Composites Part B 87 (2016) 21–26

Contents lists available at ScienceDirect

Composites Part B

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

Cellular structure control and sound absorption of polyolefin microlayer sheets

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ARTICLE INFO

Article history:
Received 28 July 2015
Received in revised form
21 September 2015
Accepted 24 September 2015
Available online 31 October 2015

Keywords:
Sound absorption
A. Foams
B. Microstructures
B. Mechanical properties

ABSTRACT

In this work, a novel microlayer foam/film sheet with alternating soft/soft layers was successfully made via the microlayer co-extrusion technology. A blend of linear low density polyethylene (LLDPE) with poly (ethylene-octene) elastomer (POE) and foamed POE were used as the film and foam layers, respectively. Cross-linked POE showed enhanced melt strength, enabling well-defined cellular structure in the foam layers of the microlayer structure. Meanwhile, this technique provides a new mean to obtain polyolefin foaming material with excellent sound absorption characteristics. In select wavelengths, the sound absorption coefficient of the microlayer foam/film structure improved 2–3 times compared with conventional single-layer materials. In addition, the mechanical properties of the foam/film sheets were also improved markedly through the multilayer assembly of foam/film layers at the micron scale.

1. Introduction

Polyolefin foams are considered as preferred foam materials in many industrial sound management applications due to their unique properties, such as thermal insulation, excellent chemical resistance, noise reduction, superior processibility and good mechanical properties [1,2,3,4,5] and [6]. Polyolefin elastomers (POE), when cross-linked, exhibit significantly enhanced melt strength and may be used to produce high quality foam products with exceptional heat aging, compression set, and weather resistance properties. It's well-known that the properties of the foams are determined by their structure, such as cell type, cell size and cell size distribution, which are, in turn, strongly dependent on the foaming condition [7,8,9,10,11,12,13,14] and [15]. Khemani and Park [16,17] and [18] revealed that many factors in the polymer extrusion process, including material property, blowing agent, nucleating agent, die temperature, die pressure, extruder head and screw design, etc., all have significant effects on the processing and properties of the extruded foam.

Polymeric foam structures can improve the sound waves absorption effectively through internal vibration and frictional loss of the sound waves in the cellular structure. It was widely used as sound absorbing materials in sound insulation and noise reduction engineering due to the good sound absorption performance. Moreover, Olek summarized four factors which were related to the sound absorption and the followings were included: (1) the thickness of the porous layer; (2) the porosity of surface layer; (3) air flow resistance of surface layer, and (4) the curvature of the pore connectivity [19]. Among these factors, the foam structure was most important affecting the sound absorption efficiency. However, most of the foam preparation methods are difficult to precisely control the foam cellular structure [20] and [21]. Therefore, foam preparation techniques which can produce foam materials with reduced density and good sound absorption performance are highly desirable in the study of sound absorption materials.

Hiltner demonstrated for the first time that high melt strength polypropylene foams with the foam/film structure and unique mechanical properties can be produced through the microlayer co-extrusion technology [22]. Furthermore, the foam/film structure can utilize different types of polymers. The co-extrusion technology provides a new method to prepare ordered foam structure with well-defined layer architecture and monodisperse cell size distribution. However, So far, there is a scant report in the literature about the new formula and structure design of microlayer foam/film materials and their acoustical property.

In this paper, we demonstrate highly efficient sound absorbing materials through structural and formulation designs using polyolefin foam and film layers alternatively. The unique structure

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http://dx.doi.org/10.1016/j.compositesb.2015.09.052
1359-8368/

effectively utilizes reflection, absorption and interface loss of sound wave propagation, resulting in increased energy transmission loss through the low density insulating material. The influence of layer number and layer thickness ratio on the sound absorption properties of the novel microlayer foam/film sheet structure is examined. The effect of layer number on the mechanical properties of the microlayer foam/film sheet will also be investigated.

2. Experimental

2.1. Materials

Poly (ethylene-octene) elastomer (POE ENGAGETM 8150, melt index = 0.5 g/10 min, density = 0.870 g/cm^3) was obtained from The Dow Chemical Company. LLDPE (DFDA-7042, melt index = 2 g/10 min, density = 0.918 g/cm^3) was made by Maoming Petrochemical Company. Dicumyl peroxide (DCP) was obtained from ACROS Organics Company. Talc was purchased from Guangxi Longguang Talc Development Co., Ltd, with average particle size of 4.5 μm. Azodicarbonamide (AC) was commercially available.

2.2. Specimen preparation

A POE composition comprising 0.3 phr DCP, 1 phr AC, and 0.5 phr Talc was mixed by a high-speed mixer. Then, the composite were compounded using HAAKE twin-screw extruder at 150 °C, and used as the foaming layer materials. Meanwhile, the film layer, comprising 50 phr POE, 50 phr LLDPE, and 0.3 phr DCP, was also prepared through the same melt-mixing process as did the foam layer material.

