# Studies of Acoustical Absorption of Flexible Polyurethane Foam

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## Synopsis

It was confirmed that one of the principal factors which influences the acoustical absorption of flexible polyurethane foam is flow resistance of foam. Normal polyester-based flexible polyurethane foam itself has an adequate value of flow resistance and shows fairly good sound absorption. Acoustical absorption of normal polyether-based flexible polyurethane foam, which generally has lower flow resistance, can be improved by using some expedients such as setting up a certain skin layer on the foam surface so that the flow resistance of the foam can be increased. Surface treatment of foam such as gluing film, heat melting, spraying, or heat adhesion with film can not only improve sound absorption and mechanical properties of polyether-based flexible polyurethane foam, but also improve the hydrolysis resistance of polyester-based flexible polyurethane foam. Inserting some metal foil or plastic film between flexible polyurethane foams can change the sound absorption behavior according to the position of the foil or the film in the foam. The effects of foam thickness, existence of air layer behind foam, and foam profiling on acoustic absorption were also investigated.

## INTRODUCTION

Various kinds of undesired noise are today a permanent element of our living and working conditions. To maintain comfortable conditions, there are some expedients such as reducing the noise level of the sound source, changing the noise transmission path, and using a noise-attenuating device at the receiver. The latter means include sound absorption materials and sound insulators.

It has been well known that flexible polyurethane foam can be considered as a good sound absorbing material, for instance as described by Watt,[1] because its sound absorption behavior at medium and high frequencies is excellent and also it is easy to process.

Generally speaking, polyester-based flexible polyurethane foam has superior mechanical properties and especially acoustical absorption; however, it has poor humid aging property. On the other hand, polyether-based flexible polyurethane foam is inexpensive, but has less acoustical absorption as compared with the polyester-based one. The acoustic absorption properties of the polyester-based and polyether-based flexible polyurethane foams were clearly indicated, and various factors which affect sound absorption properties of foam have been investigated.

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## EXPERIMENTAL

### Preparation of Samples

*Polyether-Based Flexible Polyurethane Foam*

Taking the following recipes (parts by weight), slab foams were prepared by using the high pressure foaming machine (Hennecke UBT machine). The temperature of each raw material ingredient was 25 ± 2°C (samples nos. 1–6, 12–14, 16, and 17).

Glycerin-based and propylene-oxide-adducted polyether with 56 OH value (Dow, CP-3022): 100, water: 3.8–5.2, silicon surfactant (Union Carbide Corp., L-520): 1.1–2.0, trichloromonofluoromethane (Daikin, Daifron DF-11): 0–10, triethylenediamine (Air Products, Dabco): proper quantity, tin-octylate (Johoku Chemical, MRH-110): proper quantity, and tolylenediisocyanate (2.4/2.6 isomer ratio: 80/20, Nippon Polyurethane, Desmodur T-80): index 100.

*Polyester-Based Flexible Polyurethane Foam*

Taking the following recipes (part by weight), slab foams were prepared by using the same machine as above. The temperature of each raw material ingredient was also the same (samples nos. 7–11 and 15).

Polyesterpolyol with 60.5 OH value from diethyleneglycol and adipic acid (Nippon Polyurethane, Desmophen 2200): 100, water: 1.9–3.95, dimethylbutanolamine (Kao Soap): 1.0, additive, Additive SM (Bayer) or Additive SV (Bayer): proper quantity, and tolylenediisocyanate (2.4/2.6 isomer ratio: 65/35, Nippon Polyurethane, Desmodur T-65): index 90–110.

*Surface treatment of foam*

*Gluing film to foam surface:* Low density polyethylene film 0.025 mm thick was glued to the polyether based foams (sample no. 14) of 20, 30, and 50 mm in thickness with a rubber-based adhesive agent (spray paste no. 77 of Sumitomo 3M) by spraying (sample no. 19).

Polypropylene film 0.05 mm thick was also treated in the same manner to get a sample (sample no. 20) 20 mm thick.

*Sandwiching film into foam:* Aluminum foil 0.03 mm thick was inserted into the polyether-based foam (sample no. 13) of 40 mm in thickness and glued to the foam with Spray paste No. 77 of Sumitomo 3M (sample no. 21).

*Profiling foam surface:* One face of the polyether-based foam (sample no. 13) was made uneven by wave-cutting. The ratio of the height from the top to the bottom of the profiled wave to the total foam thickness (40 mm) was 1:2, and the distance between the tops was 35 mm (sample no. 18).

*Heat melting of foam surface:* Surface of the polyether based foam (sample no. 13) 20 mm thick was melted by steel roll with 400-mm diameter heated to 360–370°C at the speed of 7.5 m/min so that an air-permeable film layer was built on the foam surface (sample no. 22).

*Spraying to foam surface:* Some skin layers were built by spraying poly(vinyl chloride)–acetone solution on the surfaces of the polyether based foam (sample no. 13) 20 mm thick and the polyester-based foam (sample no. 15) 20 mm thick. Sprayed sample no. 23 and no. 24 were obtained from samples no. 13 and no. 15, respectively.

