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Flexible polyurethane-based foam material

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Abstract

The development of polyurethane-based foams, which can be modified to obtain a wide range of properties for many specific applications, is discussed in the article. Silicone, known for its elasticity and stability, is used as a modifier. The optimal composition was characterised by a uniform porous structure, reduced surface crust formation and significantly better shape recovery properties (up to 100%) compared to unmodified PU foam (10%). IR spectroscopy confirmed the interaction of silicone with the polyurethane matrix. Experimental results showed that the modified foam has increased elasticity and is able to return to its original shape after compression. Due to its low weight, flexibility and ability to absorb shocks, the resulting material is suitable for use in medical devices. In addition, the addition of silicone increases the durability of the material by reducing the degradation of the surface layer under the influence of light. The results obtained indicate the promise of using modified PU foam with a memory effect in biomedical applications.

Keywords: foam material, polyurethane, silicone, elasticity, porous structure.

Introduction

The use of materials that respond to external physical influences expands the functional capabilities of medical devices and implants (Ates et al., 2022). Foam with a negative Poisson's ratio has better mechanical properties than traditional materials – it is lightweight, shear-resistant, auxetic – and promising for the aerospace and biomedical fields. In polymer foams, the shape memory effect is achieved through increased elasticity. The aim of the study is to create such foam materials and determine their applicability in various types of prosthetic elements.

By changing the composition of raw materials (isocyanates, polyols, catalysts, surfactants, etc.), it is possible to obtain both rigid and flexible foam with the desired properties (Ates et al., 2022; Gama et al., 2018). The formation of the PPU structure takes place in four stages: nucleation, cell growth and division, and polymerisation (Zhang et al., 2020). The foaming process and foam quality are influenced by temperature, component proportions, curing time, etc. (Dong et al., 2018; Wang et al., 2022).

Flexible open-cell PUF is used in furniture, while rigid closed-cell PUF is used for thermal insulation (Uram et al., 2021). Isocyanates (most often MDI and TDI) form rigid polymer segments, while polyols form soft ones. The more isocyanate there is, the harder the material. The functionality of the polyol also affects the characteristics of the foam (Gama et al., 2018). Silicone surfactants are used to stabilise the foam. They affect the formation and stability of pores, as well as the mechanical, thermal and acoustic properties of the material (Baferani et al., 2018; Mantha et al., 2021).

The following components were used: polyisocyanate (A) – a liquid with a density of 1.25 g/cm^3 and a viscosity of 300 mPa·s [at 20 °C], polyol (B) – a low-toxic mixture with a density of 1.09 g/cm^3 and a viscosity of 1300 mPa·s, and siloxane rubber (C) – an elastic, bioinert material, stable in the temperature range from -40 to +100 °C.

Test samples for experimental studies were obtained using the method (Hulai et al., 2024; Mikulich et al., 2024) by mechanical mixing of the ingredients. The samples were obtained without spatial restrictions at room temperature. The foaming process began 5-10 minutes after mechanical mixing of the components. The volume of the mixture increased 5-10 times depending on the ratio of the components (maximum at minimum silicone content). The hardening period was 24 hours

The ratio between polyurethane, foaming agent and silicone was established experimentally, and 6 of the 25 compositions obtained were selected for further research (Table 1). With an increase in the silicone content, the colour of the material changed from dark yellow to light yellow.

Table 1. Composition and selected physical properties of the obtained composites

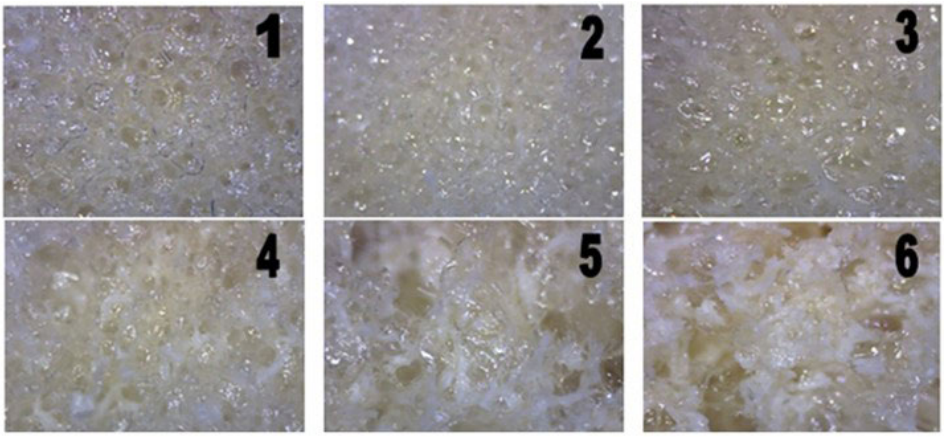
№ Sample	Contents, weight percentages			Density ρ, kg/m^3	Porosity P, %
	Component A	Component B	Silicone		
1	2	1	0	69.9	46.0
2	4	2	1	71.8	37.0
3	4	2	1.2	75.9	44.0
4	4	2	2	97.9	51.5
5	4	2	2.5	105.4	56.5
6	4	2	3	180.7	31.0

