United States Patent

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[72] Inventor Bonderinko Hollenbeck
Pelham, N.H.
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[73] Assignee W. R. Grace & Co.
Cambridge, Mass.

[54] **LEAD-LOADED MICROPOROUS ACOUSTIC PANEL**
4 Claims, 3 Drawing Figs.

[52] U.S. Cl. .... **181/33 G,** 181/33 GA, 161/159
[51] Int. Cl. **E04b 1/86,** B32b 3/26, B32b 5/18
[50] Field of Search 181/33, 33.1, 33.11; 161/159–161

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Primary Examiner—Robert S. Ward, Jr.
Attorneys—William L. Baker, C. E. Parker, Metro Kalimon and Theodore C. Browne

ABSTRACT: Sound, particularly airborne sound, is attenuated using a microporous sheet of a resilient, normally solid polymeric material (e.g. polyethylene), which sheet has finely divided lead particles uniformly dispersed therein.

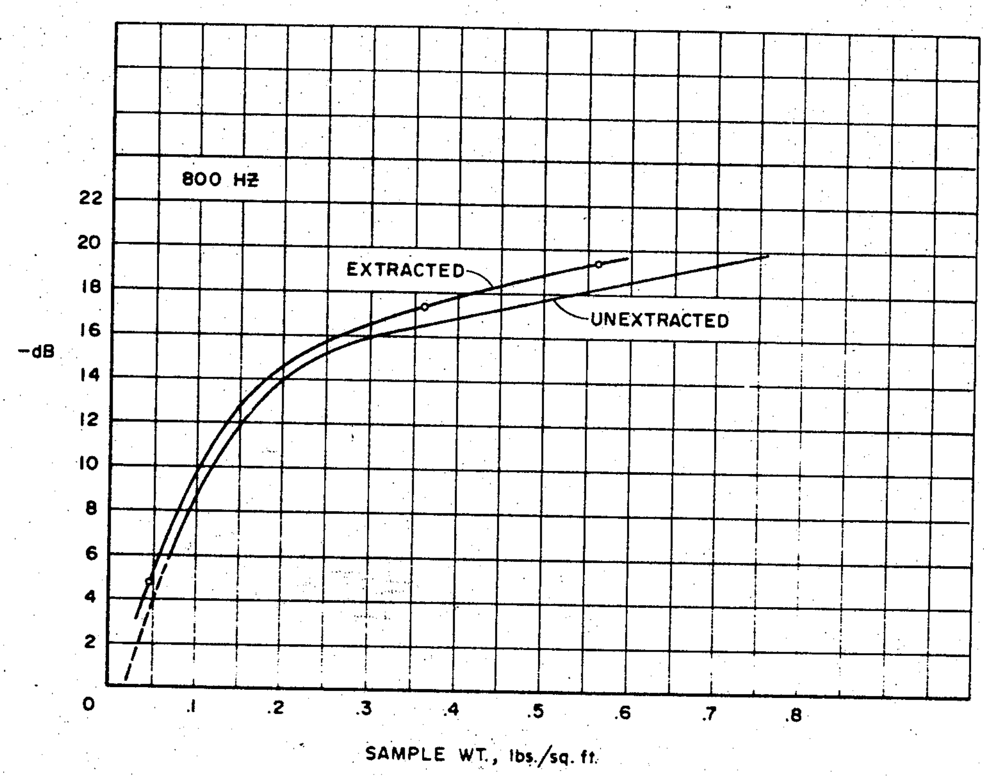
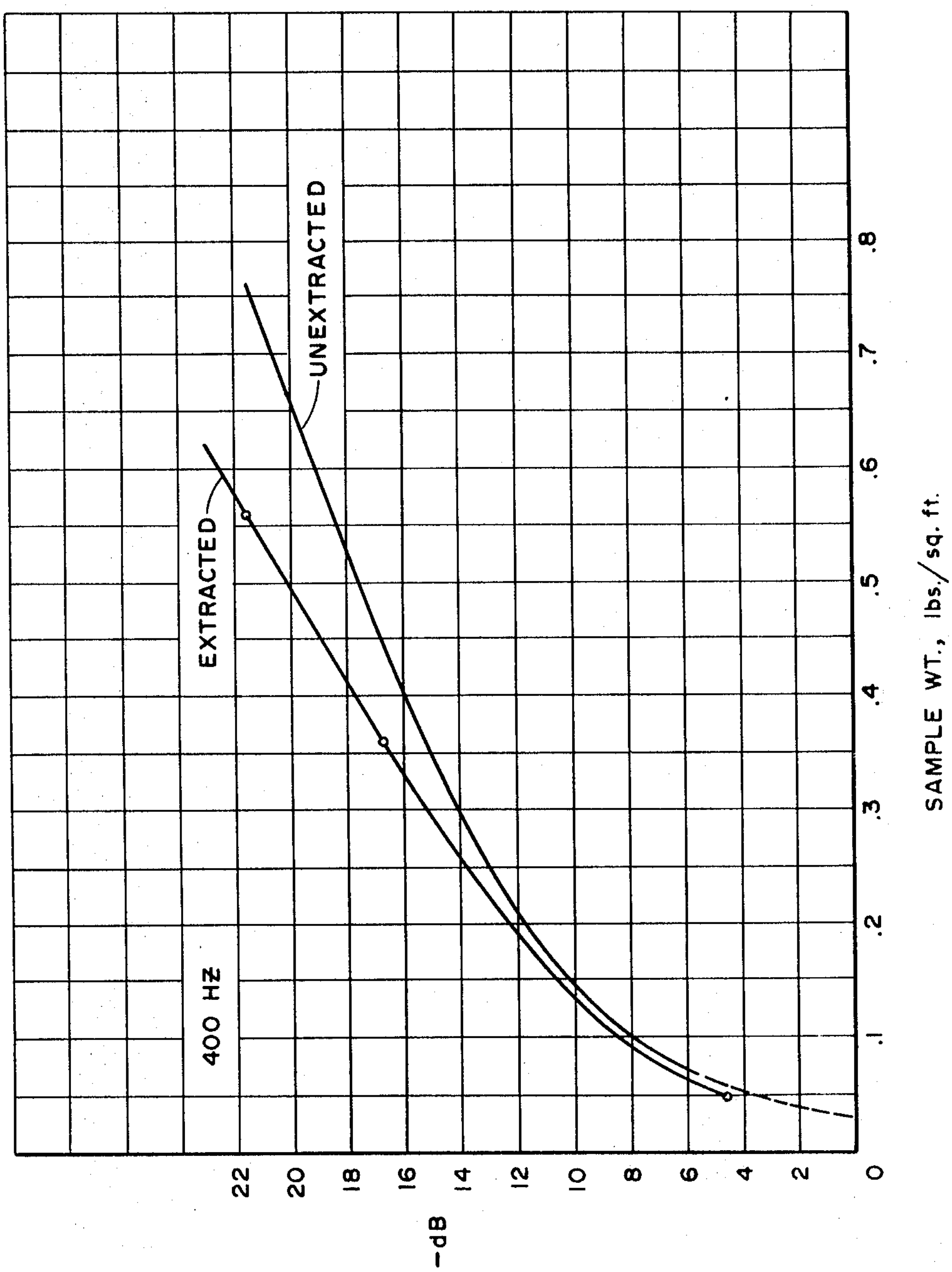


