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# Strength and mechanical characteristics of modified polyurethane foams

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## Abstract

The article is devoted to studying the influence of the polymer modifier on the mechanical characteristics of polyurethane foams under typical technologies and conditions of foam production. As a modifying component, siloxane rubber additives with high elasticity were chosen. The microstructure of the obtained foams was analyzed and the process of deformation of the samples during compression was investigated. The results of experimental studies for different cases of partial ratios of foam components showed that the proportion of siloxane rubber additives significantly affects not only the mechanical and strength characteristics of foam materials but also their microstructure. An increase in the proportion of the modifier, along with an increase in strength and mechanical characteristics, leads to a decrease in the plastic characteristics of foams and an increase in the proportion of open pores in the material. The approaches described in the work can be used to produce structural elements from foam materials with predetermined characteristics.

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*Keywords:* polyurethane foam, strength, Young’s modulus, porosity.

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## 1. Introduction

Polyurethane foams are successfully used instead of metals or plastics in various engineering fields due to the combination of hardness and durability. The industrial application of polyurethane foams includes the production of

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building materials, sound and heat insulation materials for refrigerators and freezers, furniture, shoes, automotive materials, etc. (Ates et al., 2022). A wide range of properties for many specific applications is achieved by modifying the composition of the components of isocyanates, polyols, catalysts, surfactants, foaming agents and additives (Gama et al., 2018). Due to this, the different types of hard and flexible foams can be obtained.

#### Nomenclature

$\sigma_y$	Yield strength
$\rho$	Foam density
$p$	Porosity
$E$	Young's modulus

The investigation of the stage production of polyurethane foam allows us to study the influence of various factors on the formation of foam at each stage: pore formation, growth, separation and polymerization (Zhang et al., 2020). Environmental temperature, raw material ratio, mould temperature, material temperature and curing time are important factors affecting the foaming rate and quality of polyurethane products (Wang, 2022; Quanxiao et al., 2018). The main three characteristics of obtaining polyurethane foams are common to all types of the corresponding materials. Firstly, it is a rather high-speed foaming reaction, which is mostly completed in 2–4 min. Secondly, the large amount of heat released during the reaction causes the temperature to rise by 30–150 °C. Thirdly, a rapid increase in the volume of the reaction mixture by 10–50 times is appropriated for these materials.

The mechanical properties of polyurethane mainly depend on the structure of the pores, their size, type, wall thickness, anisotropy, etc. Changing the ratios of the constituent components used in foam formation allows obtaining different types of foam with different characteristics.

The nature and content of isocyanate significantly affect the stiffness of the foam. Methylene diphenyl diisocyanate (MDI) and toluene diisocyanate (TDI) are most often used. They make up about 90% of the total consumption of diisocyanate (Guide, 2003). Isocyanate reacts with polyol to form urethane groups and with water to form urea and CO<sub>2</sub> groups. Urethane and urea fragments form hard segments of polyurethane foam (PPU), and polyol forms soft segments (Shufen et al., 2006). Thus, an increase in isocyanate content leads to an increase in the stiffness of polyurethane foam.

Another important factor is the polyol functionality (the relative amount of hydroxyl groups). Increasing the functionality of the polyol without changing the molecular weight results in a slight increase in foam hardness and a slight decrease in tensile strength and elongation. (Gama et al, 2018).

Foaming agents take part in the formation of the cellular structure. PPU is formed as a result of the chemical interaction of isocyanate and polyol with the participation of foaming agents (foaming agents). There are two main types of foaming agents: physical foaming agents (in particular, solvents with a low boiling point: pentane, acetone or hexane), which expand the polymer as a result of evaporation; and chemical blowing agents (water) that expand the polymer by producing CO<sub>2</sub> (Wypych, 2017). Distilled water as a foaming agent affects the density and architecture of rigid PPU. In particular, according to the results of the study by Thirumal et al. (2008) the density of PPU decreased by almost three times as the amount of water increased from 0.1 to 3.0 parts.

Silicone surfactants are used to stabilize polyurethane foam during the foaming process. It is shown that the silicone surfactant has an important effect on both the formation of bubbles and the stabilization stage of the cell window. Surfactants with higher silicone content will provide lower surface tension and thus help increase the amount of air bubbles introduced during mixing (Zhang et al, 1999).

