long-term aging. Mechanics of Composite Materials, 35(2): 129-138.
10. Ebe, K.; Griffin, M. J., 2001: Factors effecting static and seat cushion comfort. Ergonomics, 41(10): 901-921.
11. Ferrarin, M.; Andreoni, G.; Pedotti, A., 2000: Comparative biomechanical evaluation of different wheelchair seat cushions. Journal of Rehabilitation Research and Development, 37(3): 315-324.
12. Garber, S. L.; Krouskop, T. A.; Noble, P. C., 1982: The Effectiveness of Preventive Management in Reducing the Occurrence of Pressure Sores. Proc. 5th Ann. Conf. Rehabilitation Engineering, pp. 85.
13. Gonga, L.; Kyriakidesa, S.; Triantafyllidisb, N., 2005: On the stability of Kelvin cell foams under compressive loads. Journal of the Mechanics and Physics of solids, 53: 771-794.
14. Grujicic, M.; Pandurangan, B.; Arakere, G.; Bell, W. C.; He, T.; Xie, X., 2009: Seat-cushion and soft-tissue material modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants. Materials and Design, 30: 4273-4285.
15. Herge, J. R., 1985: Ageing og foamed polyurethane. Batiment International, Building Research and Practice, 13(6): 344-346.
16. Lakes, R. S., 1987: Foam Structures with a Negative Poisson's Ratio. Science, 235: 1038-1040.
17. Lakes, R. S., 1992: Experimental Micromechanics Method for Conventional and Negative Poisson's Ratio Cellular Solids as Cosserat Continua. J.Eng. Mat. & Techn., 113: 148-155.
18. Linder-Ganz, E.; Yarnitzky, G.; Portnoy, S.; Yizhar, Z.; Gefen, A., 2005: Real-time finite element monitoring of internal. Stress in the bittlok during whellchasir sitting to prevent sores: verification and phantom results. II International Conference on Computational Bioengineering. Lisbon, Portugal, September 14-16.
19. Lusiak, A.; Smardzewski, J., 2010: Creative thinking in designing furniture for pre-school children. Annals of Warsaw University of Life Sciences SGGW, Forestry and Wood Technology, 70: 270-278.
20. Mukhopadhyaya, P.; Bomberg, M. T.; Kumaran, M. K.; Drouin, M.; Lackey, J.; Reenen, D.; Normandin, N., 2004: Long-term thermal resistance of polyisocyanurate foam insulation with gas barrier. IX International Conference on Performance of Exterior Envelopes of Whole Buildings, Clearwater Beach, Florida, Dec. 5-10, 2004, pp. 1-10.
21. Noble, P. C.; Goode, B.; Krouskop, T. A.; Crisp, B., 1984: The influence of environmental aging upon the loadbearing properties of polyurethane foams. Journal of Rehabilitation Research and Development, 21(2): 31-38.
22. Ostrogorsky, A. G.; Glicksman L. R.; Reitz, D. W., 1986: Aging of polyurethane foams. International Journal of Heat and Mass Transfer, 29(8): 1169-1176.
23. Petre, M. T.; Erdemir, A.; Cavanagh, P. R., 2006: Determination of elastomeric foam parameters for simulations of complex loading. Computer Methods in Biomechanics and Biomedical Engineering, 9(4): 231-242.
24. Scarpa, F.; Bullough, W. A.; Lumley, P., 2004: Trends in acoustic properties of iron particle seeded auxetic polyurethane foam. Proc IME CJ Mech. Eng. Sci., 218: 241-244.
25. Schrodt, M.; Benderoth, G.; Kuhhorn, A.; Silber, G., 2005: Hyperelastic Description of Polymer Soft Foams at Finite Deformations. Technische Mechanik, 25(3-4): 162-173.
26. Seigler, M.; Ahmadian, M., 2003: Evaluation of an alternative seating technology for truck seats. Heavy Vehicle Systems. A Series of the Int. J. of Vehicle Design, 10(3): 188-208.
27. Silber, G.; Alizadeh, M.; Salimi, M., 2010: Large deformation analysis for soft foams based on hyperelasticity. Journal of Mechanics, 26(3): 327-334.
28. Smardzewski, J., 2009: Antropotechnical aspects of furniture design. Drvna industrija, 60(1): 15-21.
29. Smardzewski, J.; Barańska-Woźny, J.; Wiaderek, K.; Prekrat, S.; Grbac, I., 2010a: Mechanical and biomechanical criteria in furniture designing for 60+ users. Proceedings of the international conference, Wood is good – transfer of knowledge in practice as a way out of the crisis. Ambienta, Zagreb, Croatia, 113-122.
30. Smardzewski, J.; Grbac, I., 1998: Numerical analysis of ergonomic function of upholstered furniture. Proceedings of the international conference. Ambienta, Zagreb, Croatia, 61-68.
31. Smardzewski, J.; Grbac, I.; Prekrat, S., 2008: Nonlinear mechanics of hyper elastic polyurethane furniture foams. Drvna industrija, 59(1): 23-28.
32. Smardzewski, J.; Matwiej, Ł., 2007: Analysis of the man-bed mechanical system. Proceedings of the international conference, Calunnicke Dni, Teoria a prax. Zvolen Slovakia, 42-49.
33. Smardzewski, J.; Prekrat, S.; Pervan, S., 2010b: Research of contact stresses between seat cushion and human body. Drvna industrija, 61(2): 95-101.
34. Smardzewski, J.; Wiaderek, K.; Grbac, I., 2006: Numerical analysis of contact problems of human body and elastic mattress. Proceedings of the international conference, European Union – Challenges and perspectives for the wood-processing industry. Ambienta, Zagreb, Croatia, 81-86.
35. Smardzewski, J.; Wiaderek, K., 2007: The analysis of the human body-seat mechanical system. Proceedings of the international conference, Calunnicke Dni, Teoria a prax. Zvolen, Slovakia, 50-55.
36. Verver, M. M.; Hoof, J. V.; Oomens, C. W. J.; Wismans, J. S. H. M.; Baaijens, F. P. T., 2004: A Finite Element Model of the Human Buttocks for Prediction of Seat Pressure Distributions, Computer Methods in Biomechanics and Biomedical Engineering, 7(4): 193-203.
37. Vlaović, Z.; Bogner, A.; Grbac, I., 2008: Comfort evaluation as the example of anthropotechnical furniture design. Coll. Antropol., 32 (1): 277-283.
38. Wang, Y. C.; Lakes, R. S., 2002: Analytical parametric analysis of the contact problem of human buttocks and negative Poisson's ratio foam cushions. International Journal of Solids and Structures, 39: 4825-4838.