Fig. 1 shows the microstructure of modified polyurethane foam at 30x magnification. The sample numbers correspond to the data in Table 1. In samples with a low silicone content (№. 2-4), the structure consists mainly of uniformly closed pores. As the amount of silicone increases, the cell walls thicken and a greater number of open pores appear.

It has also been established that the addition of silicone reduces the effect of the formation of a hard surface 'crust' characteristic of PU foam that

hardens in air. In samples 4 and 5, this crust was thinner and softer. This effect contributes to a longer service life of the material, since without modification, PU foam yellows and loses its strength under the influence of light.

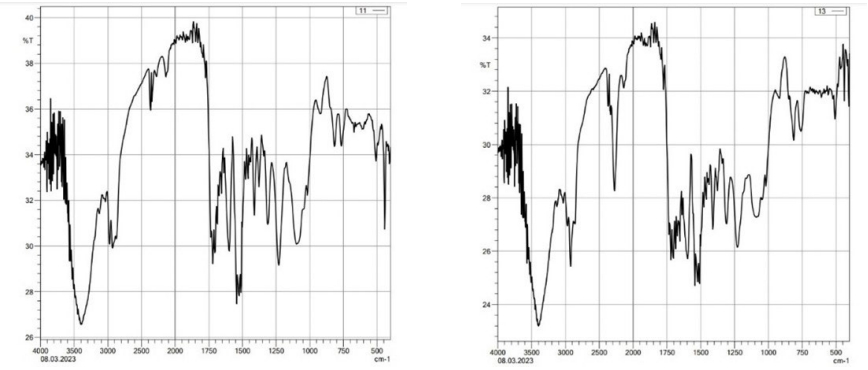
Fig. 1. Cross-sections of the microstructure of modified polyurethane foam obtained at 30x magnification



The structural parameters were studied by infrared spectroscopy (Fig. 2) using an IRAffinity-1S IR spectrophotometer. The presence of characteristic absorption bands of functional groups formed as a result of the interaction of components was established. Both spectra show bands of valence vibrations of the urethane group C=O with a maximum of 1730 cm^{-1} (more pronounced in sample 1). The formation of hydrogen bonds in the system is evidenced by intense absorption bands in the range of 3000–3500 cm^{-1}.

The IR spectrum of sample 4 shows additional absorption bands in the 2100–2200 cm^{-1} region, corresponding to Si–H bond vibrations characteristic of silicone components.

Fig. 2. IR spectra: a – sample 1; b – sample 4



Compressed samples of rigid (1) and flexible (4) foam materials are shown in Figure 3.

