Recommendations for making sound absorbing polyurethane materials

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Abstract. We performed the comprehensive studies of physical mechanical properties of KAMAZ vehicle mats from three manufacturers. It was found that structure of PU foam cells was the key structural parameter that influenced heat- and sound-absorbing properties of products. The paper provides manufacturers with the recommendations for managing structural parameters of a PU foam layer in a mat.

1. Introduction

Today, human environment is surrounded by multiple noisemakers such as vehicles, plumbing systems [1, 2]. Noise is harmful to a man: it increases the concentration of stress hormones; disrupts the function of a nervous system; leads to cardiovascular diseases; reduces hearing sensitivity.

There are two effective methods of noise reduction: sound insulation and sound absorption. The easiest one is to use sound absorbing materials. Two types of sound absorbing materials are typically used in the automotive industry: fibrous materials and polyurethane foam. The first ones have high sound absorbing properties due to a large quantity of interfaces on the noise path. The latter ones have a porous structure that consists of interconnected pores where sound waves impinge against walls of a material; wave energy transforms to oscillation of walls, heating of a material, and its heat exchange with the environment [3-9].

2. Body text

There is a strong trend in the automotive industry to use products that perform several related functions. For example, a floor mat performs the following functions in KAMAZ vehicles: heat- and sound insulation (sound absorption), protection, and decor. A floor mat consists of three layers: PVC film, flexible polyurethane (PU) foam, polyethylene film. Outer layers protect an inner layer against dirt, water, and UV radiation.

The main functional part of these products is flexible polyurethane foam which is formed as a result of reactions between liquid polyisocyanates and liquid polyols over a number of other ingredients necessary for product formation. Foams are three-dimensional agglomerations of gas bubbles that are separated from each other by thin polymer walls/strands. In the resulting flexible polyurethane material, empty spaces (cells) are remnants of gas bubbles which have been added to the reaction mixture at the beginning [10].

The comparative studies were performed for the samples of KAMAZ vehicle floor mats from three manufacturers: sample 1 is manufactured by DAIMLER (thickness of PU foam layer is 15 mm); sample 2 - by NPP Ikar (thickness of PU foam layer is 22 mm) [8]; sample 3 - by AVTOTEKHNIK (thickness of PU foam layer is 18 mm) [9].
The following properties of the samples were analyzed: normal sound absorption coefficient according to GOST 16297-80 [11]; thermal conductivity coefficient according to GOST 7076-99 [12]; apparent density of PU foam layer; thermal properties of PU foam layer according to GOST R 55134-2012 (ISO 11357-1:2009) and GOST R 55135-2012 (ISO 11357-2:1999) [13, 14]; macrostructure properties of PU foam layer.

The results of studies are shown in Tables 1 and 2.

Table 1. Normal sound absorption coefficient from 100 to 6300 Hz

| Frequency | Sample 1* | Sample 2* | Sample 3* |
|-----------|-----------|-----------|-----------|
| 100       | 0.021     | 0.061     | 0.027     |
| 200       | 0.013     | 0.064     | 0.019     |
| 250       | 0.038     | 0.115     | 0.050     |
| 315       | 0.056     | 0.162     | 0.066     |
| 400       | 0.082     | 0.188     | 0.080     |
| 500       | 0.114     | 0.189     | 0.105     |
| 630       | 0.157     | 0.204     | 0.157     |
| 800       | 0.168     | 0.058     | 0.195     |
| 1000      | 0.274     | 0.583     | 0.434     |
| 1250      | 0.337     | 0.558     | 0.534     |
| 1600      | 0.443     | 0.513     | 0.655     |
| 2000      | 0.614     | 0.488     | 0.855     |
| 2500      | 0.816     | 0.262     | 0.939     |
| 3150      | 0.977     | 0.167     | 0.979     |
| 4000      | 0.964     | 0.173     | 0.902     |
| 5000      | 0.830     | 0.220     | 0.742     |
| 6300      | 0.694     | 0.209     | 0.582     |

* arithmetic mean values of tests of three samples

Table 2. Results of physical, thermal, and texture characteristics of flexible PU foam layer

| Property                                         | Sample 1     | Sample 2     | Sample 3     |
|-------------------------------------------------|--------------|--------------|--------------|
| Thermal conductivity coefficient, $\lambda$ (W/(m*K)) | 0.085        | 0.090        | 0.095        |
| Apparent density, g/l                           | 58           | 55           | 51           |
| $T_{\text{max}}$ of decomposition, °C            | 397.5        | 391.5        | 389.2        |
| Remaining mass at 550°C, % wt.                   | 15.6         | 19.4         | 15.5         |
| Cell size distribution range, mm                 | 0.04-0.33    | 0.13-0.76    | 0.07-0.50    |
| Cell shape coefficient (degree of cell elongation)| 1.0-1.8      | 1.1-2.6      | 1.0-1.8      |

The studies showed that samples 1 and 3 had similar values of physical acoustic properties (tables 1, 2), and sample 3 had a higher sound absorption coefficient in the frequency range from 630 to 2000 Hz with a lower thickness (by 3-4 mm) than sample 2. All the samples have a comparable thermal conductivity coefficient in the range from 0.085 to 0.095 W/(m*K). The apparent density is comparable for all the samples, and it varies within 51-58 g/l. The thermal studies showed that temperature of maximum decomposition rate ($T_{\text{max}}$) was 389-398 °C, which is typical for polyurethane, and sample 3 had a lower value (389 °C) when compared with other samples, and its additional decomposition temperature was 327.7 °C, which could be typical for formation of bimodal polyurethane structures.

