Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 85 (2016) 559 – 565

Energy Procedia

Sustainable Solutions for Energy and Environment, EENVIRO - YRC 2015, 18-20 November 2015, Bucharest, Romania

Improved sound absorption properties of polyurethane foam mixed with textile waste

Ancuţa-Elena Tiuc[a*], Horaţiu Vermeşan[a], Timea Gabor[a], Ovidiu Vasile[b]

[a]*Department of Environmental Engineering and Sustainable Development Entrepreneurship, Technical University of Cluj-Napoca, 103-105 Muncii Ave, Cluj-Napoca 400641, Romania*
[b]*Department of Mechanics, University Politehnica of Bucharest, 313 Splaiul Independentei, Bucharest 060042, Romania*

Abstract

Polyurethane foam is an outstanding material for various applications. It is manufactured by propelling liquid isocyanate-polyol mixture to form foams in the presence of a blowing agent. This paper comprises an experimental study on acoustic properties improvement of rigid polyurethane closed-cell foam, by incorporating various quantities of textile waste into the matrix. In order to obtain a homogenous, easy to handle material, an optimal percent of 10-50% textile waste was used. The sound absorption coefficient of the composite materials was measured using an impedance tube. The composite materials obtained have better sound absorption properties compared to rigid polyurethane foam. The noise reduction coefficient (NRC) of the composite material with 40% textile waste and 60% rigid polyurethane foam is twice as high as the 100% rigid polyurethane material.
© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee EENVIRO 2015
Keywords: Polymer-matrix; recycled fabrics; sound absorption coefficient; composite materials; acoustic properties

1. Introduction

As industrial waste continuously accumulates, it is becoming a major problem for the environment as well as for public health. Another environmental problem, which is becoming an increasingly significant concern due to its negative impact on human health, is noise pollution [1]. Therefore, research and development of efficient and environmentally friendly sound absorbing materials is important [2-5].

* Corresponding author. Tel.: +4-026-440-1624; fax: +4-026-441-5054.
E-mail address: Ancuta.TIUC@imadd.utcluj.ro.

1876-6102 © 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee EENVIRO 2015
doi:10.1016/j.egypro.2015.12.245

Polymer foams include a plurality of cells in a polymer matrix. Foam can have an open, partially open, or a closed cell structure. Polymer foam requires less material than a solid polymer having the same volume, thus material costs are reduced in many applications [6]. Polyurethane foams are widely used in industry for their mechanical, electrical, thermal and acoustic properties [7].

Rigid polyurethane foam is currently one of the best thermal insulating materials available. As such, thermal insulation is a key feature of most of its applications. The combination of rigid polyurethane foam with different facing materials produces construction composites materials with important applications [8].

In the European Union, consumers discard around 5.8 million tones of textiles waste every year. Only 1.5 million tones of such textiles waste are recycled by charities and industrial enterprises. The remaining waste goes to landfills or to municipal waste incinerators [9].

Textile waste integrates a group of reusable materials that can be included in building construction and used in various applications. This textile waste may origin in the textile industry or may simply result from clothes that are no longer used [10].

Researches confirm the possibility to reinforce polymer foams with recycled materials to enhance their mechanical, thermal and acoustic properties. Thus, researchers have used and studied fibrous waste with various characteristics to obtain sound absorbing materials: corn cob [11], cotton [12], hemp fibers [13], jute fibers [14], textile fibers [15], agricultural waste [16], coconut fibers [17], cellulose fibers [18], tea-leaf fibers [19] and kenaf [20].

This research aims to study the two advantages of such materials use for the environment. One advantage is the superior use of waste textile materials for making new materials and the second is to use such materials to reduce noise pollution levels.

The objective of this study is to test the improved acoustic performance of rigid polyurethane foam with different percent of textile waste incorporated in its matrix, when applied for noise absorption purpose.