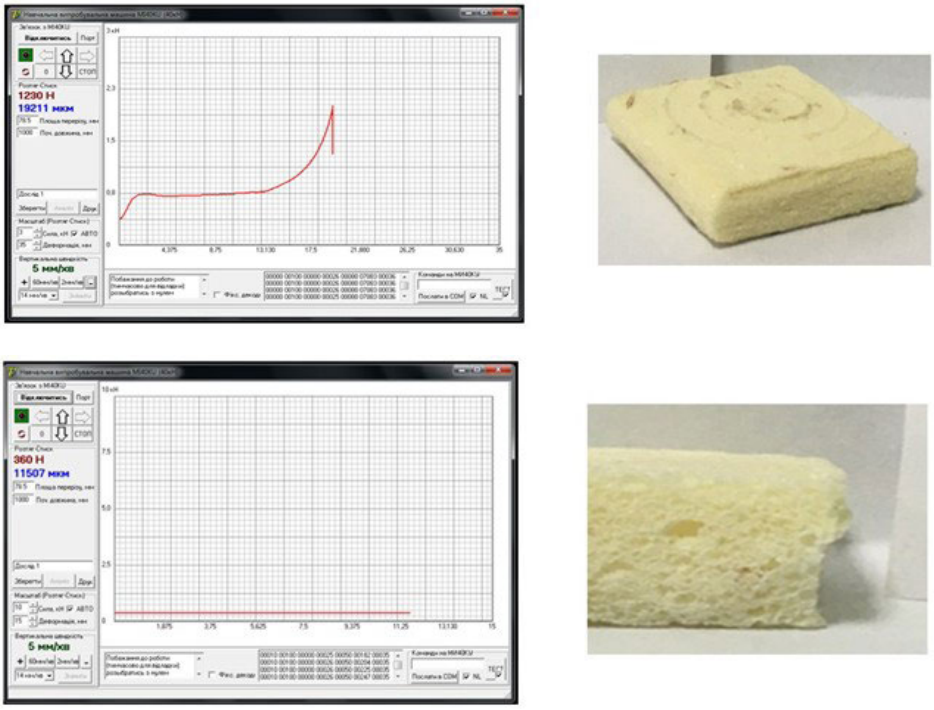


Fig. 3. Compression diagrams and appearance of samples after deformation (5 minutes after load removal): a – sample 1; b – sample 4

In sample 4, which had the optimal composition, only elastic changes were observed during deformation – the diagram was linear. After the load was removed, the sample returned to its original shape by 100%. This is important for prosthetic elements that imitate skin, as the material can withstand deformation without damage. The shock-absorbing properties also protect the rigid parts of the prosthesis from impact.

Summary. The combination of polyurethane, which forms a rigid closed-cell foam, and silicone, which is flexible and elastic, made it possible to obtain a material with the desired properties. With a component ratio of 4:2:2, the foams obtained have closed cells and high plastic characteristics. With a further increase in the silicone content, an open-cell foam material with a more brittle structure is obtained. Analysis of the compression diagrams obtained confirms the increase in elastic deformations in foam materials in the presence of silicone. It has been experimentally established that the obtained material can be used to manufacture elements of various configurations. The

material does not degrade in air and returns to its original shape regardless of the direction of the compressive load.

References

Ates, M., Karadag, S., Eker, A.A., Eker, B. (2022). Polyurethane foam materials and their industrial applications. *Polymer International*, 71, 1157–1163. https://doi.org/10.1002/pi.6441

Baferani, A.H., Keshavarz, R., Asadi, M., Ohadi, A.R. (2018). Effects of silicone surfactant on the properties of open-cell flexible polyurethane foams. *Advanced Polymer Technology*, 37, 71–83. https://doi.org/10.1002/adv.21643

Dong, Q., Li, S., Zheng, X., Xie, Y., Lou, L., Zeng, Z., Liu, J. (2018). Effect of temperature on mechanical properties of polyurethane solidifying system. *China Plastics* (Zhongguo Suliao), 32(9).

Gama, N.V., Ferreira, A., Barros-Timmons, A. (2018). Polyurethane foams: Past, present, and future. *Materials*, 11(10), 1841. https://doi.org/10.3390/ma11101841

Hulai, O.I., Shemet, V.Ya., Mikulich, O.A., Furs, T.V., Mikulich, R.S. (2024). Method for obtaining foam material with shape memory. Patent №155847 (UA). Published 18.04.2024, Bulletin №16/2024. (in Ukrainian).

Mantha, S., Chao, H., Ylitalo, A., Fitzgibbons, T., Zhou, W., Ginzburg, V., Wang, Z.G. (2021). Effect of silicone surfactant on the CO_2 bubble nucleation in polyol. APS March Meeting Abstracts, R04–012. https://ui.adsabs.harvard.edu/abs/2021APS..MAR.R04012M/abstract

Mikulich, O., Hulay, O., Furs, T., Shemet, V. (2024). Strength and mechanical characteristics of modified polyurethane foams. *Procedia Structural Integrity*, 59, 460–465. https://doi.org/10.1016/j.prostr.2024.04.065

Uram, K., Prociak, A., Vevere, L., Pomilovskis, R., Cabulis, U., Kirpluks, M. (2021). Natural oil-based rigid polyurethane foam thermal insulation applicable at cryogenic temperatures. *Polymers*, 13(24), 4276. https://doi.org/10.3390/polym13244276

Wang, J., Zhang, C., Deng, Y., Zhang, P. (2022). A review of research on the effect of temperature on the properties of polyurethane foams. *Polymers*, 14(21), 4586. https://doi.org/10.3390/polym14214586

Zhang, C., Tong, X., Deng, C., Wen, H., Huang, D., Guo, Q., Liu, X. (2020). The foaming dynamic characteristics of polyurethane foam. *Journal of Cellular Plastics*, 56, 279–295. https://doi.org/10.1177/0021955X19864374