In general, the described results show the relevance of such research and allow for the expansion of the performance characteristics of foam materials by modifying their composition. A number of works by the authors of this study are devoted to the development of methods of numerical simulation analysis of changes in the microstructural characteristics of polyurethane foams on their vibration-absorbing properties. Such developed approaches are based on the use of Cosserat continuum models, which allow account for the effect of rotational-shear deformations of material microparticles. (Mikulch, 2022, 2023).

The article is devoted to studying changes in the mechanical and strength characteristics of foam materials when silicone additives are added during the formation of polyurethane foam.

## 2. Methods of experimental research

The main components for obtaining foam were polyol and polyisocyanate, which are widely used in construction.

Polyisocyanate (component A), a non-flammable liquid with a specific smell, reacts easily with water. At a temperature of 20 °C, its density is 1.25 g/cm<sup>3</sup>, and its viscosity is 300 mPa·s. Polyol (component B), as a mixture of polyester, stabilizers and catalysts, is low-toxic and non-explosive. Its density at a temperature of 20 °C in the liquid state is 1.09 g/cm<sup>3</sup>. The viscosity of the polyol is 1300 mPa·s. Siloxane rubber (component C) was used as a modifying additive. This is a low molecular weight dimethylsiloxane fluid stabilized with silicon oxide. This material is highly elastic, biologically inert, and heat-resistant in the temperature range from -40 °C to +100 °C.

To obtain rigid polyurethane foam, the components, the ratios of which are given in Table 1, were mixed for 30 seconds. Foams were prepared in open forms. All foams were kept at room temperature for 24 hours. Table 1 also shows the values of the density of the obtained foams and their porosity.

Table 1. An experimental foam samples' characteristics.

An experimental samples' number	Partial mass correlation A:B:C*	$\rho$ (kg/m <sup>3</sup> )	$p$ (%)
1	2:1:0	69.9	46
2	4:2:1	71.8	37
3	4:2:1.5	75.9	44
4	4:2:2	97.9	51.5
5	4:2:2.5	105.4	56.5
6	4:2:3	180.7	31
7	4:2:4	189.6	25.5

A — polyisocyanate, B — polyol, C — rubber additives

For the compression test, samples with a square cross-section with a height of 20 mm were formed. Experimental tests were carried out under axial compression under the action of a uniformly applied compressive load along the cross-section of the sample. The rate of change in load intensity was 2 mm/min. Photos of the cell structure were obtained on an optical microscope at a magnification of 30 times.

## 3. Results and discussion

The study of the influence of silicone rubber additives on the change in mechanical and strength characteristics of polyurethane foams was carried out on the basis of microstructure analysis and experimental studies on the joint of the obtained samples. Fig. 1 shows sections of the microstructure of modified polyurethane foam obtained at a 30-fold magnification. The composition of the samples corresponds to the sample number in Table 1.

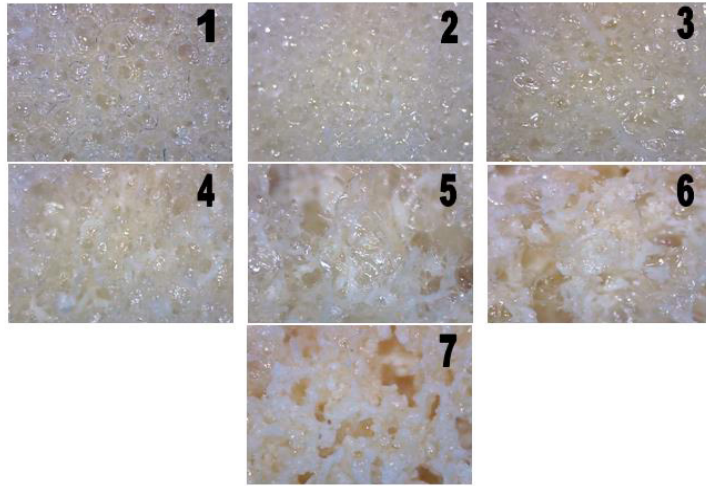


Fig. 1. Internal structure obtained foams

The averaged compression diagrams for the obtained foam samples are presented in Fig. 2.

