Properties of Flexible Urethane Foams

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Flexible urethane foams are prepared from diisocyanates and a variety of hydroxyl-containing resins. The resins most commonly used commercially have been polyesters derived from adipic acid (*2,7*). Three different and cheaper resins, investigated extensively, give softer foams with markedly improved resistance to accelerated hydrolysis conditions and greater ease of molding. One was a polyester derived from dimerized linoleic acid, "dimer acid" (*1*), and the other two were polyether glycols (*3,4*). Two types of polyether glycols were used: pure polypropylene glycol and a polypropylene glycol chain modified with ethylene oxide. These polyethers should not be confused with Teracol (E. I. du Pont de Nemours & Co.), which is a poly-1,4-butylene ether (*9*). No data are given here on the Teracol foams.

Foams having a wide variety of properties may be prepared from each of the four types of resins described here. This range of possibilities explains most cases where other published data may differ with those in this report. Also for this reason, this comparison of urethane foams is limited to those prepared in the authors' laboratory, where machine operating conditions and foam formulations were chosen to give as meaningful a comparison as possible.

RAW MATERIALS

The diisocyanate used was a commercial 80 to 20 ratio of the 2,4- and 2,6- isomers of tolylene diisocyanate, Mondur TD-80 (Mobay Chemical Co.).

Commercial resins were used. One polyester was based on adipic acid, Multron R-68 (Mobay Chemical Co.), and one, Multron F-30 (Mobay Chemical Co.), was based on dimer acid, Empol 3065S (Emery Industries, Inc.). Pure polypropylene glycols, such as polypropylene glycol 2025 (Union Carbide) and P-2000 (Dow Chemical Co.), and polypropylene glycol modified with 10% ethylene oxide, Pluronic L-61 (Wyandotte Chemical Corp.), were used. Typical properties of these resins are given in Table I.

Table I. Typical Resin Properties

Resin	Viscosity, Cps. 25 °C.	Hydroxyl No.	Acid No.	pH[a]
Multron R-68	15,000	50	1	. . .
Multron F-30	18,000	60	1	. . .
PPG 2025	300	56	. . .	6–8
P-2000	300	56	. . .	6–8
Pluronic L-61	300	56	. . .	9.5–10.5

[a] pH measured using 10 grams of polyether in 60 ml. of a 10 to 1 methanol-water mixture.

The R-68 was best foamed by a "one-shot" method—i.e., where resin, diisocyanate, catalyst, emulsifier, and water were all mixed simultaneously. The other resins gave best results by a "prepolymer" method—i.e., where the resin and diisocyanate were first combined to give a stable liquid containing free isocyanate groups, then later mixed with the catalyst, emulsifier, and water.

PREPARATION OF PREPOLYMERS

All prepolymers were prepared by a modification of the technique previously described (*4*). Table II shows typical properties of the prepolymers used.

Table II. Prepolymer Properties

Resin Used to Make Prepolymer	Viscosity, Cps., 25 °C.	Free NCO, %
Dimer acid polyester	8,000	14
Polypropylene glycol	30,000	7
Modified polypropylene glycol	20,000	7

FOAMING

All foams were prepared in a Mobay foam machine (*6*). For the one-shot technique three components—polyester, diisocyanate, and "activator" (combination of catalyst, emulsifier, and water)—were fed separately to the mixing chamber. For the prepolymer method the prepolymer was fed through the resin feed system and the activator was fed as usual. The polypropylene glycol and the modified polypropylene glycol prepolymers contained enough free isocyanate for approximately a 3-pound-per-cu. foot foam. Hence for a 2-pound foam more diisocyanate was added at the time of foaming. The dimer acid polyester prepolymer contained enough free isocyanate to provide a 2-pound-per-cu. foot foam.

The activator systems were composed of typical emulsifiers, tertiary amine catalysts, and water (*1,3,4*).

Unless noted otherwise, all foaming was done in open pan molds. Cushions were foamed in closed molds of standard design for furniture applications. Foams were permitted to cure for a minimum of 24 hours at room temperature before testing.

TEST METHODS

Standard test methods as approved by the Cellular Plastics Division of the Society of Plastics Industry (*8*) were used for tests of tensile strength and elongation, tear strength, density, constant deflection compression set, indentation load deflection, compression load deflection, and flammability (the last method is not yet standard). Other tests were standard ASTM tests, modified when necessary for the evaluation of cellular materials: pendulum rebound (similar to ASTM D 1054-55), elongation set at break (ASTM D 412-51T), oxygen bomb oxidation resistance (ASTM D 572-53), and high frequency flex fatigue (ASTM D 623-52T Method A). Indentation tests were also run by the standard Rubber Manufacturers Association method, with a 1-minute rest period at the 25 and 50% deflection points. An Instron tester was used for tensile, elongation, tear, indentation, and compression-deflection tests.