FIG. 1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SAMPLE WT., lbs./sq. ft.

FIG. 2

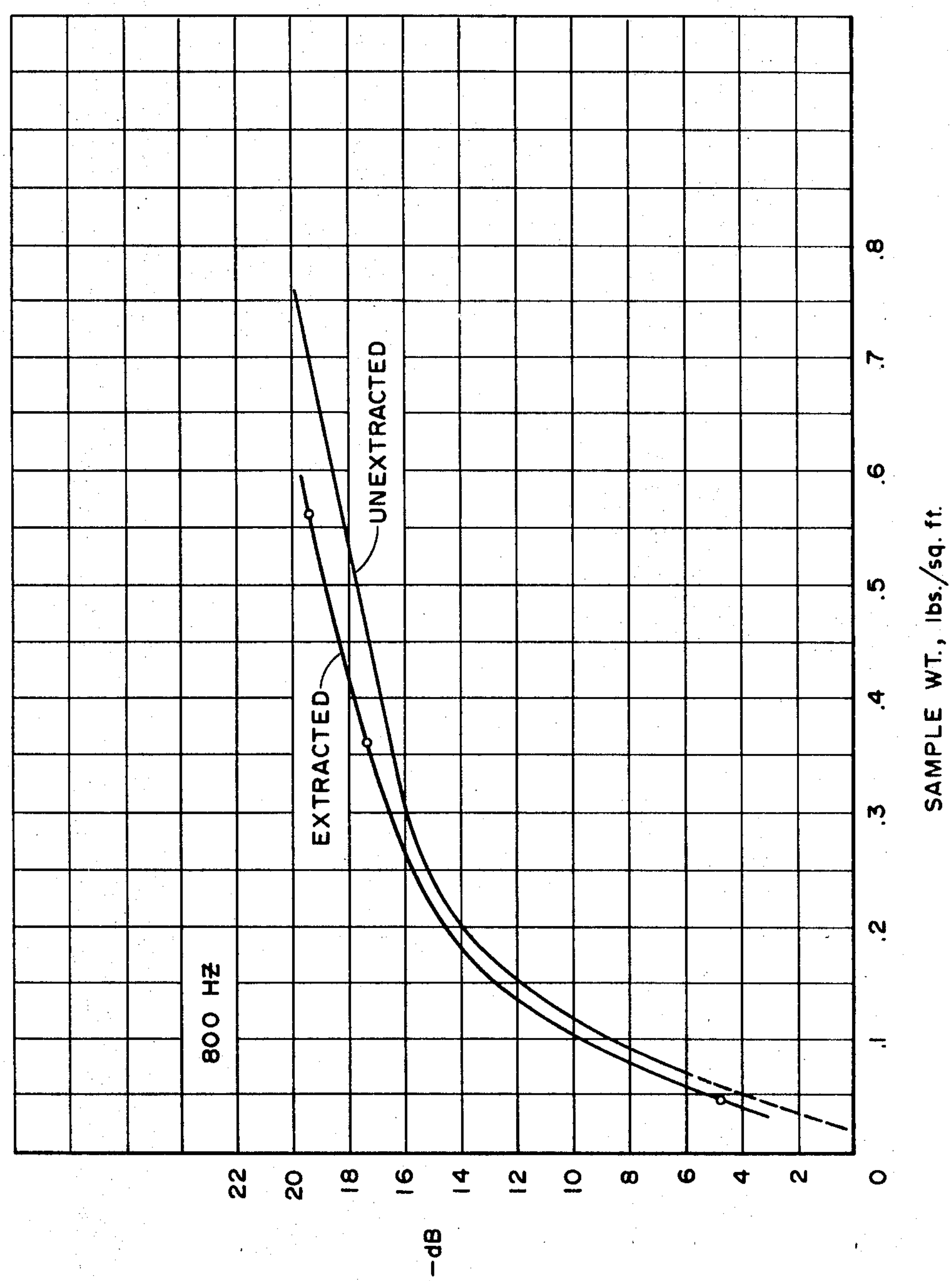
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