The amount of solids deposited on the foam surface was 150 g/m$^2$. The recipe of the solution was as follows (parts by weight): poly(vinyl chloride) (Denki Kagaku, 100 G): 14, phosphate plastisizer (Aginomoto, Leophos): 5, dioctyladipate: 2, acetone: 67, and toluene: 4.

*Heat adhesion with thermoplastic film to foam surface:* Polyethylene films (Dow CF 804) of 0.025–0.075 mm in thickness were put on the surface of the polyether-based foam, sample no. 16 (30 mm thick) and rolled with Teflon-coated roll heated to 150–180°C at the speed of 5–10 m/min (sample no. 25-1, 2, 3, and 4).

## Designation of Samples

The foams which were prepared according to the recipes described above and were used for acoustic examination are listed in Table I along with their properties such as density, hardness, cell size, and flow resistance.

The composite substances which were prepared from some of the foams listed in Table I by gluing, sandwiching, profiling, heat melting, spraying, or heat adhesion are shown in Table II.

TABLE I
Designation of Flexible Polyurethane Foam Samples (1)

| Sample no. | Density (kg/m$^3$) | Hardness (kg/314 cm$^2$) | Cell size (cell number/in.) | Flow resistence (Rayl/cm) | Remarks |
|---|---|---|---|---|---|
| 1 | 17.8 | 7.0 | 36 | 7.6 | polyether base |
| 2 | 26.9 | 10.4 | 42 | 9.2 | polyether base |
| 3 | 51.1 | 23.6 | 44 | 33 | polyether base |
| 4 | 34.2 | 14.2 | 39 | 36 | polyether base |
| 5 | 22.3 | 12.4 | 34 | 54 | polyether base |
| 6 | 24.5 | 12.5 | 36 | 125 | polyether base |
| 7 | 53.8 | 24.8 | 46 | 350 | polyester base |
| 8 | 52.6 | 19.8 | 53 | 380 | polyester base |
| 9 | 37.5 | 17.5 | 35 | 510 | polyester base |
| 10 | 28.6 | 17.0 | 31 | 930 | polyester base |
| 11 | 32.2 | 11.8 | 37 | 1150 | polyester base |
| 12 | 24.0 | 13.5 | 35 | 600 | polyether base (hand mix foaming) |
| 13 | 20.3 | 9.2 | 42 | 12 | polyether base |
| 14 | 22.3 | 12.6 | 35 | 34 | polyether base |
| 15 | 35.2 | 13.2 | 42 | 420 | polyester base |
| 16 | 25.7 | 13.5 | 38 | 4.0 | polyether base |
| 17 | 20.5 | 10.8 | 25 | 4.2 | polyether base (irregular cell) |

TABLE II
Designation of Flexible Polyurethane Foam Samples (2), Composites

| Sample no. | Remarks on composite making processes |
|---|---|
| 18 | Profiling of sample no. 13(40 mm thick) |
| 19 | Gluing of polyethylene film (0.025 mm thick) to sample no. 14 (20 mm, 30 mm, and 50 mm thick) |
| 20 | Gluing of polypropylene film (0.05 mm thick) to sample no. 14 (20 mm thick) |
| 21 | Inserting aluminum foil (0.03 mm thick) in sample no. 13 (40 mm thick) |
| 22 | Heat melting of sample no. 13 (20 mm thick) |
| 23 | Spraying PVC to sample no. 13 (20 mm thick) |
| 24 | Spraying PVC to sample no. 15 (20 mm thick) |
| 25 | Heat adhesion with polyethylene film (0.025 mm thick) to sample no. 16 (30 mm thick); sample no. 25—1, 2, 3, and 4 were from various heat adhesion conditions |

## Testing Procedures

### *Density and Hardness*

Based upon JIS (Japanese Industrial Standard) K 6401-1980, Flexible Urethane Foam for Cushion.

### *Cell Number*

Based upon JIS K 6402-1976, Flexible Urethane Foam for Garments.

### *Flow Resistance*

Based upon the air flow test according to ASTM D-1564-1971, Testing Slab Flexible Urethane Foam.

Flow resistance $R$ is obtained from the following formula, $R = P/vl$, where $P$ = static pressure differential between both faces of sample (dyn/cm$^2$) ($10^{-1}$ Pa), $v$ = air velocity (cm/s), l = thickness of sample (cm). The unit in common use for the flow resistance is Rayls (N·S/m$^3$ × 10).

### *Normal Incident Sound Absorption Coefficient*

Based upon JIS A 1405-1963, Methods of Test for Sound Absorption of Acoustical Materials by the Tube Method, or ASTM C-384-1977, Impedence and Absorption of Acoustical Materials by the Impedance Tube Method.

Type 4002 apparatus of B and K Co. was used in which there was a rigid wall behind the acoustic material. Acoustic tube A with 10-cm diameter for 100–1600 Hz and tube B with 3-cm diameter for 800–5000 Hz were used. The values of sound absorption coefficient in the range of 800–1600 Hz are the average values obtained from A and B. Each measurement was done at room temperature. In this connnection, the temperature-dependent acoustical properties of various polymer systems were discussed in terms of the viscoelastic theory of polymers by Chen and Williams.[2]

*Reverberant Sound Absorption Coefficient*

Based upon JIS A 1409-1977, Method for Measurement of Sound Absorption Coefficients in a Reverberation Room, or ASTM C-423-1977, Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method.

