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NEW SOUND-ABSORBING FOAMS MADE FROM POLYOLEFIN RESINS

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ABSTRACT
Novel acoustical materials that can be used in a moist environment have been developed. The materials are large-celled foams prepared from polyolefin resins by the extrusion process. Macrocellular polyolefin foams absorb sound well even though the foams are closed-celled. Large cells facilitate cell opening by perforation. The sound insulation capability of perforated foam is shown to increase as the porosity of the foam increases.

1 - INTRODUCTION
Conventional acoustical materials have a number of drawbacks. Materials based on mineral fibers lack mechanical integrity and present a handling difficulty, while polyurethane and melamine-formaldehyde foams tend to undergo hydrolysis during prolonged exposure to moisture, and are not recyclable. These deficiencies are compounded by the fact that these porous materials absorb water during real-life uses, where they are often in contact with moist air or condensation. A moisture-resistant acoustical material that is recyclable has been in demand.
An acoustical foam product prepared from a hydrophobic thermoplastic resin could fill this demand. However, no such product with satisfactory acoustical performance has been offered to date. Methods of preparing open-cell polyolefin foams have been disclosed in the patent literature [1, 2, 3]. The literature says that open-cell foam can be prepared by mechanically crushing a crosslinked polyolefin foam [1] or by direct extrusion with a proper selection of the formulation and the expansion conditions [2, 3]. Current commercially offered open-cell polyolefin foams have less than satisfactory acoustical performance, and require secondary fabrication for acoustical uses [4]. Directly preparing a large-pored foam by an expansion process is difficult since cell opening interferes with foam expansion.
We conceived the idea of preparing an acoustical foam by opening the cells of a large-celled foam by perforation. Commercial polyolefin foams produced by the extrusion process have a cell size typically between about 1.2 mm and 2 mm. Opening the cells of such a foam by perforation is difficult. A foam having a large cell size would lend itself to ready cell opening by perforation. Conceptually, if the perforation distance is smaller than the cell size, most of the cells will be pierced open. In addition, perforation would facilitate opening of the remaining cells by compression crushing.

2 - EXPERIMENTAL PROCEDURE
The plank foams used in this study were produced by the conventional extrusion process from both a low density polyethylene (PE) resin and a 70/30 blend of a PE resin and an ethylene-styrene interpolymer (ESI) resin. The ESI resin used was INDEX (trademark of The Dow Chemical Company) DS 201 brand produced by The Dow Chemical Company. Reducing the amount of cell nucleating agent enlarged the cell size of the foams. Some of the foam products had already been perforated in the production plant in an approximately 10 mm $\times$ 10 mm square pattern in order to accelerate diffusion of the flammable blowing agent [5]. Additional holes were perforated through the foams with a 2 mm-diameter needle in a square pattern with a hole-to-hole distance of 5, 4 and 3 mm.

The cell size was determined per ASTM D-3756. Open cell contents of the foams were measured using cylindrical foam specimens of 29 mm in diameter and 55 mm in length per ASTM D-2856. The open cell calculation was done per Procedure A with a slight modification in order to subtract the large contribution of the surface cut cells to the specimen volume. The interior open cell content is expressed against the interior foam volume instead of the specimen volume. The interior foam volume is estimated by subtracting the surface foam volume (the void volume of surface cut cells and associated polymer volume) from the specimen volume.
The sound absorption coefficients of the foams were determined by the impedance tube method (ASTM E-1050) using specimens of 35 mm-thickness unless otherwise stated. A selected foam was tested by the reverberation room method (ASTM C-423). In addition, the perforated PE/ESI foam was exposed to a moist environment and its sound absorption coefficients were studied. Two 30 mm-thick specimens of 29 mm and 100 mm in diameter were let to absorb water by diffusion with one surface touching a 0°C plate and the other exposed to humid air at 50°C (EN 12088). The specimens were periodically tested for sound absorption as well as for water absorption. For comparison, a melamine-formaldehyde foam and a polyurethane foam were similarly tested.
The sound insulation performance of perforated polyolefin foams was measured as an insert in a sandwich panel. The panels were of 1.05 m $\times$ 2.05 m dimensions and faced with press wood sheets of 13 mm thickness. The foams were profiled into a low-stiffness configuration with a 35mm-thick core supported by 40 mm-wide and 7 mm-thick strips spaced in 337 mm distance alternately on the opposite side contacting the facers [6]. The sound transmission loss through the panels was measured at an outside testing facility and is reported in a weighted sound reduction index (R_w) per ISO R 717.