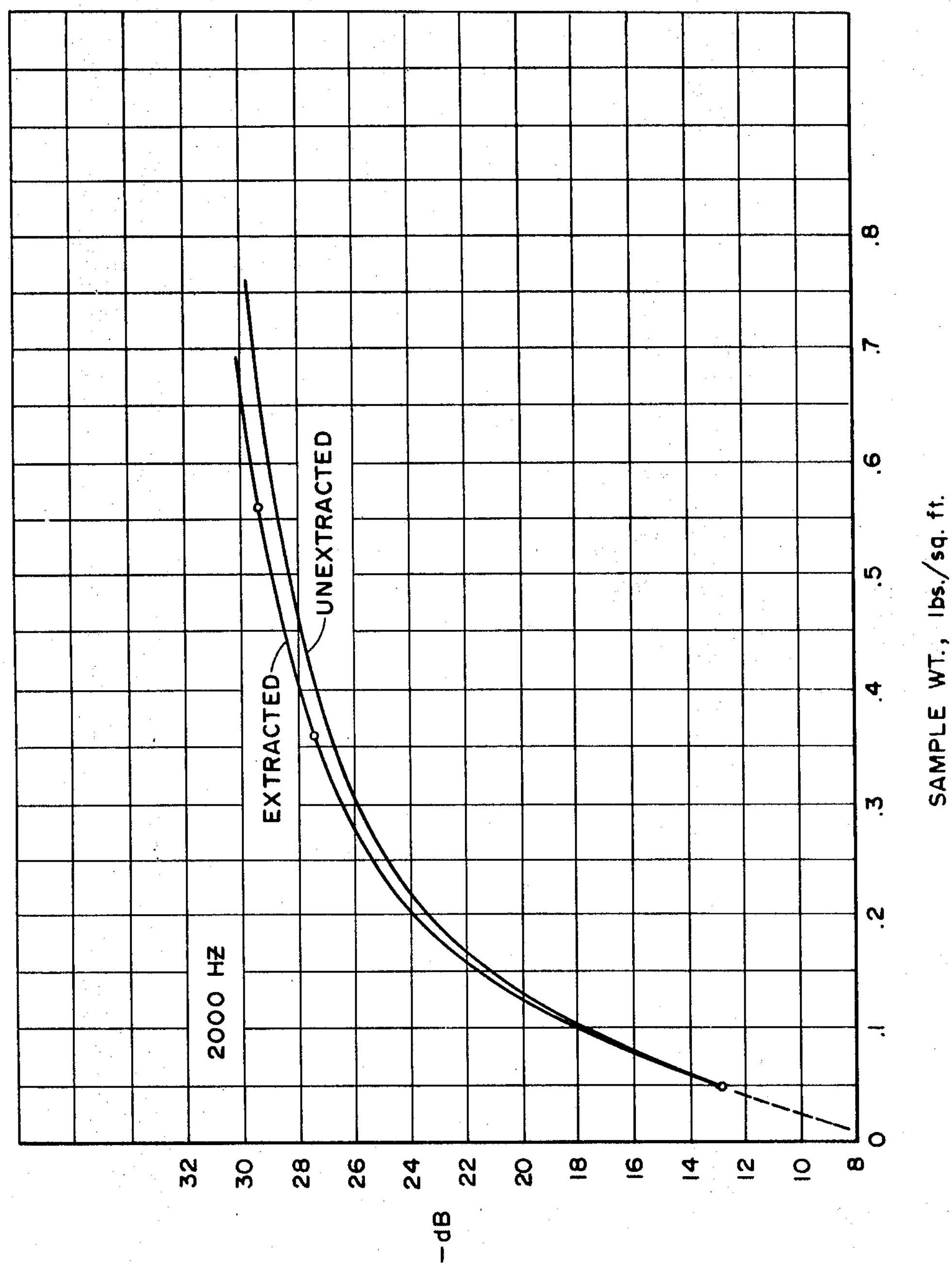
FIG. 3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LEAD-LOADED MICROPOROUS ACOUSTIC PANEL