The reverberation room of Tokyo Industrial Technology Center was used. The specification of the room was as follows: asymmetric seven faces, volume = 450 $m^3$, total area = 350 $m^2$, floor area = 52 $m^2$, steel bar concrete 30 cm thick, and scratched man-made stone finishing 3 cm thick. Six sheets of samples of 900 mm × 1800 mm were located in the middle of the floor. Each measurement was done at 28°C.

## RESULTS AND DISCUSSION

### Effect of Flow Resistance of Foam on Sound Absorption

Paffrath and Schmidt[3] showed that flexible polyurethane foams, some cell membranes of which were dissolved by alklai treatment, had different flow resistances and that they played an important role for the sound absorption characteristics.

Suminokura, Mori, and Miyake[4] examined the relation between acoustic properties and the air flow resistance of the flexible polyurethane foams which had, however, lower values of the flow resistance such as 8–170 Rayl/cm.

Koyasu and Sugita[5] also reported that the specific flow resistance had a close correlation with the sound absorption coeffcient, taking some optional flexible polyurethane foams. Relation between the flow resistance and some absorption charateristics of specified foam samples was investigated in our paper.

As to the foam samples no. 1–11 which are shown in Table I, it was confirmed that their sound absorption largely depended upon the flow resistance, as shown in Figure 1, and rarely depended upon the density, hardness, and cell number of the foam.

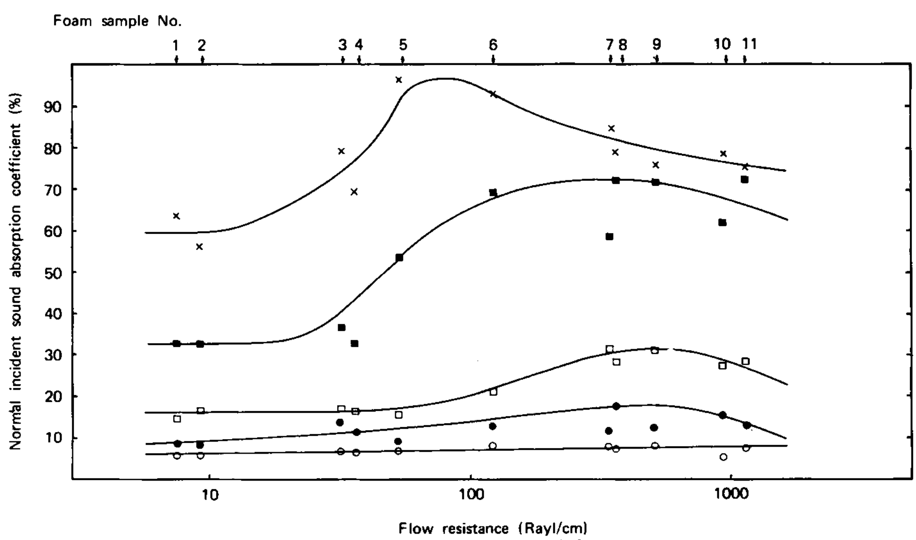


Fig. 1. Effect of flow resistance of polyurethane foam (10 mm thick) on sound absorption at 250 (○), 500 (●), 1,000 (□), 2,000 (■), and 4,000 (×) Hz.

The maximum sound absorption coefficient at 4000 Hz was found for the foam with about 100 Rayl/cm of flow resistance. As the applied frequency is reduced, the value of the flow resistance which maximizes the sound absorption becomes higher, and the level of its sound absorption is decreased.

If the value of the flow resistance becomes too high, as seen for the foam sample no. 10 or 11, the acoustic absorptivity at the higher frequency region will be reduced. It is considered that sound may be reflected near the surface area owing to the fact that the foam with a higher flow resistance also has a higher closed cell content.

The reason why polyester-based flexible polyurethane foam generally shows better sound absorption may be due to its fairly higher flow resistance as compared with polyether based flexible polyurethane foam.

### Effect of Foam Thickness on Sound Absorption

Figures 2 and 3 show the acoustic absorption behavior of flexible polyurethane foams, depending on their thickness(sample no. 12 and no. 15). As the foam thickness increases, the sound absorption at the lower frequencies improves and decreases slightly at the higher frequencies. The same tendency has been shown by Paffrath and Schmidt[3] and Ball, Schwartz, and Long.[6]

### Effect of Back Side Medium behind Foam on Sound Absorption

Sound absorption when changing the thickness of air layer as back side medium behind foam (sample no. 13) is shown in Figure 4.

As the thickness of air layer increases, the frequency which maximizes the acoustic absorptivity is reduced, increasing the absorption rate. This behavior has also been referred to Paffrath and Schmidt.[3] When the air layer behind foam is substituted by a foam which has coarse cells and lower flow resistance (sample no. 17), the acoustic absorptivity is improved.

