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Material Properties

Biobased porous acoustical absorbers made from polyurethane and waste tire particles

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ABSTRACT

The production of flexible polyurethane foams (FPF) with good acoustical performance to control sound and noise and incorporating bio/recycled raw materials is an interesting alternative to conventional acoustic absorbent materials. In this sense, biobased polyols like glycerol (GLY) or hydroxylated methyl esters derived from tung oil (HMETO) as multifunctional polyols, and waste tire particles (WTP) as fillers of low thermal conductivity and good capability for acoustical absorption, are prospective feedstocks for FPF preparation. In this work, FPF were prepared by adding different amounts of these components to a formulation based on a commercial polyether polyol. Results of scanning electron microscopy (SEM) analysis, compression tests and normal-incidence sound absorption coefficient (α_N) measurements are presented and discussed. The addition of WTP or GLY to the commercial formulation enhanced both the modulus and yield stress of the obtained FPF in all cases. Moreover, a high recovery of the applied strain (>90%) was attained 24 h after the compression tests. On the other hand, the normal-incidence sound absorption coefficient, α_N, reached high values mostly at the highest evaluated frequencies (α_N ~0.62–0.89 at 2000 Hz and α_N ~0.70–0.91 at 5000 Hz). SEM micrographs revealed that the foams obtained present a combination of open and closed cell structure and both the modifiers and particles tend to decrease the cell size.

1. Introduction

Noise pollution is one of the worst environmental problems and continues to get worse due to rapid developments of modern industries and transportation [1,2]. Especially, the car is a source of serious noise pollution, which consists of structural noise (sound from the engine or contact with the road) and airborne noise (sound from the engine, road noise, or wind caused at high speeds) [3,4]. One of the key solutions for reducing noise pollution is to improve sound absorption efficiency in houses and edifices by increasing damping capacity and optimizing pore structure of construction materials [1–3].

Polyurethane (PU) is one of the most versatile polymeric materials with regard to both processing methods and mechanical properties. Foams constitute more than 60% of all PU products, the flexible ones constituting the main part of polyurethane production [5]. Flexible polyurethane foams (FPFs) offer the possibility to be used both in thermal insulation and acoustic absorption, among others interesting technological applications. FPFs are porous materials able to absorb the sound energy, making them very useful for noise control. When a porous material is exposed to incident sound waves, the air molecules at the surface and moving through the material within the pores are forced to vibrate and lose some of their original energy. This is because part of the energy of the air molecules is converted into heat due to thermal and viscous losses at the walls of the internal pores and tunnels within the material [6]. Thus, the most important characteristic of flexible polyurethane foams is to have cavities with interconnecting open pores, and its cell structure can play a crucial role in controlling not only mechanical but also acoustic properties. The cell structure in FPF synthesis is simultaneously determined by the two main chemical reactions: gelling to produce urethane groups between isocyanates and polyols, and blowing to produce urea groups between isocyanates and intermediate amines from unstable carbamic acids by

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inclusion of water [2]. The reactions are directly affected by various main ingredients used in the foam formulations. Commonly, the ingredients consist of polyols, isocyanates, chain extenders, silicon surfactants, blowing agents and catalysts [7]. In addition, the cellular structure can be modulated by controlling the relative formation rates between urethane and urea groups, and thus the relative rates can significantly influence the modulus build-up and CO_2 gas liberation during the formation of final foam morphology.

Nowadays, the production of FPF is based on petrochemical feedstocks and the use of natural raw materials and/or waste products in their formulation is a big challenge with environmental and economic advantages [8]. Therefore, to move forward towards more eco-friendly materials, the use of polyols derived from natural sources is attractive, not only due to environmental reasons but also because of the economic benefits. With the exception of castor and lesquerella oils, vegetable oils do not bear hydroxyls naturally. Thus, the chemical modification of vegetable oils is a promising alternative in the production of green polyols to be further reacted with the isocyanate component to achieve the required polyurethane [8,9]. Several methods are currently known to add hydroxyls at the unsaturated sites: hydroformylation followed by hydrogenation, epoxidation followed by oxirane opening, ozonolysis followed by hydrogenation, and microbial conversion [5].