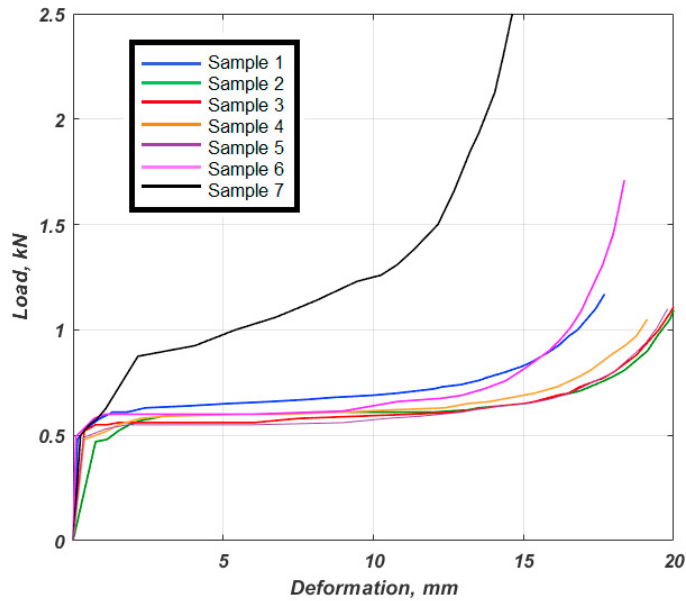


Fig. 2. Load diagrams for obtained foam samples

Based on the results of experimental studies, the values of the Young's modulus  $E$  and the yield strength of the obtained foams were calculated. The corresponding calculation results are shown in Table 2.

Table 2. The mechanicals and strength characteristics obtained foams

An experimental samples' number	$E$ (MPa)	$\sigma_Y$ (MPa)
1	64	1.25
2	61	1.23
3	63.1	1.26

4	62	1.32
5	69	1.33
6	74	1.37
7	106	2.34

Analyzing the results shown in Table 2, it can be concluded that the modification of polyurethane foams with rubber additives in the optimal ratio of components allows for obtaining foam materials with higher values of mechanical and strength characteristics.

Compared to unmodified polyurethane foam (sample 1), the introduction of rubber additives in a ratio of 4:2:1 slightly lowers the value of Young's modulus  $E$  and the yield strength of the resulting foams. However, with a further increase in the content, optimal strength characteristics were achieved for samples of compositions 3 and 4. The results of experimental studies show that the addition of modifying additives in the ratio of 1.5-2.5 to 4 mass parts of polyisocyanate is effective for increasing strength and mechanical characteristics. With a lower content of the modifier, the strength and mechanical characteristics of the obtained foam materials decrease. Also, the analysis of the microstructure of the obtained foams (Fig. 1) and deformation diagrams (Fig. 2) shows that in the case when the proportion of rubber additive is equal (sample 7) and almost equal (sample 6) to the proportion of polyisocyanate in the compound, then obtained samples have increased fragility and mixed type of porosity. Some pores are open. As the proportion of silicone increases, the number of open pores in the resulting foam increases. However, in this case, the thickness of the walls of the pore cells increases, which contributes to the strengthening of the obtained material.

The study of the deformation processes of the obtained foams shows that foam materials with low addition of modifying additives (composition samples 2-4) have the properties of almost equable distribution loads corresponding to the yield stresses, and closing of cells under its action (Table 2). In the case of a high content of siloxane rubber additives, the resulting foams are harder and more brittle. A diagram of their deformation (the curve corresponding to sample 8 in Fig. 2) shows the existing process of layer-by-layer crumpling of pores from the zone of application of external forces under a load corresponding to the yield point.

#### 4. Conclusions

1. The method of obtaining modified foams considered in the work allows for an increase in the mechanical and strength characteristics of foam materials without changing the technologies and conditions of their production.

2. Experimental studies show that the selection of the content of modifying additives for polyurethane foams allows to increase in the strength and mechanical characteristics of foams by up to 50%.

3. The selection of modifiers allows you to obtain foams with high plastic characteristics, as well as foams with a different type of porosity compared to the original material.

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