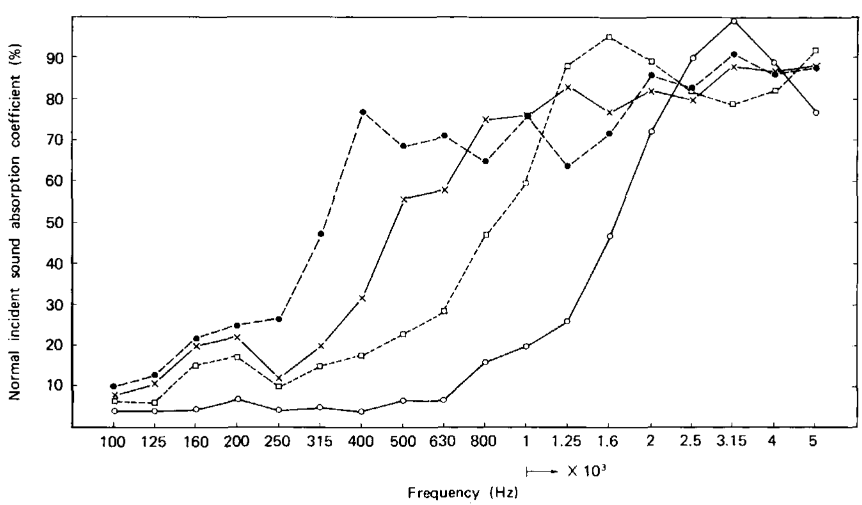


Fig. 2. Effect of foam thickness on sound absorption (1), for foam sample no. 12 with 12.7 mm (○), 28.7 mm (□), 31.7 mm (×), and 52.0 mm (●) thick.

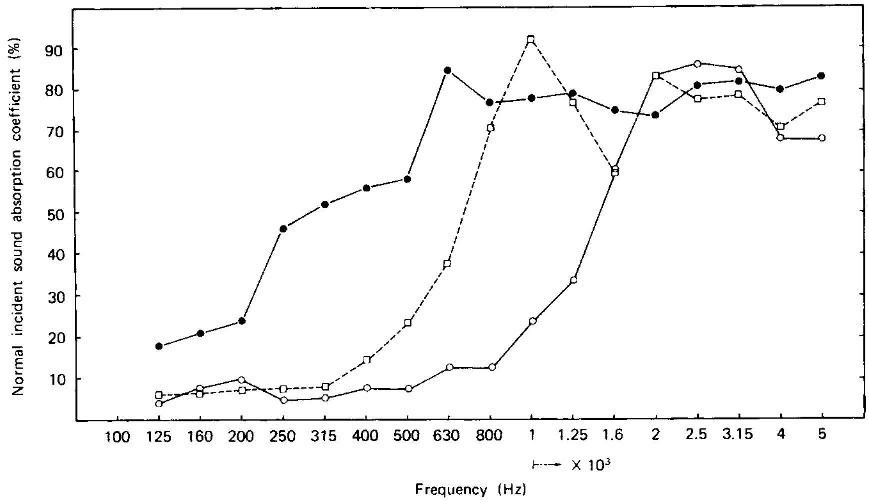


Fig. 3. Effect of foam thickness on sound absorption (2), for foam sample no. 15 with 10 mm (○), 20 mm (□),and 50 mm (●) thick.

## Effect of Foam Profiling on Sound Absorption

The effect of the shape of foam surface by profiling finish on acoustic absorptivity was examined.

As shown in Figure 5, the profiled sample no. 18 (40 mm thick) shows similar sound absorption behavior to the flat plate sample no. 13 (30 mm thick). This is due to the fact that they were from the same material and had almost the same volume, even though their surface shapes were different. This kind of profiling shows no effect on the sound absorption properties of the foam, considering that an approximately 20 mm high wave shaped profiling between the top and the bottom may be too small as compared with the wave length of sound, about 340 mm at 1000 Hz.

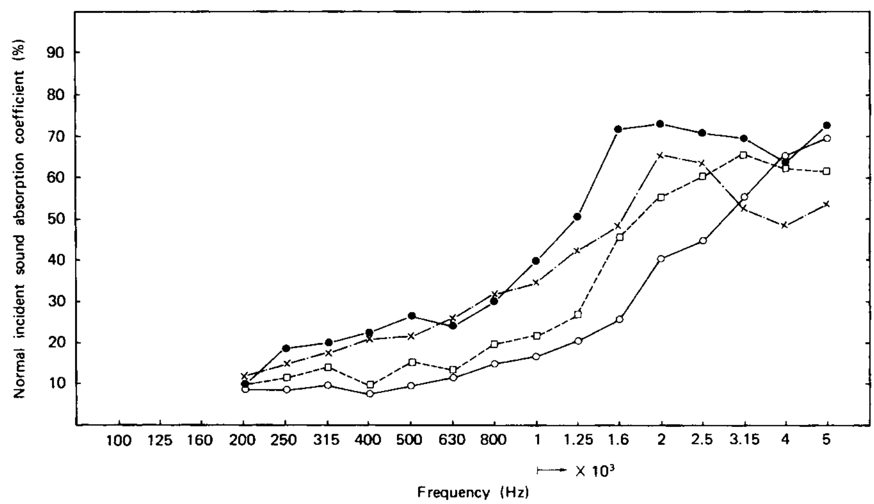


Fig. 4. Effect of back side medium behind foam on sound absorption for foam sample no. 13 (20 mm thick) without air layer (○), with air layer (10 mm thick) (□), with air layer (20 mm thick) (X), and with foam sample No. 17 (20 mm thick) (●).