It is well known that end performance properties of flexible PU foam is the result of a complex combination of factors, which are associated with macroscopic geometry of cells, i.e. with foam texture [10].
The main characteristic of macrostructure of expanded foams is the structure of their cells, which depends on the parameters of gas-structural elements [15]. The study of parameters of PU foam macrostructure (determination of linear cell dimensions) showed that sample 1 and sample 3 had the smallest cell size distribution range (0.04-0.33 mm and 0.07-0.50 mm respectively) with a cell shape coefficient of from 1.0 to 1.8, sample 2 with an elongation degree of 1.1-2.6 had more elongated cells with a bigger cell size distribution range (0.13-0.76 mm) when compared with samples 1 and 3. The elongation of cells affects anisotropy for not only mechanical but also physical properties of PU foam, and sizes of cells and strands define their acoustic properties. Therefore, sample 1 features a fine-cellular structure of PU foam. It may result from substances in a compound, which make it easier to release solution gases as a separate phase as a change in the nature and concentration of such additives leads to the formation of cellular materials with various structures.

3. Conclusion
The studies showed that structure of PU foam cells was the key structural parameter that influenced heat- and sound-absorbing properties of products.

Therefore, in order to ensure the required physical mechanical and performance properties for floor mats, it is necessary to be able to manage and modify dimensions and nature of cellular structure of flexible PU foam, on the other hand, the structure of cells depends on a number of factors active at the stage of PU foam formation.

References
[1] Gottlieb E M, Galimov E R, Zenitova L A and others 2016 Polyurethanes: synthesis, properties and application in mechanical engineering (Kazan: Kazan publishing house UN-TA) p 149
[2] Shafigullin L N, Yurasov S Yu, Shafigullina G R, Shafigullina A N and Zharin D E. 2017 Sound-Absorbing Polyurethane Foam for the Auto Industry Russian Engineering Research vol 37 Issue 4 pp 38-40
[3] Shafigullin L N, Gumerov I F, Gumerov A F, Lakhno A V, Yurasov S Yu and Shafigullina G.R. 2017 Glass-Filled Polyurethane Materials Produced by Fiber Composite Spraying Russian Engineering Research vol 37 Issue 11 pp 925-28
[4] D.E. Zharin, S.Y. Yurasov, M.I. Gumerov, L.N.Shafigullin, Vibration-and noise-absorbing polymer composites used in manufacturing Russian Engineering Research vol 30 Issue 2, pp 194-96
[5] Kashapov N F, Nafikov M M, Gazetdinov M X, Nafikova M M and Nigmatzyanov A R 2016 Innovative production technology ethanol from sweet sorghum IOP Conference Series: Materials Science and Engineering vol 134 issue 1 8 number 012012
[6] Fedyaev V L, Galimov E R, Galimova N Ya, Gimranov I R and Siraev A R 2017 Dynamics of coalescence and spreading of liquid polymeric particles during coating formation IOP Conf. Series: Journal of Physics: Conf. Series vol 789 number 012006
[7] Fedyaev V L, Galimov E R, Galimova N Ya, Takhaviev M S and Siraev A R 2017 Mathematical modeling of processes occurring during deposition of sprayed particles of polymeric powder IOP Conf. Series: Journal of Physics: Conf. Series vol 789 number 012006
[8] Official website of NPP IKAR, OOO [Electronic resource]. - Access mode: http://ikar-ufa.ru/about (accessed 20.09.2019)
[9] Official website of Avtotekhnik, OOO [Electronic resource]. - Access mode: http://avtotekhnik.net/ru/producti/ (accessed 20.09.2019)
[10] Klempner D 2009 Polymeric Foams and foam technology (Saint Petersburg: Professiya Publ.) p 600
[11] GOST 16297-80 1981 Sound insulation and sound absorption materials. Methods of testing (Moscow, Izdatelstvo Standartov Publ.)
[12] GOST 7076-99 2000 Building materials and products. Method of determination of steady-state thermal conductivity and thermal resistance (Moscow, Gosstroy Rossii Publ., GUP TsPP)
[13] GOST R 55134-2012 (ISO 11357-1:2009) 2012 Plastics. Differential scanning calorimetry (DSC). Part 1. General principles (Moscow, Standartinform Publ.)
[14] GOST R 55135-2012 (ISO 11357-2:1999) 2014 Plastics. Differential scanning calorimetry (DSC). Part 2. Determination of glass transition temperature (Moscow, Standartinform Publ.)

[15] Dementyev A G 1997 Structure and properties of expanded polymers Dissertation of doctor of Technical Sciences (Moscow: VNII Sinteticheskikh Smol Publ.) p.409