Nomenclature

RC	noise reduction coefficient
MDI	methylene diphenyl diisocyanate
RPF	rigid polyurethane foam
α	sound absorption coefficient
α_{250}	sound absorption coefficient at a frequency of 250 Hz
α_{500}	sound absorption coefficient at a frequency of 500 Hz
α_{1000}	sound absorption coefficient at a frequency of 1000 Hz
α_{2000}	sound absorption coefficient at a frequency of 2000 Hz

2. Experimental setup

2.1. Materials

Textile waste (Fig. 1) used to improve acoustic properties of rigid polyurethane foam, come from the production of knitted clothing. The textile waste is made of synthetic fibers, with the following composition: 15% polyamide (nylon), 40% polyacril and 45% modal. The density of the textile fibers used as reinforcing material in composite materials is of 0.051g/cm3.

The synthetic textile fibres used are made by polymerising smaller molecules into larger molecules through an industrial process [21, 22].

The matrix of composite materials obtained in this research is bi-component rigid polyurethane foam. The polyol component of the foam mixture includes polyol, catalyst, stabilizing agents, flame retardant and blowing agent (polyol: density = 1.09 g/cm3 at 20°C, viscosity = 560 mPa at 20°C). The isocyanate component includes a polymeric MDI (methylene diphenyl diisocyanate) (density = 1.24 g/cm3 at 20°C, viscosity = 170÷250 mPa at 20°C) [23].

Fig. 1. Textile waste

Isocyanates based on MDI are used almost exclusively for producing polyurethane foam. These are mixtures of MDI (mainly 4,4'-diisocyanato-diphenylmethane with an isomeric 2,4'-diisocyanato-diphenylmethane content) and higher molecular components. As a molecular unit is repeated in the structure of these higher molecular components, the isocyanate mix is also called polymeric MDI.

The composite materials produced have a cellular structure with closed pores (Fig. 2). By introducing textile waste into the polyurethane foam matrix we aimed to improve the sound absorption properties.

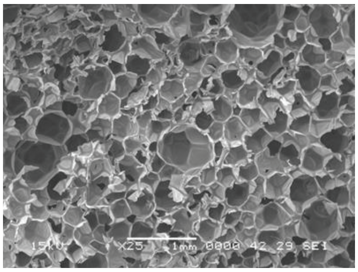

Fig. 2. SEM image of rigid polyurethane foam

2.2. Sample preparation

Composite samples were prepared by mixing textile waste with a polyurethane formulation including isocyanate and forms of polyol. The polyurethane foam was prepared by mixing the polyol and isocyanate at a 1:1.5 ratio at room temperature of 22÷25°C by a process described bellow.

At the beginning of the study different weight percentage (wt%) of textile waste in polyurethane foam were established. For this purpose the maximum weight percentage was established. In order to determine the maximum amount of textile waste that can be added to polyurethane foam, several samples with different textile waste weight percentage were produced. The weight percentage range of textile waste used varies between 0 and 50 (Table 1). When textile waste weight percentage is above 50%, the obtained composite material is not homogenous and cannot be handled.

Table 1.Foam composites contents

Samples	Rigid polyurethane foam (wt%)	Textile waste (wt%)	Sample thickness (mm)
100-RPF	100	0	40
90-RPF	90	10	40
85-RPF	85	12	40
80-RPF	80	20	40
75-RPF	75	25	40
70-RPF	70	30	40
60-RPF	60	40	40
50-RPF	50	50	40

Polyol and isocyanate were mixed with textile waste at determined weight ratios. After pouring the mixture into the mold, a mixer tool of up to 2000 rpm was used to mix the composition in order to obtain a homogeneous composition. Out of each mold, 3 samples with 63.5 mm diameter were produced for impedance tube testing (Fig. 3). The composite material was 40 mm thick.

Fig. 3. Samples prepared for sound absorption coefficient measurement

2.3. Density of the composite materials

The densities of the composite materials were measured according to ASTM D 1622-08. Eight samples of 50×50×30 mm size (length ×width× thickness) were cut from the composite materials, after moisture conditioning at 23°C for 24h.

2.4. Sound absorption coefficient measurement

A sound wave incident on a material can be absorbed, reflected and/or transmitted by the material. These three phenomena are all possible depending upon the types of material. The absorption of the incident sound wave is an effective way to control noise.