In recent years, a number of studies have been carried out to develop new materials and technologies improving the sound absorption properties. However, studies on the soundproof properties of composite products are still limited. In this sense, the use of recycled rubber in the production of sound absorbers can help to solve the existing problems of both, waste disposal and noise pollution. Hong et al. [10] found that recycled rubber particles had some excellent sound energy absorbency properties and a composite panel made with recycled crumb rubber created good sound attenuation. Yang et al. [11] studied straw—waste tire composites and showed that straw/recycled waste tire rubber composites had similar mechanical properties to wood/recycled tire rubber composites. Moreover, the straw/waste tire composites also possessed better sound insulation. More recently, Zhao et al. [12] showed that wood-waste tire rubber composite panel (WRCP) possesses better soundproof effect than that of commercial wood particleboard and composite floorboard. However, as far as we know, no studies about the sound insulation properties of biobased FPFs reinforced with waste tire particles had been published.

In this work, hydroxylated methyl esters and glycerol were obtained, respectively, as main and by-product of the chemical modification of tung oil, following a two-step procedure. First, fatty acid methyl esters and glycerol (GLY) were obtained by means of alkaline transesterification. Then, the resultant fatty acid methyl esters were modified by hydroxylation with performic acid generated *in situ*. In this way, hydroxyl groups (-OH) were added to the carbon chain, resulting in hydroxylated methyl esters derived from tung oil (HMETO). Both (HMETO and GLY) are multi-functional polyols that would allow modifying the cross-linking density and, consequently, the morphological, physical, mechanical and acoustic properties of the FPFs [9], and thus were used to change a formulation based on a commercial polyether polyol and a polyisocyanate. Furthermore, the foams were modified by the addition of waste tire particles (WTP) as filler of poor thermal and acoustic conduction. The effects of these changes on the mechanical and acoustic properties of the resulting foams were evaluated.

2. Materials and methods

The FPF formulation was based on a commercial polyether polyol (JEFFOL G31-35) provided by Huntsman Polyurethanes and modified with different contents of GLY or HMETO (with respect to the mass of the commercial polyol). Both natural polyols were derived following a two-step method which has been described elsewhere [9]. Waste tire particles (WTP) with an average diameter less than 2 mm were used as filler. For FPF preparation, the following reagents were used: a pre-polymer 4,4-diphenylmethane diisocyanate (pMDI) Rubinate 5005, Hunstman Polyurethanes; distilled water as blowing agent; Tergostab B8404 as surfactant agent (Hunstman Polyurethanes); n,n-dimethylbenzyl amine (DMBA, 99.9%) and dibutyltin dilaurate (DBLE, 99.9%), both from Sigma-Aldrich, as blowing and gelling control catalysts, respectively. The formulation was based on the same total mass of components by setting an isocyanate index = 1.1. Different amounts of GLY, HMETO and WTP were added to prepare FPFs, according to Table 1. In addition, 4 wt% of water, 1.5 wt% of surfactant, 3 wt% of DMBA and 1.5 wt% of DBLE, respect to the total polyol mass were added. The polyols were dehydrated under vacuum at 70 °C before use. Polyols, WTP, water, catalysts and surfactant were previously weighed and mechanically mixed for 20 s. Then, the pMDI was added and the whole system was mixed for another 20 s. The reactive mixture was placed in an open container and allowed to free rise at room temperature. The foams were stored for a week at room temperature prior to be characterized.

2.1. Characterization techniques

Apparent density was calculated as the ratio between the mass and the volume of cylindrical samples (28 mm diameter and 30 mm height) cut from the middle of the foams; the average values of four specimens of each sample are reported.

2.1.1. Scanning electron microscopy (SEM)

The surfaces of the foams were analyzed using a scanning electron microscope (JEOL, model JSM-6460 LV). Small specimens were cut from the middle of the foams in the direction of rise. The pieces were coated with gold before being observed under the microscope.

2.1.2. Compression tests

Cylindrical specimens of 28 mm diameter and 30 mm height were cut from the foams, and tested at room temperature in an INSTRON 8501 universal testing machine. The compression force was applied in the foam rise direction. At least four specimens taken from the center of the free raised foams were tested. Samples were first compressed to 80% of the original length at a crosshead speed of 10 mm/min. The average values of compression modulus (calculated as the slope of the stress-strain curve at low deformations), compressive strength (according to ASTM D1621 it was taken as the stress reached at the compressive yield point, since it occurs for all samples before 10% deformation) and densification strain (taken as the strain at the point of intersection between the horizontal plateau stress line and the backward extended densification line, as described in a previous paper [13], were calculated from these tests.

Then, the samples were unloaded and allowed to recover for 1 minute and 24 hours. The length reached after the recovery time (l_r) was compared to the initial specimen height (l_i) and used to calculate the recovery (R_r) ratio, as indicated in equation (1):

$$R_r = \frac{l_r}{l_i} \times 100 \quad (1)$$