This invention relates to a method of attenuating sound, and, more particularly, to a method of attenuating sound using a lightweight sheet material having excellent sound attenuating properties.

Of increasing concern to architects and structural engineers is the problem of unwanted sound or noise. Of particular concern is the problem regarding noise transmitted by pressure waves in the air, often termed airborne noise. One major contributing factor is the increase in the sources of airborne noise, for example, urban population, automotive vehicles, appliances and machinery, etc. The result is a demand for better and more efficient methods and materials for reducing undesirable sound, particularly air-transmitted sound.

The reduction of sound has been often accomplished in the past through the use of sheet lead. The superior performance of sheet lead barriers as airborne sound-attenuating media, for instance, over other barrier materials has been attributed to sheet lead's high density, freedom from stiffness, good damping capacity and integrity as a nonpermeable membrane. Sheet lead, however, is heavy making it costly to ship and manipulate. Moreover, thin lead sheet is easy to tear when handled.

A material has now been found which is ideally suited for use as a sound-deadener, especially in the form of a barrier for deadening airborne sound. The material comprises a lightweight, microporous, resilient, normally solid, polymeric material containing uniformly dispersed finely divided lead particles. It has been discovered that such a sheet is similar in performance to sheet lead of equivalent weight per area with respect to the attenuation of sound, particularly airborne sound. Such an advantageous result is somewhat unexpected in view of the fact that porous or permeable materials in the past have been considered to be undesirable for use as airborne sound-attenuating media. The lightweight sheets of the invention, for example of less than about 1 pound per square foot, have high strength and high attenuation performance as compared to lead sheet. The present discovery enables effective airborne sound deadening with less costly, lighter weight, flexible barrier materials. Moreover, when the pores of the material of the present invention are interconnecting or "open," the material is permeable, permitting good oxygen/water vapor transmission in applications where such transmission is critical or desirable. The mechanisms accountable for the highly desirable sound attenuating characteristics of the porous material of the invention even when the pores are open are not completely understood.