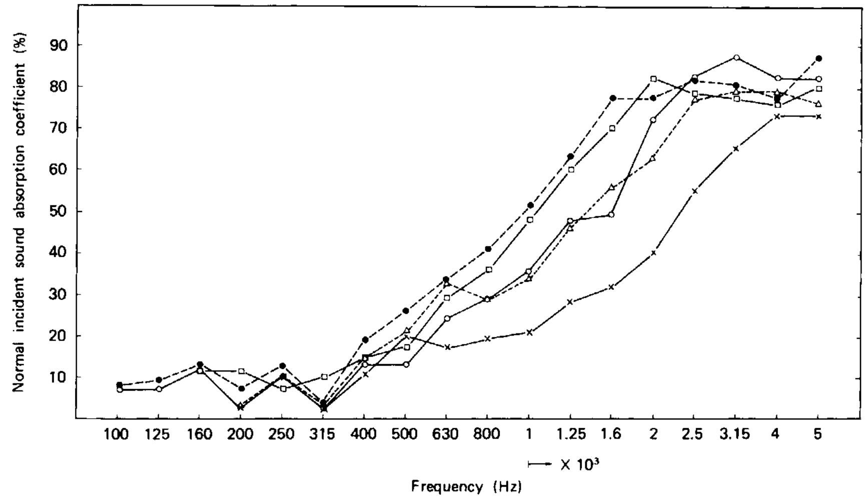


Fig. 5. Effect of foam profiling on sound absorption for foam sample no. 18 (40 mm thick) (○), in comparison with foam sample no. 13, 40 mm thick (●), 30 mm thick (△), 20 mm thick (×), and in case of putting the profiled surface on the opposite side of sound source for foam sample no. 18, 40 mm thick (□).

When putting the profiled surface on the opposite side of sound source, the air layer between the profiled surface of the foam (sample no. 18) and the rigid wall indicates better sound absorption, which is also shown in Fiugre 5.

## Effect of Nonporous Film Glued on Foam Surface on Sound Absorption

Figure 6 shows the sound absorptivity when gluing polyethylene film 0.025 mm thick and polypropylene film 0.05 mm thick, which faced the sound source, to the foam sample no. 14, 20 mm thick. The absorption peak can be seen in the

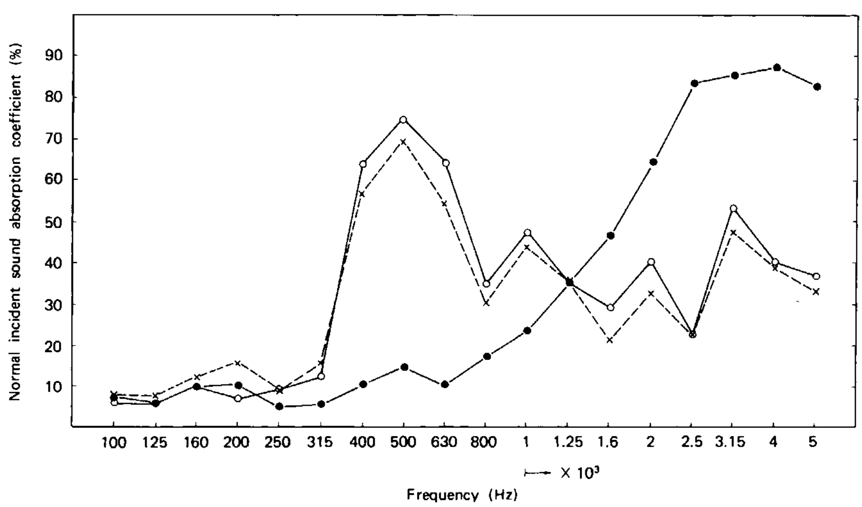


Fig. 6. Effect of nonporus film glued on foam surface on sound absorption (1) for foam sample no. 19 (no. 14 of 20 mm thickness with PE film of 0.025 mm thickness) (×), and no. 20 (no. 14 of 20 mm thickness with PP film of 0.05 mm thickness) (○), in comparison with foam sample no. 14 (20 mm thick) (●).

region of 400–800 Hz and the level of sound absorption of the samples at the higher frequencies is reduced, as compared with the unglued foam.

Ball, Schwartz, and Long[6] also coated the foam surfaces with nonporous polyethylene sheets whose maximum thickness was 5 mils. At lower frequencies, the absorption coefficients were considerably increased, whereas they significantly decreased at higher frequencies. As the film thickness increased, it was also observed that for a sufficiently large film thickness the absorption coefficients decreased even at the low end of the frequency range.

