Materials Letters 194 (2017) 234–237

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/mlblue

Epoxy foams with tunable acoustic absorption behavior

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ARTICLE INFO

Article history:
Received 31 May 2016
Received in revised form 26 January 2017
Accepted 18 February 2017
Available online 21 February 2017

Keywords:
Polymers
Porous materials
Functional
Microstructure
Amorphous materials

ABSTRACT

Herein, epoxy foams with tunable acoustic behavior were innovatively fabricated via non-traditional expandable microspheres. By adjusting the preparation parameters, changes in cellular structure from closed cells to partial open cells were observed, which exhibited tunability and resulted in diverse sound absorption behaviors. Short procuring time, high microsphere contents and foaming temperatures contribute to constructing more open cells and enhancing the sound absorption properties. High absorption coefficient up to 0.75 is achieved. Such a novel light-weight epoxy foam can serve as a promising structural and sound-proof material, and satisfy the needs of many multifunctional systems including vehicles, buildings, aircrafts, etc.

1. Introduction

Noise pollution is always one of the major environmental issues. A growing environmental awareness throughout the world has triggered the trend towards seeking for the proper acoustic material to cater to various fields [1]. Currently, sundry acoustic polymer foams are fabricated for noise protection, such as polyolefin foams [2], polymethylmethacrylate foams [3], polyvinyl formal foams [4], etc. However, these are all thermoplastic materials lacking sufficient strength, outdoor weather ability and heat stability despite their acoustic performance. If ignited, thermoplastic foams will contract, melt, come into molten drop and then aid flames. In contrast, the thermosetting foams are infusible and insoluble, and it will form a carbide layer on the burning surface, exhibiting certain degrees of flame resistance. But until now, only a few thermosetting foams, such as flexible melamine foams [5] and polyurethane foams [6], are available in acoustic absorption areas. However, in the areas, acoustic barrier in rail transit for instance, light weight, high strength and acoustic absorption are required simultaneously. Compared to the aforementioned foams, epoxy foams are the best candidates due to its high strength. Nevertheless, traditional foaming methods just bring epoxy foams a closed cellular structure which is undesirable for sound absorption. Besides, for fabricating epoxy foam, coordinating the curing reaction, viscosity changes, volatilization or decomposition of blowing agent and pore stabilization is extremely challenging [7]. That's the reason why no acoustic absorption epoxy foams are reported so far.

This letter aims at exploring acoustic absorption epoxy foams to cater to the structural applications. Recently, one of the hottest topics in polymer foams is focused on expandable microspheres that consist of low-boiling liquid hydrocarbons encapsulated in thermoplastic polymer shells [7]. Upon heating, the liquid core vaporizes, and meanwhile the shell softens and begins to expand. This nontraditional foaming agent may help to simplify the foaming process. Here, an epoxy/polyether amine system was selected as the matrix. Significant relations between the sound absorption behavior and the foam structures obtained at different preparation conditions are found. Interestingly, the foam structure can be well-controlled from closed cells to partial open cells, which sets an example to develop novel acoustic polymer foams.

2. Materials and methods

Bisphenol A epoxy resin with an epoxide equivalent of 184–190 g/eq. was purchased from Nan Ya Plastic Corporation (Taiwan). Low molecular polyether amine with an amine hydrogen equivalent weight of 61 g/eq. was bought from BASF (Germany). An expandable microsphere with a commercial name of *EXPANCEL* 031DU40, which has particle sizes of 10–16 μm and allowable operating temperatures from 80 to 135 °C, was supplied by Akzo-Nobel (Sweden). The microsphere comprises a low-boiling hydrocarbon core and a thermoplastic polymer shell with a glass-transition temperature about 80 °C.

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http://dx.doi.org/10.1016/j.matlet.2017.02.054

Firstly, metered microspheres were added to the epoxy resin (100 g) and mixed well. Then, the curing agent (32 g) was pour into the epoxy pulp, and followed by rapid stir. Afterwards, the pulp was procured for a certain period of time at 45 °C. Finally, the expandable pulp was move into an air-circulating oven for foaming. The preparation parameter settings were summarized in Table 1.

The foam structures were examined via a JEOL-7500F scanning electron microscopy (SEM, Japan). The sound absorption coefficients (α) of circle samples (Φ = 78 mm and d = 12 mm) were evaluated by the impedance tube method (BSWA Technology, China) in the frequency range of 100–2500 Hz (See Fig. 1). The absorption coefficient can be calculated as

$$\alpha = 1 - \left| \frac{P_2 e^{jk_0 x_1} - P_1 e^{jk_0 x_2}}{P_1 e^{-jk_0 x_2} - P_2 e^{-jk_0 x_1}} \right|^2$$

where k_0, x_i and P_i denote the wavenumber, the sensor-sample distance and the sound pressures at the different sensor positions, respectively.