The sound-attenuating material of the invention is preferably employed in the form of a sheet or film, having a thickness, generally, of from 10 to 200 mils. In use for reducing airborne sound the material of the invention is preferably employed in the form of a sheet secured to a conventional construction material such as, for example, gypsum board, wood, rock wool or fiberglass batt, functioning as a barrier between the source of the unwanted sound the point of reception. It can also be used effectively hung in plenums in a fashion similar to lead sheet.

The amount of lead dispersed in the porous material of the invention can vary over a relatively wide range. At least an amount of lead is employed which is sufficient to effect sound attenuation. Generally, the material will contain about 5 to 80, preferably about 10 to 25, percent by weight of resilient, normally solid polymeric material and about 20 to 95, preferably about 45 to 75 percent by weight of lead particles. Additional optional additives, for instance, other fillers such as silica, high density ore particles and carbon black, stabilizers, flame retardants, plasticizers, antioxidants, processing aids, etc., can be used in an amount of up to about 50 weight percent.

By the term microporous as used here and in the claims is intended a material possessing pores having an average diameter in the range of about 0.01 to about 10 microns. The pores can be open, as mentioned above, or closed, that is, noninterconnecting. The void volume of the porous material of the invention will generally be in the range of about 30 to 70 percent. Preferably, as an airborne sound attenuating barrier, the material has an average pore diameter in the range of about 0.01 to 1 and a void volume of about 40 to 60 percent.

The normally solid polymeric material in which the lead particles are dispersed should be resilient in order to allow for flexibility. Suitable normally solid resilient polymeric materials include thermoplastic resins, for example, polyolefins such as polyethylene, polybutene, polypropylene, etc., and vinyl polymers such as polymers of vinyl chloride, vinyl acetate, vinyl alcohol, etc., natural and synthetic elastomeric materials such as natural rubber, butyl rubber, polyurethane rubber, acrylonitrile polymers, etc.; as well as copolymers of the aforementioned materials.

Finely divided lead powder or dust having an apparent diameter of less than **40** microns is preferably employed in the porous material of the invention. Compounds containing lead such as lead oxide, lead silicate, lead sulfide, etc., can also be used and the term "lead particles" as employed in the specification and the claims is intended to include elemental lead, and compounds of lead which would not have a deleterious or undesirable affect, for example be highly toxic, on the finished material of the invention.

The porous sound deadening material of the invention can be prepared by any of the suitable known polymer processing techniques. For instance a microporous sheet can be prepared by mixing a particulate, resilient, normally solid polymeric material such as polyethylene with a liquid solvent, for instance, hydrocarbon, or with a particulate solid material and heated to a temperature above the melting point of the polymer but below the decomposition temperature of solid liquid solvent or particulate solid material, molded or suitably shaped and then cooled to a temperature below the hardening point of the polymer. The liquid solvent or particulate solid can then be removed by known techniques, for example, evaporation, extraction with a solvent for the liquid or particulate solid which is a nonsolvent for the polymer, etc. The liquid solvent or particulate material removed to form the pore structure of the final material may be one which is capable of plasticizing the resilient, normally solid polymeric material employed. Thus a small amount of the material can be left in the final porous product to produce a more flexible product.

The porous sound-attenuating materials of the invention can also be prepared using foaming or blowing agents such as azobisbutylnitrile, celogen, etc.

In the present invention, a polyolefin such as polyethylene is preferably employed as the resilient normally solid polymeric material. Suitable pore-forming agents for use with the polyolefin may be soluble or insoluble in water. Representative of the water-insoluble pore-forming agents are organic esters such as the sebacates, phthalates, stearates, adipates and citrates; epoxy compounds such as epoxidized vegetable oil; phosphate esters such as tricresyl phosphate; hydrocarbon materials such as petroleum oil including lubricating oils and fuel oils, hydrocarbon resin and asphalt and pure compounds such as eicosane; low molecular weight polymers such as polyisobutylene, polybutadiene, polystyrene, atactic polypropylene, ethylenepropylene rubber; ethylene-vinyl acetate copolymer, oxidized polyethylene coumarone-indene resins and terpene resins; tall oil and linseed oil.

Illustrative of the water-soluble pore-forming agents are ethylene glycol, polyethylene glycol, polypropylene glycol, clycerol, and ethers and esters thereof; alkyl phosphates such astriethyl phosphate; polyvinyl alcohol; polyacrylic acid and polyvinyl pyrrolidone.