Acoustic performance of sound absorbing material is valued by the sound absorption coefficient. An impedance tube was used to determine the sound absorption coefficient of sound absorbing materials analyzed.

The absorption coefficient is the ratio of the absorbed energy to the total incident energy and the reflection coefficient is the ratio of the reflected energy to the total incident energy.

The measurements were based on a two-microphone transfer-function method according to ISO 10534-2, international standard for horizontally mounted orientation sensitive materials [24]. A medium Type 4206 A Brüel&Kjaer tube kit was used to measure acoustic parameters for a frequency range of 100÷3200 Hz.

The testing apparatus is part of a complete acoustic material testing system (Fig. 4), featuring a Brüel&Kjaer Type 4206 A medium impedance tube (1), two 4187 Brüel&Kjaer microphones (2), an Analyser PULSE 3560-B-030 acoustic signal generator (3), a 2716 Brüel&Kjaer signal amplifier (4) and a PC (5) for recording and processing results, connected with the Brüel & Kjaer PULSE interface [25].

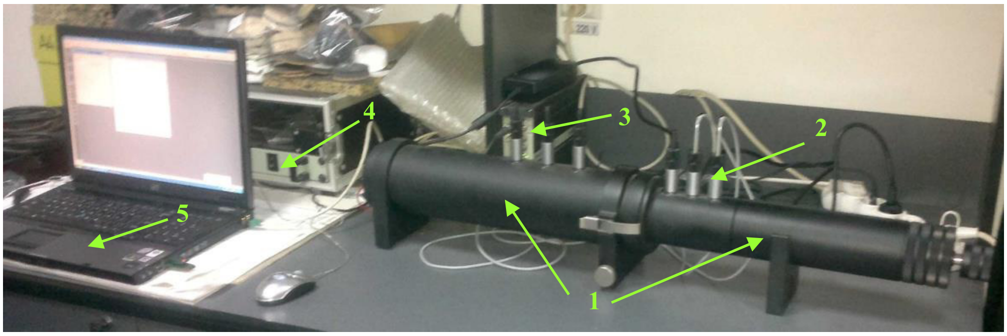

Fig. 4. Experimental stand used for the sound absorption coefficient measurement

3. Results and discussion

3.1. Density

Density variation plot of sound absorbing composite materials used in this research, depending on the percentage of added waste, is represented in Fig. 5. It can be observed that the material density increases with the increase of textile waste percentage used for obtaining sound absorbing composite materials.

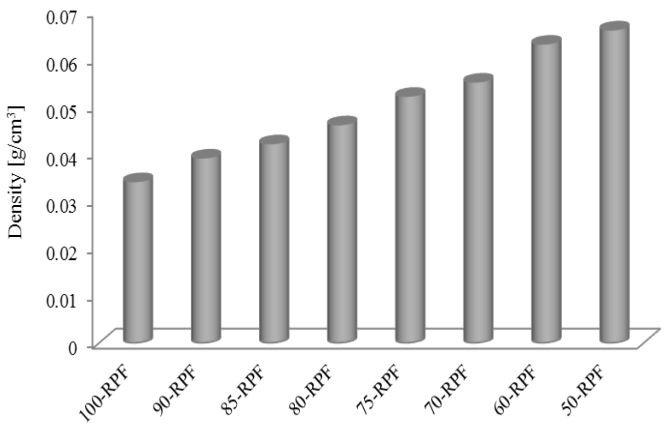

Fig. 5. Density of composite materials

3.2. The effect of textile waste percentage on sound absorption coefficient

The influence of textile waste percentage used in obtaining composite materials based on rigid polyurethane foam on the sound absorption coefficient is presented in Fig. 6.

In the graphic representation it can be observed that composite materials have better sound absorption properties compared to the 100-RPF material (100% rigid polyurethane foam) in the whole frequency range analyzed. The 60-RPF material (40% textile waste and 60% rigid polyurethane foam) has the best sound absorption properties in the frequency ranges of 250÷900 Hz and 1400÷3100 Hz.

The 85-RPF material (15% textile waste and 85% rigid polyurethane foam) has the best sound absorption properties for frequencies under 250 Hz, and the 70-RPF material in the frequency range of 900÷1400 Hz.