A microlayer co-extrusion equipment, shown in Fig. 1, consisting of two single-crew extruders, a feed block and a number of multiplying elements, water chill block, and haulage dram [23], was used to prepare the layered POE/PE-POE composite sheets. An assembly of n multiplying elements produced $2^{(n+1)}$ layers and was used to co-extrude the POE foaming sheets with alternating multilayered structure. POE and PE-POE composite were extruded from extruders A and B, respectively. These two melt streams were combined and controlled in a feedblock as two parallel layers. From the feedblock the two layers flowed through a series of multiplying elements and each element doubled the number of layers. In the multiplying element, the layered composites were first sliced vertically, then spread horizontally and finally recombined. In this work, an assembly of 0, 2, 4 multiplying elements produced 1, 8, 32 layers as shown in Fig. 2. The temperatures of zone1, zone2, zone3 and zone4 were set at 130 °C, 190 °C, 200 °C and 195 °C, respectively, from the hopper to the exit of the extruder. The temperature of multiplying element was 190 °C. Exit die was maintained at a colder temperature of 185 °C. In order to create a pressure drop, a nip roll set-up was used as a sheet take-off.

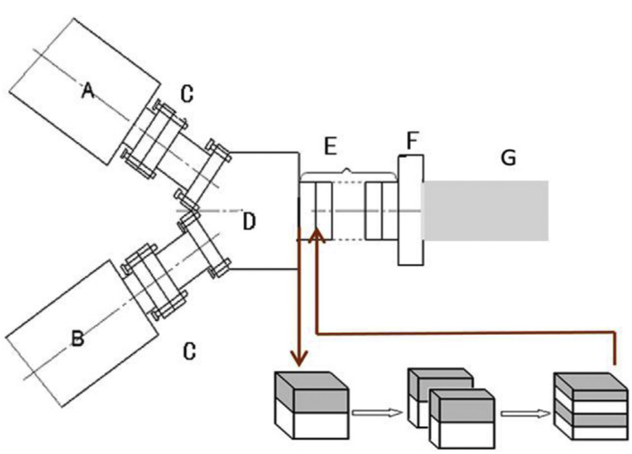

Fig. 1. Schematic of alternate microlayer co-extrusion system (A, B-extruder, C-connector, D-co-extrusion block, E-multiplying elements, F-die, G-sample).

2.3. Measurements and characterizations

2.3.1. Sound absorption testing

Sound absorption property was tested using a dual channel acoustic analyzer designed by Beijing Shengwang Acoustoelectric Technology Co., Ltd. Through testing the sound wave reflection and transmission at the surface of the test specimen, the acoustic parameters were calculated by material transfer function method. Three specimens were test to calculate the average value.

2.3.2. Rheological measurement

The thickness of the disc-shaped sample for the rheological measurement was 1.5 mm, and the diameter was 25 mm. The rheological experiment was conducted using TA rheometer (HR-2, TA Instruments, USA) with a 40 mm parallel plate fixture under a nitrogen atmosphere, and the strain amplitude was 1%. Measurements were performed in a frequency sweep of 0.01–100 Hz at 200 °C. All tests were performed after a preheating step about 3 min and nitrogen atmosphere protection was used during the whole process.

2.3.3. Crosslinking process analysis

A rubber processing analyzer (RPA2000P by Alpha Company, USA) was used to measure and analyze the cross-linking and blowing agent decomposition processes. The heating rate was 10 °C/min.

2.3.4. Tensile testing

Tensile specimens were obtained directly from the alternating multilayered foaming sheets and cut into the dumbbell-shaped samples. The tensile testing used an Instron 5567 tension machine (Instron Corporation, USA) at 23 °C, according to ASTMD 638, at the displacement rate of 50 mm/min. At least five specimens for each sample were tested and the average value was calculated.

2.3.5. Electron microscopy (SEM)

Electron microscopy images were obtained using a JSM-5900LV type (Japan) Scanning electron microscope (SEM). The liquid nitrogen fractured surface was sprayed with gold before SEM examination.

3. Result and discussion

Sound propagation through an interface such as interlayers in a microlayer structure can cause phase shift and reflection of the sound wave, and thus reduction of the transmitted sound wave intensity. The higher the difference in impedance of the adjacent layer materials toward sound propagation, the stronger the reflection will be at the interface. Therefore, a microlayer composite sheet with large differences in density or modulus between the adjacent layers is an effective mean to enhance sound absorption. One way to achieve high impedance difference between adjacent layers is incorporation of foam or highly filled composition or both [24]. Similarly, with increase of the number of layers, the reflection of the incident wave increases while the sound wave transmitted diminishes successively at each additional layer interface. Fig. 3 shows the schematic diagram of the sound wave propagation and reflection in a microlayer foam/film structure.