Suitable extracting solvents for the above pore-forming agents which are nonsolvents for the polyolefin will be evident to those skilled in the art. In the present invention, petroleum mineral oil is the preferred solvent pore-forming agent and suitable extracting solvents for the petroleum mineral oil include chlorinated hydrocarbons; such as trichloroethylene, tetrachloroethylene, carbon tetrachloride, methylene chloride, tetrachloroethane, etc.; hydrocarbon solvents such as hexane, benzene, petroleum ether, toluene, cyclohexane, gasoline, etc.

The polyolefin and pore-forming agent can be mixed by any conventional manner which will produce a substantially uniform mixture. To produce a particularly uniform mixture, the components can be premixed at room temperature in a blender. The polyolefin pore-former blends may then be fluxed in a conventional mixer such as a Banbury mixer or melt homogenized in a convention two roll mill.

After being suitably mixed, the composition is molded or shaped in any conventional manner. Specifically, it can be fed to an extrusion, calendering, injection molding, or compression molding machine to be processed into its final form.

Extraction of the shaped polyolefinic material may be carried out at a temperature which can range anywhere from room temperature up to the melting point of the polyolefin as long as the polyolefin does not dissolve. The time of the extraction will vary depending on the temperature used and the nature of the pore forming agent being extracted. For example, when a higher temperature is sued, the extraction time for petroleum mineral oil of low viscosity can be only a few minutes, whereas if the extraction is performed at room temperature, the time required for extraction of a polymeric pore-forming agent can be in the order of several hours.

The invention is further illustrated by the following examples:

EXAMPLE 1

A composition containing **10** parts by weight of an ethylene-butene copolymer (**99** mole percent ethylene-**1** mole percent butene), **27** parts by weight of petroleum oil ("Shellflex 411," 547 SSU at 110° F.), **43** parts by weight of lead oxide, **12** parts by weight of amorphous silica, 1.5 parts by weight of an antioxidant, and **1** part by weight of carbon black, was added to a Hobart mixer and mixed until a uniform blend was achieved. The blend was then introduced to a standard extruder to which was attached a sheeting die. The temperature profile along the length of the extruder from the feed end to the die end progressively decreased from 325° F. to 305° F. and the die temperature held at 300° F. The extruded sheet was then immersed in hexane for 1 hour to extract the oil. The extracted sheet was 0.135 inches thick and weighed 0.90 lbs. per sq. ft.

The microporous sheet produced in Example I was tested for airborne sound attenuation properties according to the procedure and specifications of ASTM E90-66T. In this test, the sound insulating property of a partition element is expressed in terms of the sound transmission loss. The sample to be tested is mounted as a 4'×8' **partition between two reverberation rooms, one of which, the source room, contains one or more sound sources. The rooms are so arranged and constructed that the only significant sound transmission between them is through the test specimen. The transmission loss is the difference expressed in sound of sound incident on the test partition to the sound power transmitted through and radiated by the partition. Measurements are made in a series of frequency bands.**

Table I gives the results obtained in three specific tests of the sheet prepared in Example I. For comparative purposes, a lead sheet having a thickness of 0.150 inches and a weight of 0.98 lbs. per sq. ft. was subjected to the same three tests.

In Test I, the material to be tested is employed as the partition in the form of a free hanging sheet. The sheet was fastened to wood stops that had been attached to the test opening on the receiving room side. The joint between the perimeter of the test sheet and the test opening was sealed with a flexible mastic.

In Test II, the material is tested as part of a simulated floor-ceiling assembly. The simulated floor assembly used as the partition consisted of a 5/8 inch plywood floor, 2' by 8' wood joints spaced 16 inches o.c., ceiling side, 3/8 inch thick gypsumboard nailed to the joints with 1/2 inch thick acoustical tile glued in a typical manner. The material to be tested for sound attenuation is placed adjacent the plywood. For comparative purposes, the assembly is first tested without the test material adjacently placed.

In Test III, the material is tested in a simulated wall assembly. In this test, the partition consisted of 1/2 inch thick gypsum board on both sides of 2'×4' wood studs placed 16 inches o.c. The material to be tested is placed behind gypsum board on one side only and held in place by the board. For purposes of comparison, the assembly is first tested without the test material included.