The maximum value of the acoustic absorption coefficient of 0.86 is achieved by sample material 75-RPF (25% textile waste and 75% rigid polyurethane foam) at a frequency of 1000 Hz.

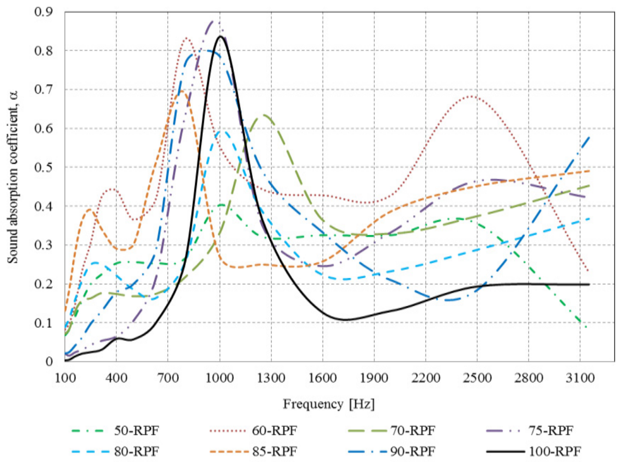

Fig. 6. Sound absorption coefficient variation with textile waste percentage used

Indicating the sound absorbing properties of materials by using the absorption coefficient values at different frequency ranges might be too complex. To solve this problem, the ability of a material to absorb sound is generally calculated using a single value: the noise reduction coefficient (NRC). The NRC can be calculated using formula (2) [26]:

$$NRC = \frac{(\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000})}{4} \quad (1)$$

Improvement of acoustic properties of rigid polyurethane foam by adding textile waste can be observed from the values of noise reduction coefficient (Fig. 7), which are higher in the case of composite materials. We can also observe that with the increase of textile waste percentage, the value of noise reduction coefficient (NRC) also increases. The 60-RPF material has the maximum NRC value of 0.593, which is twice as the 100% rigid polyurethane foam.

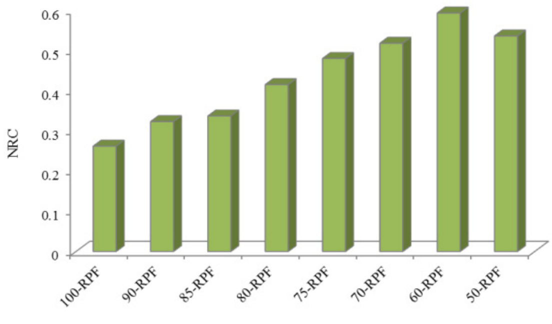

Fig. 7. Noise reduction coefficient

4. Conclusions

Properties of materials obtained in this study are of a great importance for improving the existing materials properties and for developing new materials with better physical, mechanical and thermal properties.

These alternative materials can be cost beneficial as well as useful in green building initiative by developing materials from natural and recycled resources.

Composite materials obtained by introducing textile waste in rigid polyurethane foam matrix have sound absorption properties much improved compared to the 100% rigid polyurethane foam. The 60-RPF material has the best capacity to absorb noise, reaching a value of minimum 0.4 of sound absorption coefficient on the whole analyzed frequency ranges.

The developed materials can be used both in the outdoor and in the indoor environment.