3 - RESULTS AND DISCUSSION

3.1 - Cell opening by perforation

As shown in Table 1, the polyolefin foams used in this study have relatively low densities and large cell sizes in the range from 1.7 mm to 6.5 mm. Foams other than PE 6.2 had already been perforated in the production plant in 10 mm x 10 mm pattern. The nascent foams were substantially closed-celled as indicated by PE 6.2 and judged from the open-cell contents of the perforated foams. The large-celled foams have large surface open-cell contents. The surface open cell content is the void volume of the cut surface cells as a percentage of the specimen volume. In Figure 1, almost all of the cells are shown to be opened when the cell size is greater than 1.2 times of the hole spacing.

Foam Desig.	Foam Density (kg/m^3)	Cell Size (mm)	Surface Open Cell Content (%)	Open Cell	
				Nascent Foam (%)	Perforated Foam (%)
PE 6.2	23	6.2	59	16	52
PE 4.4	32	4.4	41	–	21
PE 2.4	23	2.4	23	–	50
PE 1.7	40	1.7	18	–	15
PE/ESI	29	6.5	62	–	46

Table 1: Polyolefin foams used in this study.

3.2 - Sound absorption coefficients

Sound absorption coefficients of the nascent foams and the perforated (in 10 mm x 10 mm) foams are presented in Figures 2, Figure 3, respectively. Except for PE 6.2, the data so-called 'nascent' foams were generated with specimens prepared to receive the sound wave in a direction perpendicular to the perforation direction. In Figure 2, the nascent foams having large cells are shown to absorb sound well while those having smaller cells do not. That a closed-cell foam absorbs sound well is surprising. Perforation makes the foams having a medium-large cell size (PE 4.4 and PE 2.4) absorb sound noticeably better. Perforation has a minor impact on the sound absorption capability of the macrocellular foam (PE 6.2) and the small-celled foam (PE 1.7).
In Figure 4, the sound absorption coefficients of perforated PE 6.2 foam generated using the reverberation method are compared with those determined using the impedance tube. Except for a shift to the higher frequencies, the reverberation absorption curve resembles the impedance tube curve in the shape and the level.

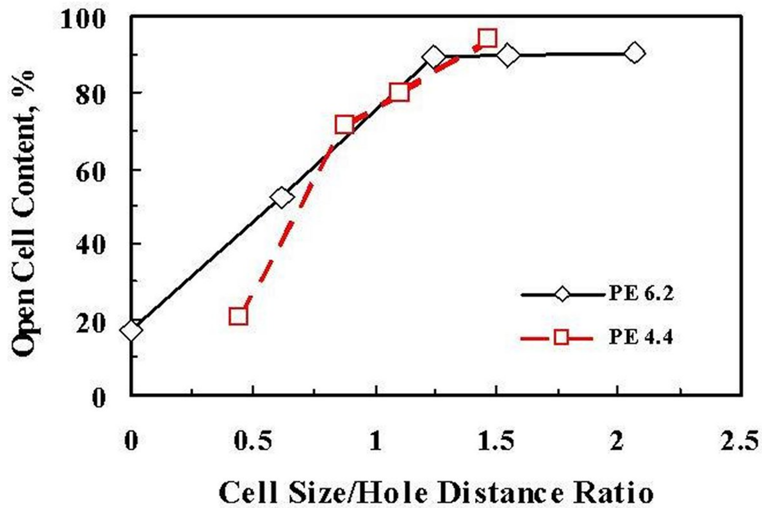

Figure 1: Cell opening by perforation.