A single figure rating, the Sound Transmission Class, of the performance of the materials tested in the above tests was calculated from the transmission loss data, according to the method described in "Determination of Sound Transmission Class (RM 14–2)," American Standard Acoustical Terminology, S1.1, American Standards Association. In this method, the sound transmission loss values at the test frequencies centered between 125 and 4000 Hertz are compared with those of a reference contour (the STC contour). The Sound Transmission Class for each of the materials tested in each test is reported in Table I.

From the results shown in Table I it can be seen that the sheet of the invention functions ideally as a sound attenuator. In Test I, wherein the materials were tested as free hanging sheets, the sheet of the invention exhibited a Sound Transmission Class rating very nearly that exhibited by the lead sheet,

TABLE I

	Sound transmission loss [1]							
	Test I		Test II			Test III		
	Sheet of Ex. 1	Lead sheet	Control	Sheet of Ex. I	Lead sheet	Control	Sheet of Ex. I	Lead sheet
Frequency (Hertz):								
100	12	12	17	20	19	17	19	21
125	14	15	19	22	21	17	21	19
160	15	15	24	25	25	26	28	24
200	16	16	28	33	23	32	33	31
250	18	19	33	39	37	37	39	39
315	19	20	38	41	40	34	37	35
400	20	21	40	43	41	42	42	40
500	22	22	40	43	43	43	44	43
630	23	24	45	47	46	45	46	45
800	25	25	48	48	48	46	48	47
1,000	26	27	48	48	51	48	49	49
1,250	28	29	50	51	52	49	52	52
1,600	30	31	51	54	54	50	53	53
2,000	32	32	52	56	56	50	54	54
2,500	33	34	55	59	58	46	53	52
3,150	35	35	55	59	58	44	57	49
4,000	36	36	54	60	59	46	53	52
5,000	37	38	56	60	60	50	56	55
Sound transmission class [2]	26	27	43	46	45	41	45	43

[1] According to ASTM E90-66T.

[2] According to ASTM E90-66T and American Standard Acoustical Terminology, American Standards Assn. (RM 14-2).

even though the sheet of the invention was lighter in weight. In fact, in Tests II and III, wherein the materials are tested in a simulated floor-ceiling assembly and wall assembly, respectively, the sheet of the invention surprisingly exhibited a sound transmission class rating equal to or higher than that of the lead sheet.

The significance of the porosity of the sound attenuating material of the invention is illustrated by the following Examples.

EXAMPLES II–V

Four sheets having the thicknesses shown in Table II were prepared using the ingredients and procedure of Example I except that the extraction step was omitted. Two adjacent samples, each 12 inches by 12 inches, were cut from each of the unextracted sheets and one each of the samples extracted with hexane as in Example I. The weight of each of the unextracted and extracted samples is given in Table II.

TABLE II

		Wt. (Lbs./Sq.Ft.)	
	Thickness (Mils)	Unextracted (Nonporous)	Extracted (Porous)
Example II	9	0.07	0.05
Example III	33	0.30	0.22
Example IV	55	0.51	0.36
Example V	80	0.76	0.56

The unextracted and extracted sheets of Examples II–V were tested for sound attenuation properties in a sound chamber constructed of 3/4 inches plywood having an internal volume of approximately 53 cubic feet and which is internally insulated with glass wool. Within the chamber is a speaker enclosure having an internal volume of approximately 0.5 cubic foot. The speaker enclosure is constructed of 3/4 inches plywood with one inch inner wall of sound deadening tile. A section of the speaker enclosure swings open to allow for insertion of the test specimen. The speaker is 8 inch–8ohms. A signal is generated by an RCA WA–44C signal generator. This is fed through one channel of a Lafayette LA 224T stereo amplifier to the speaker, across which the output voltage is noted. A dynamic microphone is centrally located in the main body of the sound chamber and is separated from the speaker by the test specimen. The microphone detects the speaker output and delivers its voltage to the second channel of the amplifier. The appropriate output is terminated with a ten ohm wire wound resistor across which the output voltage is monitored with a Simpson AC VT VM (.001 to 300 volts) and an oscilloscope for wave form observation. Signals are generated at selected frequencies of 200, 400, 600, 800, 1000, 2000 and 4000 hertz. The drop in decibels of the signal as it passes through the test specimen is calculated as follows:

$$20 \log_{10}(V_a/V_b)$$

where V_a is the voltage across mike output, with no test specimen and V_b is the voltage across mike output with the test specimen. The loss in sound transmission for each sample tested at the various frequencies is shown in Table III.