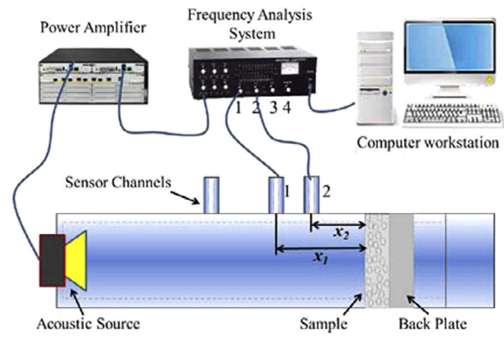

Fig. 1. Sketch map for acoustic absorption test.

3. Results and discussion

An excellent acoustic material should attenuate the sound energy or convert it to other energy effectively, and finally exhibit high absorption coefficient. Open-cell foams are confirmed as the most efficient absorption materials, in which the air vibrates via the coming of sound waves into micro pores. Thus, the sound energy attenuates due to the air viscous resistance, interface friction and heat transmission between the air and the pore walls [8]. Here, the acoustic property of the foams obtained at varying conditions are firstly examined, and interestingly exhibit well tunability.

Fig. 2a shows the acoustic absorption coefficients of the foams **A1**, **A2**, **A3** and **A4** prepared at the procuring time of 60, 75, 90 and 105 min, respectively. Well-defined acoustic absorption spectra can be seen clearly in the tested frequency range. Generally, the coefficient increases with the increasing frequency according to the Stokes-Kirchhoff formula [4]. All foams show two main absorption peaks at similar frequencies (about 1100 Hz and 2200 Hz) except for those with long procuring time. No theoretical and experimental studies can elucidate the underlying mechanisms of this phenomenon due to the multiple forms of wave attenuation which are too complex to analyze [3]. Studies indicate that the noise peak frequency existing in hospitals, emporiums, schools and factories are all located around 1000 Hz or 2000 Hz, which significantly jeopardizes health [8,9]. More importantly, the foams with short procuring time show enough ability to attenuate the sound waves while those over-procuring samples cannot. The foam with procuring time of 60 min (**Sample A1**) has an absorption coefficient above 0.2 and peak absorptions of 0.75 at 2100 Hz. However, with increase in procuring time, depressed peak absorptions were observed. The specimen procured for 105 min (**Sample A4**) exhibits quite minor absorption coefficient of just around 0.15 despite some fluctuation. Besides, the foams we obtained present a snow-white appearance without any motley and structural defects (Fig. 2b), which verifies the perfect technic for preparing acoustic epoxy foams.

Table 1
Summary of parameter settings for preparing acoustic epoxy foams.

Sample Number	Preparation Parameters		
	t [a](min)	T [b] (°C)	φ [c] (wt%)
A1	**60**	80	**2**
A2	**75**	80	**2**
A3	**90**	80	**2**
A4	**105**	80	**2**
B1	90	**60**	2
B2	90	**110**	2
C1	90	80	**1**
C2	90	80	**3**

Highlight the changes in preparation parameters in each group.
[a] Procuring time.
[b] Foaming temperatures.
[c] Microsphere content.

The changes in sound absorption coefficient must be relevant to the variation occurred in cellular structures (Fig. 2c-e). Compared to those with long procuring time, the foam pores obtained at short procuring time are larger and even cracked. More importantly, the numbers of cracked pores at the same resolution significantly diminish with the increasing procuring time, and the pore has changed from open cell to closed cell. Therefore, the high absorption coefficients of the foams at short procuring time should be ascribed to more open-cell structures as well as their high foam expansion. The epoxy slurry with short procuring time has a lower onset foaming viscosity and cannot produce enough viscous resistance to restrict the expanding microsphere during foaming, which contributes to generating larger pores [7,10]. Some of them even burst and connect together.

Based on this, it can be predicted that different acoustic behavior and well-controlled foam structures can also be achieved via adjusting the foaming temperatures. In Fig. 3a, the sound absorption coefficient of the sample foamed at 60 °C (Sample **B1**) just fluctuates between 0.08 and 0.3. As the foaming temperature is further elevated to 110 °C (Sample **B2**), the fluctuation range of absorption coefficient is obviously improved to 0.18–0.51. As can be seen in Fig. 3b-c, the cellular structures have partially changed from closed cells to open cells due to the growing foaming temperatures, and pore sizes also increase. The microspheres at high temperatures produce high internal expanding forces to grow and squeeze each other [7]. As a result, more connected pores are formed.

The similar improvements can be observed in the samples with different microsphere contents. The foam with 1 wt% of microspheres (**Sample C1**) just has a peak absorption coefficient about 0.29, while that with 3% (**Sample C2**) achieves a peak absorption coefficient up to 0.53. The cell walls in the foam with high microsphere content are thinner than that with low content due to the high expanding forces, leading to more cracked or connected pores (Fig. 3e-f). All results indicate that high sound absorption coefficient can be obtained just via shortening the procuring time or increasing the foaming temperatures and microsphere contents.