39. Webber, R. S.; Alderson, K.; Evans, K. E., 2008: A novel fabrication route for auxetic polyethylene, part 2: Mechanical properties. Polym. Eng.Sci., 48: 1351-1358.
40. Wiaderek, K.; Smardzewski, J., 2008: Analysis of the contact problem of human thighs and elastic seat cushion. Annals of Warsaw University of Life Sciences SGGW, Forest and Wood Technology, 66, 184-188.
41. Wiaderek, K.; Smardzewski, J., 2010a: Numerical evaluation of seat hardness, Annals of Warsaw University of Life Sciences SGGW, Forestry and Wood Technology, 70: 305-311.
42. Wiaderek, K.; Smardzewski, J., 2010b: Modeling of foam seats in terms of comfortable relaxation furniture design. Proceedings of the international conference, Wood is good - transfer of knowledge in practice as a way out of the crisis. Ambienta, Zagreb, Croatia, 139-146.
43. Wilkes, K. E.; Yarbrough, D. W.; Gabbard, W. A.; Nelson, G. E.; Booth, J. R., 2002: Aging of polyurethane foam insulation in simulated refrigerator panels-three-year results with thrid-generation blowing agents. Journal of Cellular Plastics, 38(4): 317-339.
44. Wilkes, K. E.; Gabbard, W. A.; Weave, F. J.; Boot, J. R., 2000: Aging of polyurethane foam insulation in simulated refrigerator panels - two -year results with third-generation blowing agents. Oak Ridge National Laborator. Polyurethanes Conference 2000 Boston, MA: pp. 16.
45. PN-EN ISO 845:2000: Gumy i tworzywa sztuczne porowate - Oznaczanie gęstości pozornej (objętościowej)
46. PN-EN ISO 3386-1:2000: Elastyczne tworzywa sztuczne porowate - Oznaczanie charakterystyki naprężenie-odkształcenie przy ściskaniu - Materiały małej gęstości
47. PN-EN ISO 8307:2008: Elastyczne tworzywa sztuczne porowate - Oznaczanie sprężystości przy odbiciu

Corresponding address:

Professor JERZY SMARDZEWSKI, Ph. D.

Poznan University of Life Sciences
Faculty of Wood Technology
Department of Furniture Design
ul. Wojska Polskiego 28
Poznan 60-637, POLAND
e-mail: jsmardzewski@up.poznan.pl