Accelerated Hydrolysis Resistance. Samples were exposed for the indicated time in a humidity cabinet under controlled and recorded conditions of 70° C. and 95 to 100% relative humidity. At the end of the indicated intervals samples were tested by the standard methods.

Torsional Stiffness. A Clash-Berg apparatus was used in the standard manner, similar to ASTM D 1043-51. The sample size was 1 inch wide by ½ inch thick. Silicone oil was the medium.

Solvent and Chemical Resistance. Tensile or tear specimens were totally immersed in a solvent or chemical for 50 days (tear) or 28 days (tensile). At the end of this period the samples were removed, squeezed as dry as possible, and further dried for 24 hours at 40° (tear) or 16 hours in the ambient air, then for 2 hours in a 70°C. oven (tensile) (Table V).

The adipic acid polyester foam used in this specific test was that prepared from Multron R-18 (Mobay Chemical Co.), which has a slightly higher hydroxyl number (60) than Multron R-68. A 65 to 35 ratio of the 2,4- and 2,6- isomers of tolylene diisocyanate was used in making this foam, rather than the 80 to 20 ratio normally used. This experiment was performed at Farbenfabriken Bayer, Leverkusen, Germany.

Ultraviolet Resistance. Tensile specimens were placed in a Fade-Ometer with a continuous light source. Specimens were observed and tested at the indicated intervals.

RESULTS AND DISCUSSION

The foams described were considered typical of those of greatest commercial interest. The adipic acid polyester foam was chosen because it was representative of a standard grade of foam used for rug underlay, clothing interliners, seating, and padding. Similarly the dimer acid polyester foam and polyether foams were considered to be those of greatest interest, especially for cushion, pillow, and mattress use. In every case the resins used had nearly the same hydroxyl numbers and were linear or nearly so, thus providing a chemical basis for comparison as well as a comparison from the consumer's viewpoint.

The properties of the adipic acid polyester foams have been observed for several years, and have been established for numerous activator systems and densities. Consequently more data were available for these foams than for the newer products based on other resins.

General Mechanical Properties. Except for softness, the mechanical properties of the adipic acid polyester foams have been adequate for essentially all applications. As shown in Table III, the tensile, elongation, tear strength, and compression set improved slightly as the density was increased. The softness or load-bearing properties were nearly independent of density at 10 to 25% deflection. As would be expected, the denser foams had higher load-bearing capacities at the 50 to 70% deflection levels.

Table III. Typical Mechanical Properties of Urethane Foams
(Adipic acid polyester system, slab stock)

Property	Foam Density, Lb./Cu. Ft. 1.5	2	3	4
Tensile strength, lb./sq. inch	24–26	25–30	25–35	30–40
Tensile elongation, %	250–300	250–350	300–400	300–400
Tensile elongation set, %	25	6–13	4–13	3–10
Tear strength, lb./inch	4–6	4–6	4–6	5–7
Compression set, 70° C., % (based on original height)	10–15	2–10	2–6	2–6
Compression-deflection, lb./sq. inch at				
10% deflection	0.60–0.65	0.55–0.65	0.65–0.75	0.75–0.80
25% deflection	0.65–0.75	0.65–0.75	0.65–0.75	0.80–0.85
50% deflection	0.70–0.85	0.70–1.0	0.80–1.0	1.0–1.3
70% deflection	1.1–1.3	1.4–2.5	1.5–2.5	2.0–2.8

Table IV. Typical Mechanical Properties of Urethane Foams
(2 lb./cu.ft. density, slab stock)

Property	Resin System: Adipic acid	Dimer acid	PPG	Mod. PPG
Tensile strength, lb./sq. inch	25–30	18–25	15–25	15–25
Tensile elongation, %	250–350	200–300	200–300	200–300
Tensile elongation set, %	6–13	8–12	5–10	5–10
Tear strength, lb./inch	4–6	4–6	4–6	4–6
Compression set, 70° C., % (based on original height)	2–10	7–15	2–10	2–10
Rebound, % (based on 60–70% values for latex foam)	20–30	35–45	30–45	30–45