In this connection, Gilford and Druce[7] worked on obtaining wide band absorbers with impermeable facings, and designed an absorption unit which could, if necessary, be used on the top of other systems to increase low-frequency absorption. The receiving face of the unit was a thin film of polythene or polyester (about 0.025 mm thick) covering a layer of polyurethane foam 6 mm thick.

Figure 7 shows the second absorption behavior when gluing polyethylene film 0.025 mm thick to foams of different thickness. As foam thickness increases, the absorption effect can be seen to increase at the lower frequencies.

## Effect of Inserting Film between Foams on Sound Absorption

Figure 8 shows the changes of sound absorption behavior by inserting aluminium foil of 0.03-mm thickness whose position was varied in the foam sample no. 13 with a total thickness of 40 mm.

As the thickness of the foam facing to the second source increases, keeping the total thickness of the composite system as 40 mm (sample no. 21), the sound absorption effect decreases at the lower frequencies and increases in the higher frequency region. The turning point of the effect is at about 1250 Hz. The composite with a total thickness of 40 mm which has 20–30-mm-thick foam facing the sound source shows better sound absorption behavior at almost the whole frequency region, as compared with that of a foam sample alone (sample no. 13) with the same thickness.

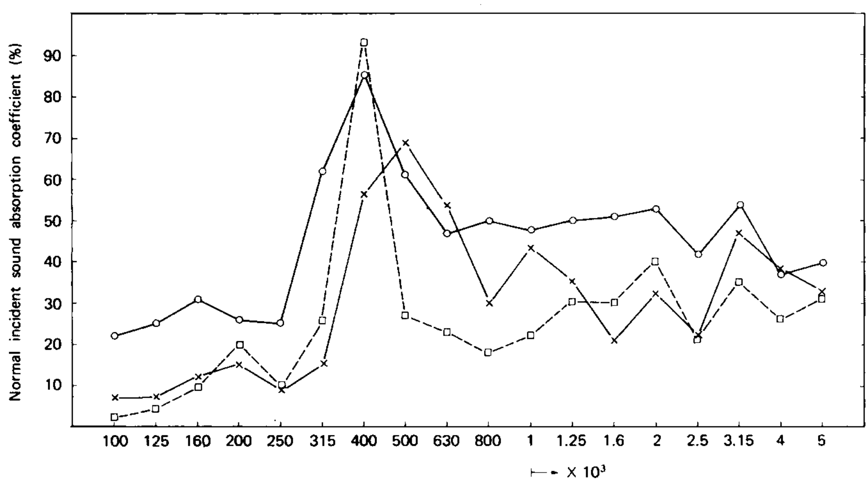


Fig. 7. Effect of nonporous film glued on foam surface on sound absorption (2) for foam sample 19 with 20 mm (X), 30 mm (□), and 50 mm (O) thick with PE film of 0.025 mm thickness.

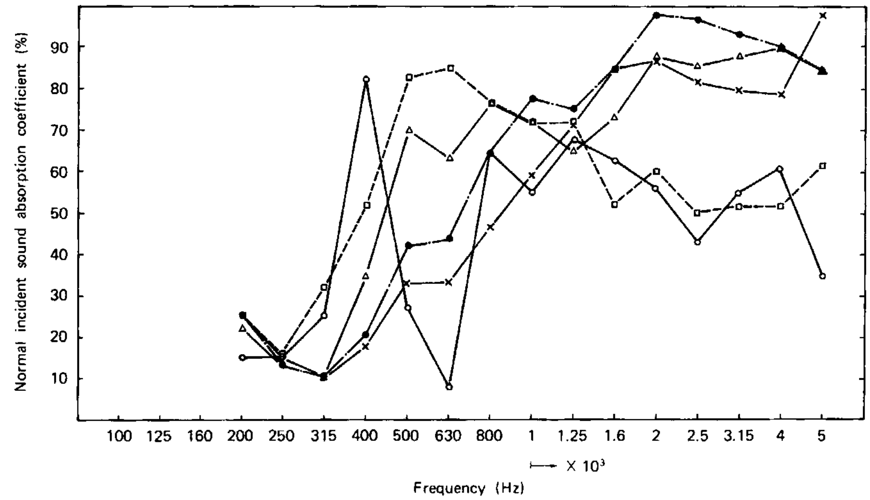


Fig. 8. Effect of inserting aluminum foil 0.03 mm thick in the foam sample no. 13 with a total thickness of 40 mm on sound absorption. Thickness of the foam facing the sound source for the foam sample no. 21 was 0 mm (○), 10 mm (□), 20 mm (△), 30 mm (●), and 40 mm (×).

A similar effect was observed in case of using a poly(vinyl chloride) sheet 0.8 mm thick and thermoplastic polyurethane elastomer films of between 0.05–0.3 mm thick.