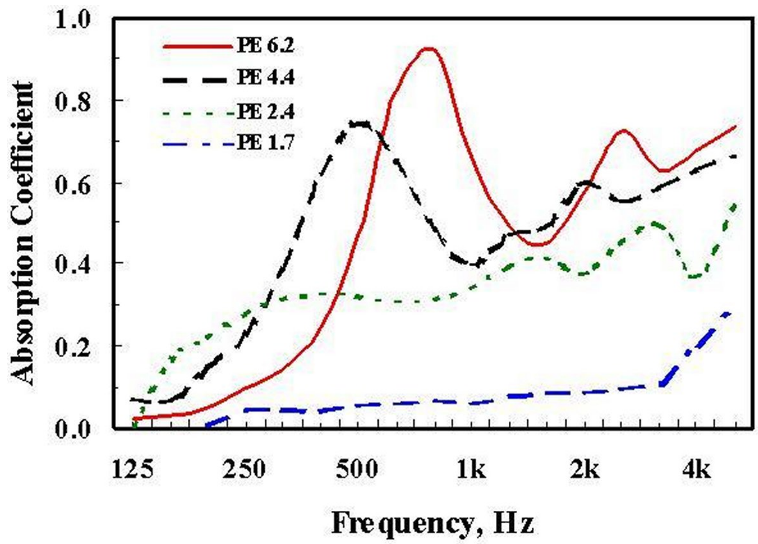

Figure 2: Sound absorption by nascent foams.

In Figure 5, the sound absorption curves of perforated PE 6.2 foam specimens of three different thickness are shown to gather together reasonably well when plotted against the frequency factor (thickness/wave length).

A multi-layer film model is proposed to explain sound absorption by a macrocelllular foam of substantially closed-cell structure. The cell walls of the low-density polyolefin foams are thin and flexible. The thin cell windows vibrate to the sound wave if the sizes are large enough. The vibration of the windows of the surface cells induces the inner windows to vibrate thereby letting the sound wave propagate into the foam body. The fluid motion in the cells against the solid matrix and the vibration of the cell windows result in dissipation of the acoustical energy.

3.3 - Sound absorption by foams exposed to moisture

In Figure 6, the macrocellular PE/ESI foam is shown to absorb much less water than the conventional thermoset foams. The data are for 100 mm-diameter specimens. The perforated PE/ESI foam absorbs less than 2 % water while the polyurethane foam absorbs 35 % and melamine-formaldehyde foam absorbs 63 % during a two-week exposure to condensing moisture. The water absorption has a dramatic impact on the sound absorption performance of melamine-formaldehyde foam (Fig. 7). The PE/ESI foam is relatively unaffected (Fig. 8).

3.4 - Sound insulation properties

In Figure 9, the sound reduction index (R_w) of sandwich panels cored with acoustical polyolefin foams

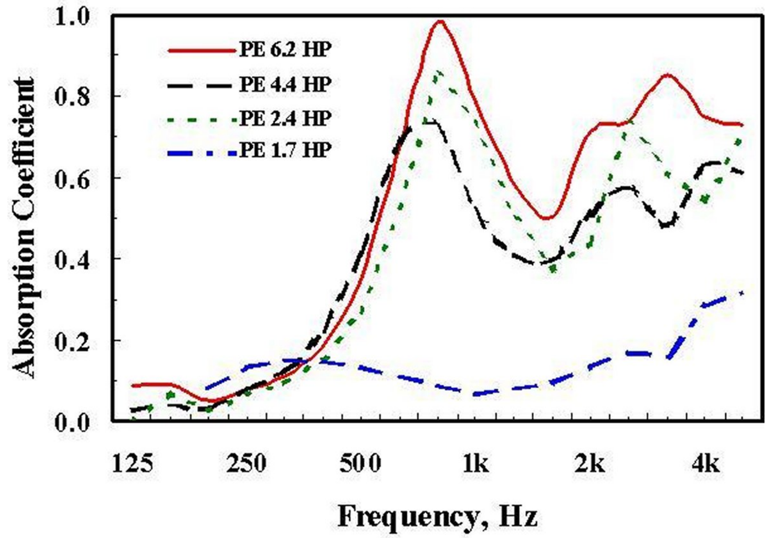

Figure 3: Sound absorption by perforated foams.