References

[1] Arenas C, Leiva C, Vilches LF, Cifuentes H. Use of co-combustion bottom ash to design an acoustic absorbing material for highway noise barriers. Waste Manage 2013;33:2316–21.
[2] Jiang S, Xu Y, Zhang H, White CB, Yan X. Seven-hole hollow polyester fibers as reinforcement in sound absorption chlorinated polyethylene composites. Appl Acoust 2012;73:243–7.
[3] Xu Z, Wang B, Zhang S, Chen R. Design and acoustical performance investigation of sound absorption structure based on plastic micro-capillary films. Appl Acoust 2015;89:152–8.
[4] Azkorra Z, Pérez G, Coma J, Cabeza LF, Bures S, Álvaro JE, et.al. Evaluation of green walls as a passive acoustic insulation system for buildings. Appl Acoust 2015; 89:46–56.
[5] Hung T-C, Huang J-S, Wang Y-W, Lin K-Y. Inorganic polymeric foam as a sound absorbing and insulating material. Constr Build Mater 2014;50:328–34.
[6] Niaounakis M. Biopolymers: Processing and Products. Chapter 9 – Foaming and Foamed Products. Elsevier; 2015.
[7] Verdejo R, Stampfli R, Alvarez–Lainez M, Mourad S, Rodriguez–Perez MA, Bruhwiler PA, et.al. Enhanced acoustic damping in flexible polyurethane foams filled with carbon nanotubes. Compos Sci Technol 2009;69:1564–9.
[8] Kapps M, Buschkamp S. The production of rigid polyurethane foam, Insulation Technical Information, Bayer MaterialScience; 2004, http://virtualpu.com/uploads/user_doc_attachment/0-2015-04-16%2018:32:05-T_The-production-of-rigid-polyurethane-foam.pdf
[9] Competitive and Sustainable. GROWTH, making the European research area a reality. Recycling textiles. http://ec.europa.eu/research/growth/gcc/projects/recycling-textiles.html
[10] Briga-Sá A, Nascimento D, Teixeira N, Pinto J, Caldeira F, Varum H, et al. Textile waste as an alternative thermal insulation building material solution. Constr Build Mater 2013;38:155–60.
[11] Paiva A, Pereira S, Sá A, Cruz D, Varum H, Pinto J. A contribution to the thermal insulation performance characterization of corn cob particleboards. Energ Buildings 2012;45:274–9.
[12] Binici H, Gemci R, Kucukonder A, Solak HH. Investigating sound insulation, thermal conductivity and radioactivity of chipboards produced with cotton waste, fly ash and barite. Constr Build Mater 2012;30:826–32.
[13] Glé P, Gourdon E, Arnaud L. Acoustical properties of materials made of vegetable particles with several scales of porosity. Appl Acoust 2011;72:249–59.
[14] Fatima S, Mohanty AR. Acoustical and fire-retardant properties of jute composite materials. Appl Acoust 2011;72:108 – 14.
[15] Curtu I, Stanciu MD, Cosereanu C, Vasile O. Assessment of acoustic properties of biodegradable composite materials with textile inserts. Rev Mat Plas 2012;49:68-72.
[16] Binici H, Eken M, Dolaz M, Aksogan O, Kara M. An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres. Constr Build Mater 2014;51:24–33.
[17] Shan CW, Idris MI, Ghazali MI. Study of flexible polyurethane foams reinforced with coir fibres and tyre particles. Int J Appl Phy Math 2012;2(2):123-30.
[18] Li Y, Ren HF, Ragauskas AJ. Rigid polyurethane foam reinforced with cellulose whiskers: Synthesis and characterization. Nano-Micro Lett 2010;2(2):89-94.
[19] Ekici B, Kentli A, Kucuk H. Improving sound absorption property of polyurethane foams by adding tea-leaf fibers. Arch Acoust 2012;37(4):515–20.
[20] Nar M, Webber III C, D'Souza NA. Rigid polyurethane and kenaf core composite foams, Polym Eng Sci 2015;55:132–44.
[21] McIntyre J. Synthetic fibres: Nylon, polyester, acrylic and polyolefin. Cambridge, UK: Woodhead Publishing Limited; 2004.
[22] Sinclair R. Textiles and Fashion. Elsevier; 2015.
[23] Hassan MNN, Rus AZM. Acoustic performance of green polymer foam from renewable resources after uv exposure. Int J Automot Mechan Engineer 2014;9:1639-48.
[24] Standard SR EN ISO 10534-2, Determination of sound absorption coefficient and acoustic impedance with the interferometer. Part 2. Transfer function method, 2002.
[25] Borlea (Tiuc) A, Rusu T, Ionescu S. Research on obtaining soundproof materials from wastes. Acta Technica Napocensis, Series: Environmental Engineering and Sustainable Development Entrepreneurship 2012;1(3):13-20.
[26] Sukontasukkul P. Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel. Constr Build Mater 2009;23:1084-92.