## Effect of Heat Melting Foam Surface on Sound Absorption

The surface of the foam sample no. 13 was melted by heat rolling, and a skin layer was built so that the flow resistance of the foam (sample no. 22) increased to 350 Rayl/cm from 12 Rayl/cm. Figure 9 shows the excellent sound absorption behavior due to heat melting over the whole frequency region as compared with

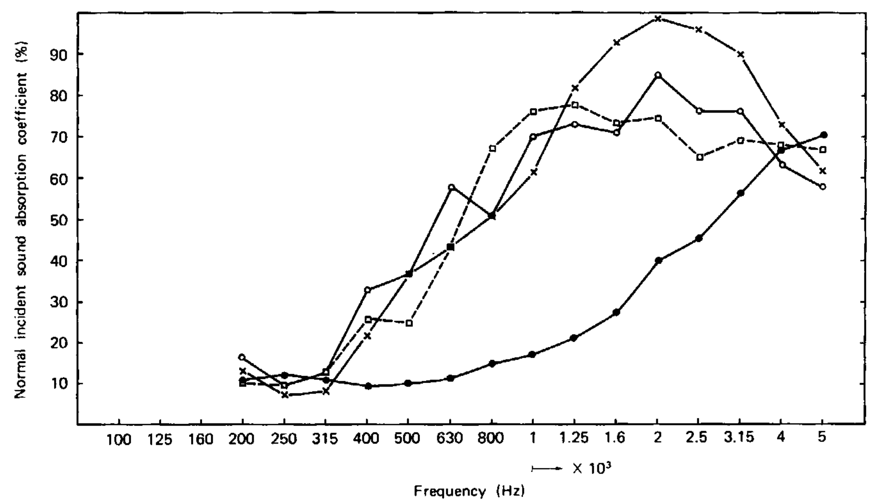


Fig. 9. Effect of heat melting and spraying on foam surface on sound absorption for the foams (each 20 mm thick) of heat melting, sample no. 22 (○), and PVC spraying, sample no. 23 (×), from the original sample no. 13 (●), in comparison with polyester-based foam, sample no. 7 (□).

the original foam. It is also indicated that this surface-melted foam has almost the same sound absorption behavior as the foam sample no. 7 which is polyester-based and has nearly the same flow resistance as the foam in question.

This suggests that polyether-based foam can be used as a good sound absorbent in the place of polyester-based foam which, although it has excellent mechanical properties, has smaller resistance to hydrolysis and has a rather high manufacturing cost in comparison with polyether-based foam.

## Effect of Foam Surface Spraying on Sound Absorption

Schwartz and Gohman[8] investigated the acoustic absorption characteristics for flexible polyurethane foam with surface coating. It was found that thin coating of the order of 0.005g/cm$^2$ resulted in an increase in sound absorption for foams of 0.5–1-in. (12.7–25.4-mm) thickness.

Schwartz and Buehner[9] also applied thin coatings of the order of 0.002–0.04 g/cm$^2$ on flexible foam 1 in. (25.4 mm) thick. It was found that coatings of 0.002 g/cm$^2$ improved the absorption over a wide range of frequencies.

As shown in Figure 9, the foam sample no. 23, which was prepared by spraying poly(vinyl chloride) solution on the surface of polyether-based foam sample no. 13, has 350 Rayl/cm of flow residence and also has almost the same sound absorption behavior as the foam sample no. 22, which has a melted skin layer on the surface as described above. This also suggests that polyether-based foam can be used as a good sound absorbent, the spraying method being applicable.

The polyester-based foam sample no. 15 and the foam sample no. 24, which was prepared by spraying on the surface of the foam sample no. 15, have flow resistance of 420 and 440 Rayl/cm, respectively. There was no big difference in sound absorption between these samples, as shown in Figure 10.

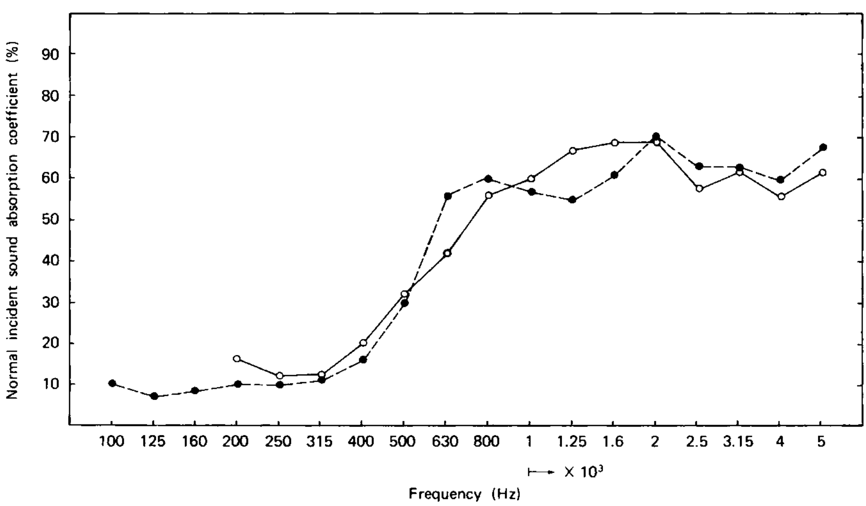


Fig. 10. Effect of spraying on foam surface on sound absorption for polyester-based foams (each 20 mm thick) of sample no. 15 (●) and sample no. 24 (○) which was prepared from no. 15.