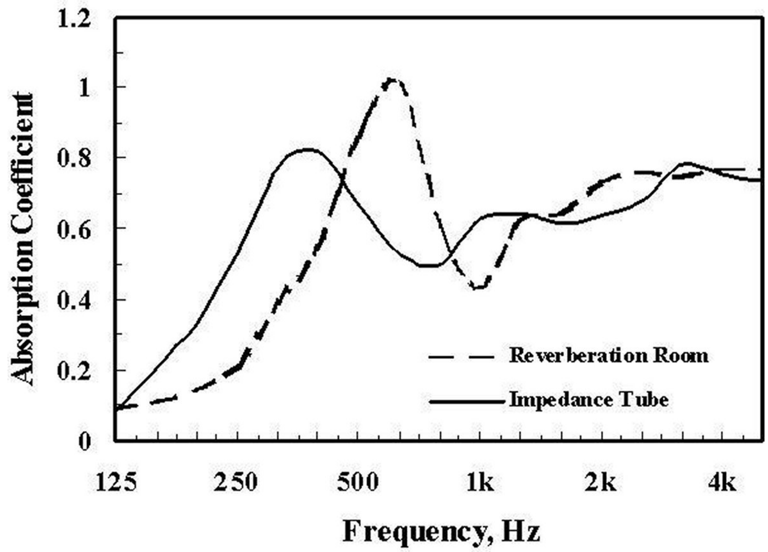

Figure 4: Sound absorption by two different test methods.

is represented against the open cell content (porosity). In general, the sound insulation capability of the open-cell polyolefin foams is shown to linearly increase with the porosity of the foams.

4 - CONCLUSIONS

Macrocellular polyolefin foams absorb sound even though the foams are closed-celled. Large cells facilitate cell opening by perforation thereby preparation of acoustical foams. The sound insulation capability of the foam increases as the porosity of the foam increases. The acoustical polyolefin foams are suitable for the management of noise in a moist environment.

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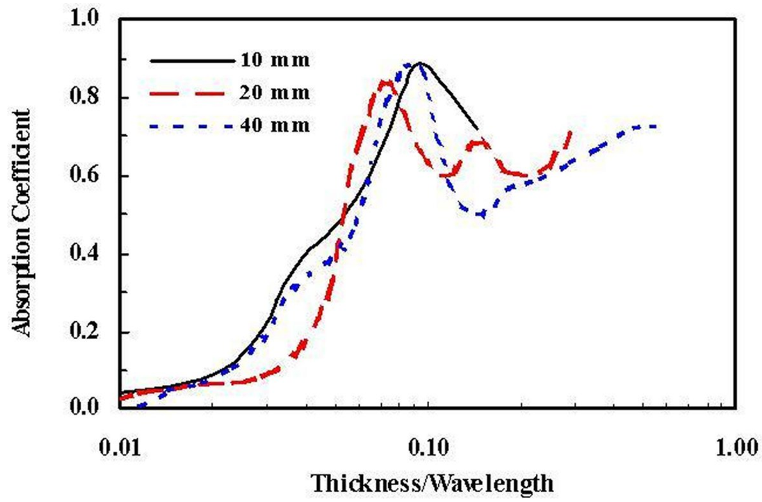

Figure 5: Thickness effect on sound absorption.

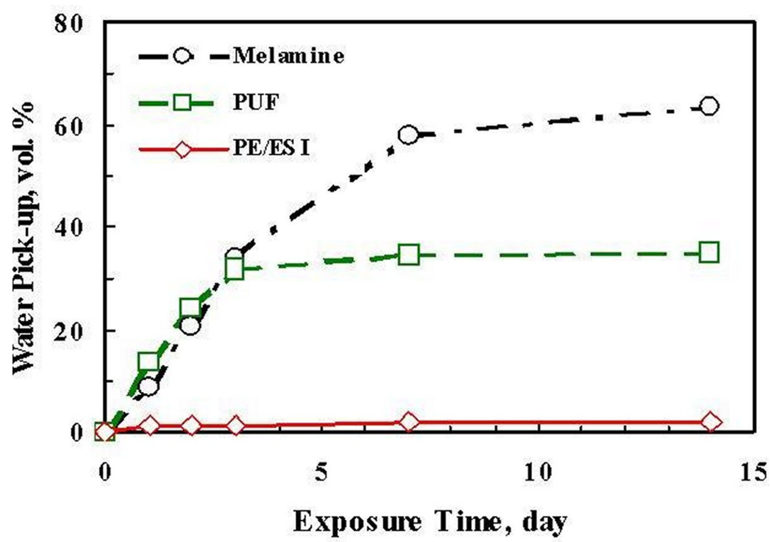

Figure 6: Water absorption by acoustical foams.