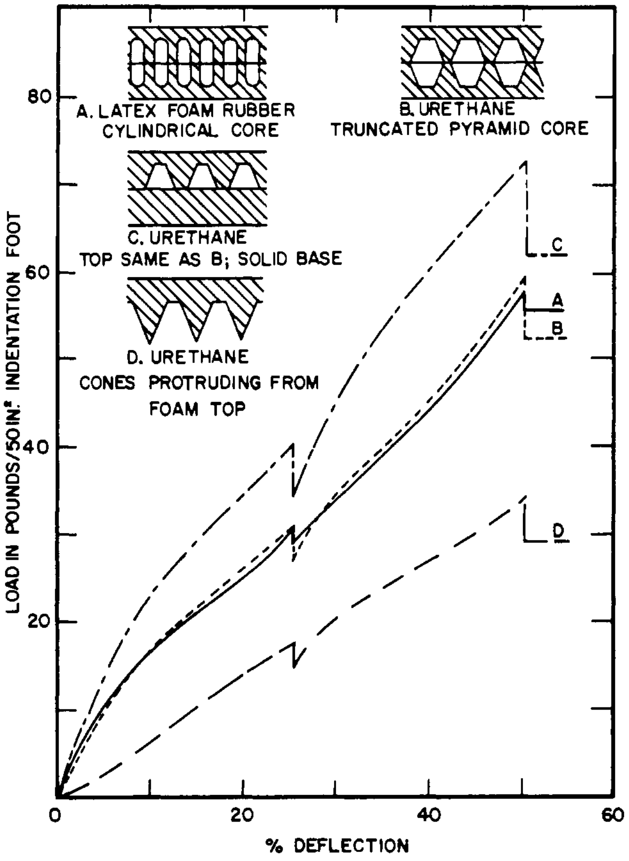

Figure 1. Indentation characteristics of adipic acid polyester urethane cushions compared with commercial foam rubber cushion

The compression-deflection data given in Table III were characteristic of the specific adipic acid polyester system used. Foams with a variety of compression-deflection characteristics have been prepared from other adipic acid polyesters or blends of polyesters. Somewhat stiffer foams have been prepared which had other properties generally equivalent to those given in Table III. In some cases, however, moderate increases in stiffness were accompanied by slight losses in tensile strength and elongation. Softer foams, prepared from different adipic acid polyesters or by modifying other components or ratios of components, usually showed losses in levels of one or more of the following properties: compression set, hydrolysis resistance, tensile strength, elongation, and tear strength.

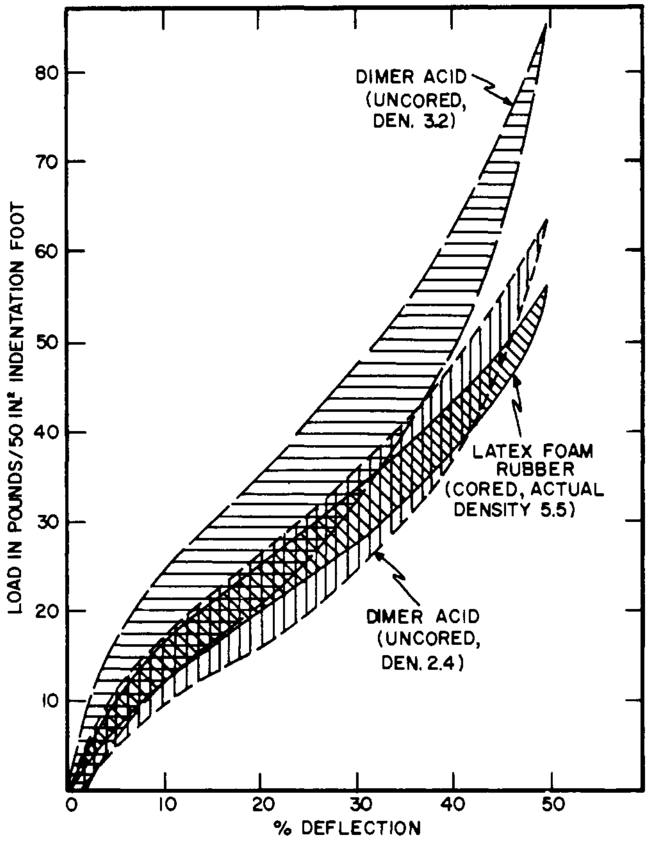

Figure 2. Indentation hysteresis characteristics of dimer acid polyester urethane and latex foam rubber molded cushions

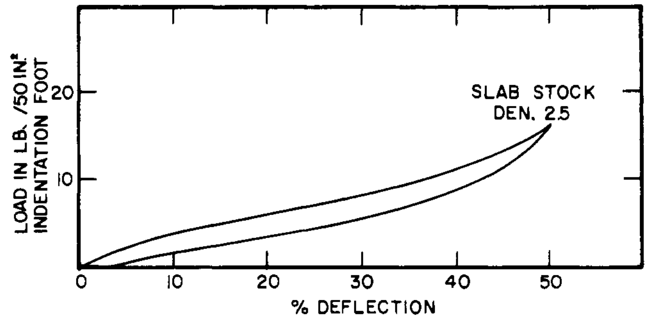

Figure 3. Indentation characteristics of dimer acid polyester urethane foam

The newer foam systems had properties generally equivalent to those of the adipic acid polyester foams (Table IV), but with greatly improved softness and hydrolysis resistance. The tensile strength of the newer foams was somewhat less, but adequate for all uses. The tensile strength of the modified and unmodified polypropylene glycol (PPG) foams was about equal to that of the adipic acid polyester foams of 2 years ago; similar improvement may be expected in these new foams as better formulations and processing techniques are developed. In each case rebound elasticity was better than that of the adipic acid-based foams.