A direct comparison of the sound attenuation performance data listed in Table II of the extracted and unextracted sheets of Examples II–V can be obtained by plotting the sound transmission loss data obtained for both the extracted and unextracted sheets as a function of the weight per square foot of the sheet at selected frequencies. The graphs shown in FIG. 1, 2 and 3 portray the performance of the extracted and unextracted sheets as a function of their weight per square foot at the frequencies of 400, 800 and 2000 Hertz, respectively.

It is readily seen from FIGS. 1–3 that the extracted or porous samples performed equally to, or better than the unextracted or nonporous samples with regards to sound attenuation.

This same performance can also be demonstrated by calculating the expected sound attenuation performance of the extracted sheet according to the mass law and comparing this with the actual performance obtained. The difference in weight per square foot between the unextracted and extracted samples is measured and the mass law applied to calculate the decrease in sound attenuation to be expected by the loss (difference) in mass. This calculated loss is subtracted from the measured unextracted sound data to provide sound attenuation data of an unextracted sheet having a mass equal to the extracted samples. The mass law unextracted data, calculated from the measured unextracted data, when compared with the measured data of the extracted samples obtained above, confirmed that, for all four thicknesses of sample materials the extracted or porous samples exhibited at least equal, or improved, sound attenuation properties over the unextracted or nonporous samples of equal weight.

The porous sheet materials obtained in the following Examples also exhibit sound attenuating properties:

EXAMPLE VI

A porous sheet weighing 0.225 pounds per square foot was prepared using the ingredients and the procedure of Example I, except that a polyethylene homopolymer having a molecular weight of about 1 million was employed in place of the ethylene coploymer.

EXAMPLE VII

Ten parts by weight of a polyvinyl chloride homopolymer having an inherent viscosity of 1.062–1.160 (Geon 101 EP) is introduced to a Banbury Mixer along with 12 parts by weight of amorphous silica, 43 parts by weight of lead oxide, 31 parts by weight of dioctyl phthalate plasticizer, 1 part by weight carbon black and 1.5 parts by weight of an antioxidant. The ingredients were mixed at a temperature of about 250° F. until homogeneous. The homogeneous mass was formed into a thin sheet weighing 0.46 pounds per square foot on a roll mill.

EXAMPLE VIII

115 parts by weight of natural rubber are uniformly mixed with 58 parts by weight sulfur, 6 parts by weight of stearic acid, 250 parts by weight of silica gel, 215 parts by weight water and 257 parts by weight of lead oxide and the uniform mix molded into a sheet at a temperature of 275° F. The sheet was then heated to a temperature of 220° F. to evaporate the water.

TABLE III

	Sound transmission Loss (db)							
	Example I		Example III		Example IV		Example V	
Frequency (H₂)	Ext.	Non-ext.	Ext.	Non-ext.	Ext.	Non-ext.	Ext.	Non-ext.
200	4	4	11.5	12.5	12.9	15	3.5	19
400	4.8	5.7	12.9	14	17.0	17.9	21.3	21.5
600	4.8	6.1	12.1	14.6	16.1	18.6	19.1	20.9
800	4.9	6.0	12.8	16	17.5	17.9	19.3	20
1,000	7.3	7.9	17.8	19.5	21.8	22.9	23.2	24.5
2,000	13	15	23.5	25.9	27.1	28.2	29	29.9
4,000	24.7	26	32.5	33	33	33.4	34	33.7

I claim:

1. A sound attenuation barrier comprising a layer of construction material, and, adjacent said layer, a microporous sheet comprising resilient normally solid polymeric material containing about 20 to 95 percent by weight of finely divided lead particles uniformly dispersed therein, said pores being interconnecting and having an average diameter of about 0.01 to 10 microns.

2. The barrier of claim 1 wherein said finely divided lead particles comprise particles of lead oxide.

3. The barrier of claim 6 wherein said polymeric material is a polyolefin.

4. A sound attenuating barrier comprising a layer of construction material, and, adjacent said layer, a microporous sheet comprising a resilient normally solid polyolefin containing about 20 to 95 percent by weight of finely divided lead particles uniformly dispersed therein, said pores being interconnecting and having an average diameter in the range of about 0.01 to 1 microns and said sheet having a void volume in the range of about 30 to 70 percent.