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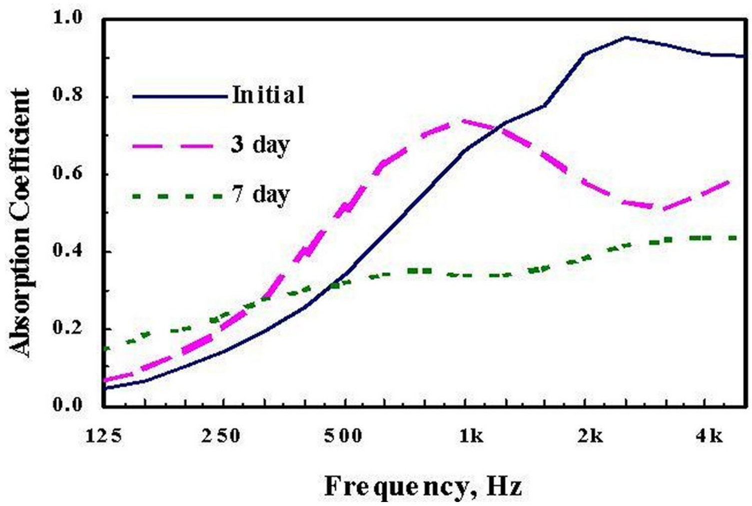

Figure 7: Sound absorption by water-absorbed melamine-formalhedyde foam.

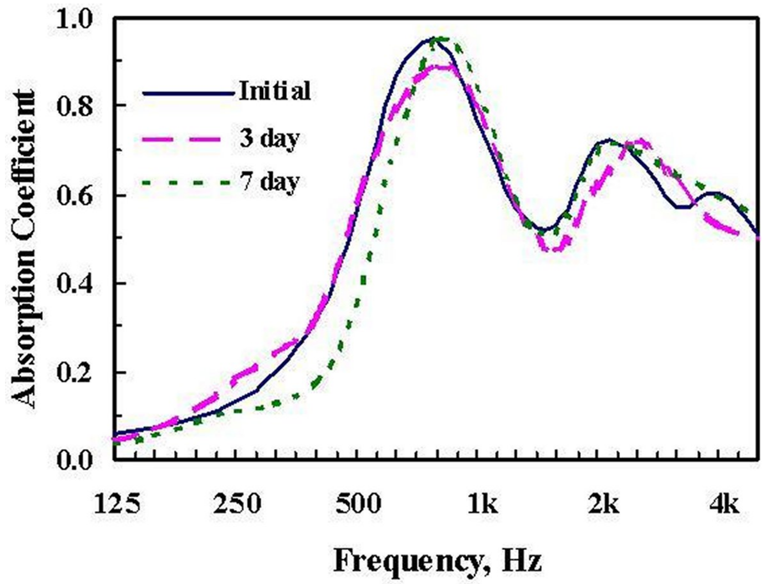

Figure 8: Sound absorption by water-absorbed PE/ESI foam.

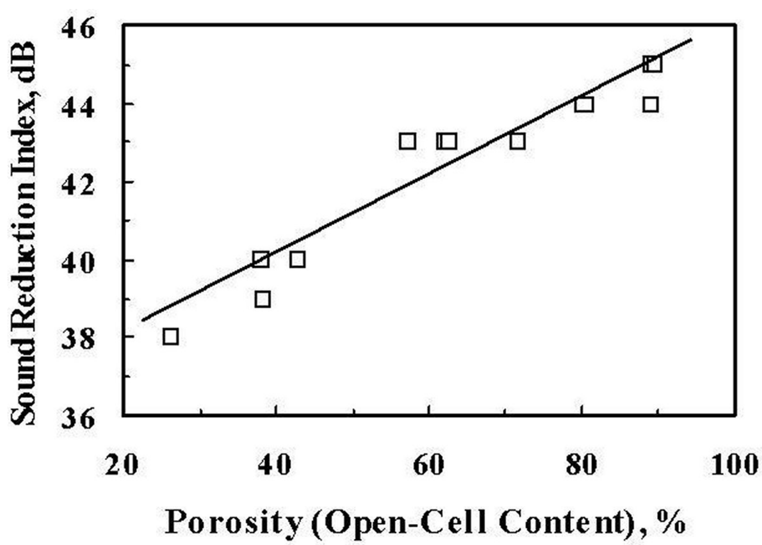

Figure 9: Sound reduction index (R_w) vs. porosity.