## Effect on Sound Absorption for Foam Surfaces Heat Adhesion Coated with Thermoplastic Film

Samples in the category of no. 25 which were prepared by heat melting with polyethylene film 0.025 mm thick on the surface of polyether-based foam, sample no. 16, have different values of flow resistance, 14–245 Rayl/cm, depending on heat adhesion conditions. Increasing the flow resistance gave better sound absorption in the middle frequency region, as shown in Figure 11. It was also shown that polyether-based foam can be used as a good sound absorbent, a proper flow resistance being obtained by heat melting with thermoplastic film.

## Comparison of Normal Incident and Reverberant Room Sound Absorption Measurements

So far many investigations have been done on sound absorption using various kinds of materials based upon the values of the normal incident sound absorption coefficient. The evaluation of sound absorption coefficient by the reverberant room method has been also adopted for some samples.

Olynyk and Northwood[10] compared results of the reverberation room absorption measurements on some 50 samples of commercial acoustical materials with values predicted from impedance tube measurements in the same materials. At frequencies of 125, 250, 500, 1000, and 2000 Hz, various degrees of correlation were found between impedance tube data and reverberation room results. Highly absorptive materials correlated better than those with low absorption, for which reverberation room results still tended to be somewhat higher than predicted.

The comparisons of both measurements were done for the samples (no. 25-1 and no. 25-2), which was prepared by heat adhesion of the polyethylene film 0.025 mm thick on the surface of the foam sample no. 16. The result for sample no. 25-1 was shown in Figure 12. Although the values of absorption characteristics

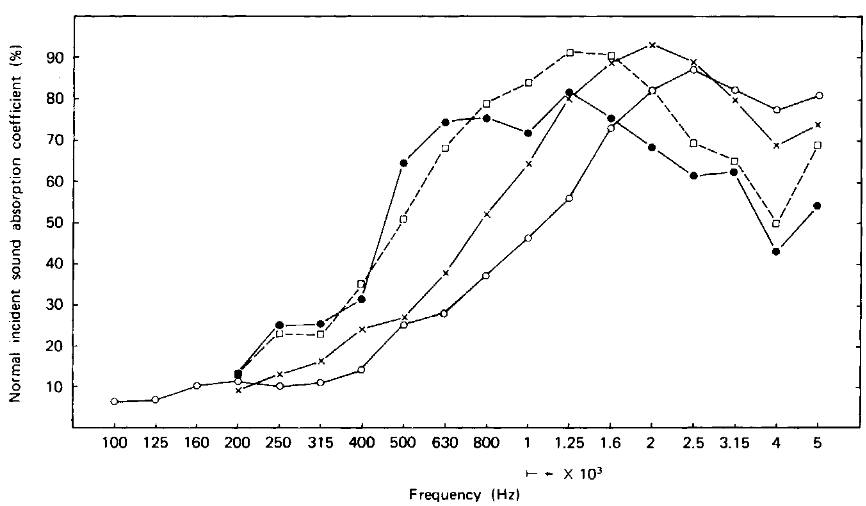


Fig. 11. Effect of heat adhesion-produced foam surface (coated with polyethylene film) on sound absorption for the foams of sample no. 25-1, 2, 3, and 4 (each 30 mm thick) with flow resistance of 14 (○), 36 (×), 120 (□), and 245 (●) Rayl/cm, respectively.

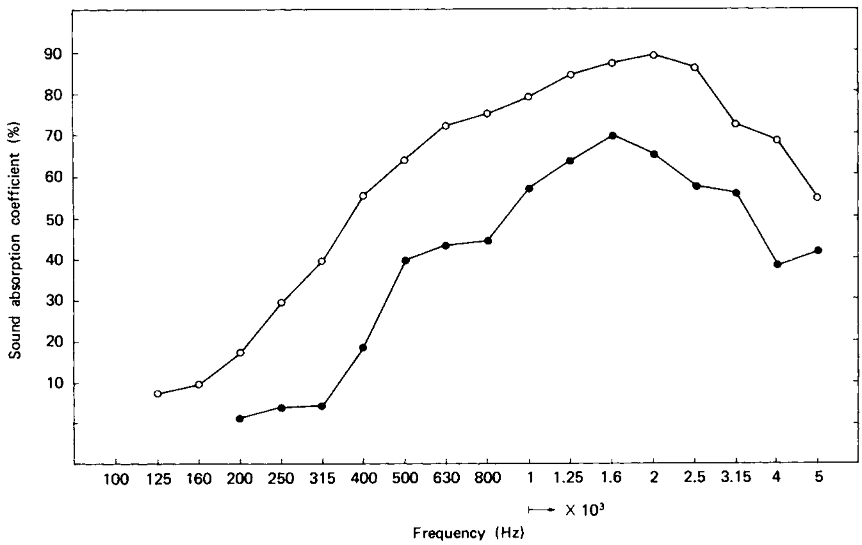


Fig. 12. Comparison of normal incident and reverberant room sound absorption measurements, for foam sample no. 25-1 (30 mm thick) by normal incident (●) and reverberant room (○) sound absorption measurements.

obtained by the reverberant room method are generally higher in comparison with those determined by the normal incident measurements, the absorption peak positions were close to each other. The results for sample no. 25-2 was the same as that shown for sample no. 25-1.

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