Indent and Hysteresis Characteristics. One of the early limitations of adipic acid polyester foams was the "plateau" effect (*7,9*) in compression: A steady increase of load on the foam resulted in little change until a yield point of about 10% deflection was reached. With only a small increase in loading, the foam was rapidly compressed to approximately 50 to 60%. Beyond that point the deflection increased more slowly as more load was applied. This compression-deflection behavior may be altered greatly by the proper coring of the foam, however.

Figure 1 illustrates the effects of three different coring systems. Molding the foam with cone-shaped cores (section *D*, Figure 1) gave a very soft cushion with an essentially linear Rubber Manufacturers Association indent curve, with little drift at 25 and 50% deflection rest points (curve *D*, Figure 1). Long, sharp cones of foam gave softer cushions than shorter, flatter cones. The same type of relationship held with pyramid-shaped cores. Molded cushions with truncated pyramid cores (section *B*, Figure 1) gave a Rubber Manufacturers Association indent curve (curve *B*, Figure 1) nearly identical to that of a commercial latex foam cushion with cylindrical cores (section *A* and curve *A*, Figure 1). Stiffer cushions with nearly linear curves were obtained by reducing the amount of coring (section *C* and curve *C*, Figure 1). As the percentage of foam in the cushion increased—i.e., as the core volume was decreased—the drift at the Rubber Manufacturers Association rest points increased ($C > B > D$). The drift with sample *C* approached that of slab stock.

In contrast to the adipic acid polyester foams, dimer acid polyester foams gave rubberlike indent curves without coring. Figure 2 gives typical indentation curves for molded dimer acid polyester cushions of 2.4 and 3.2 pounds per cubic foot. The denser cushion was prepared from the same formulation as the lighter cushion by charging more prefoam mixture into the mold. This 2.4-pound cushion had essentially the same indent curve as the latex cushion, whereas the 3.2-pound cushion was somewhat stiffer. Each cushion had somewhat greater hysteresis than the latex cushion, resulting in a more stable feel of the cushion in use.

Slab stock from the dimer acid type foam—i.e., "free rise" foam with skin removed—was much softer (Figure 3) than the molded cushions with skin intact.

The poly(propylene glycol) and modified poly(propylene glycol) foams exhibited essentially the same indentation behavior, and were similar to the dimer acid polyester foams. Figure 4 shows typical indent behavior of molded cushions, of 2 and 3 pounds per cubic foot which was very similar to that of the latex cushion. Again, the hysteresis

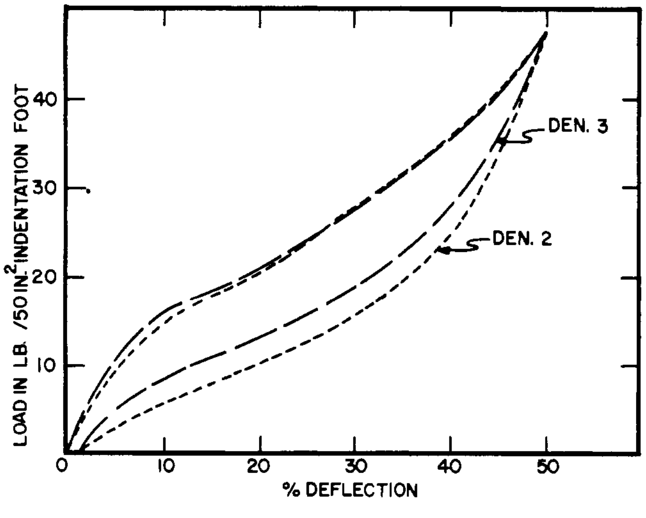

Figure 4. Indentation characteristics of poly(propylene glycol) urethane molded cushions

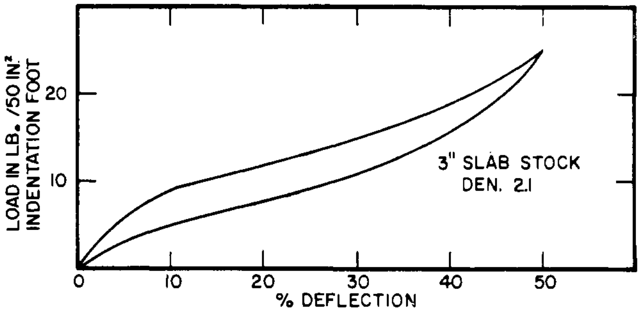

Figure 5. Indentation characteristics of poly(propylene glycol) urethane foam

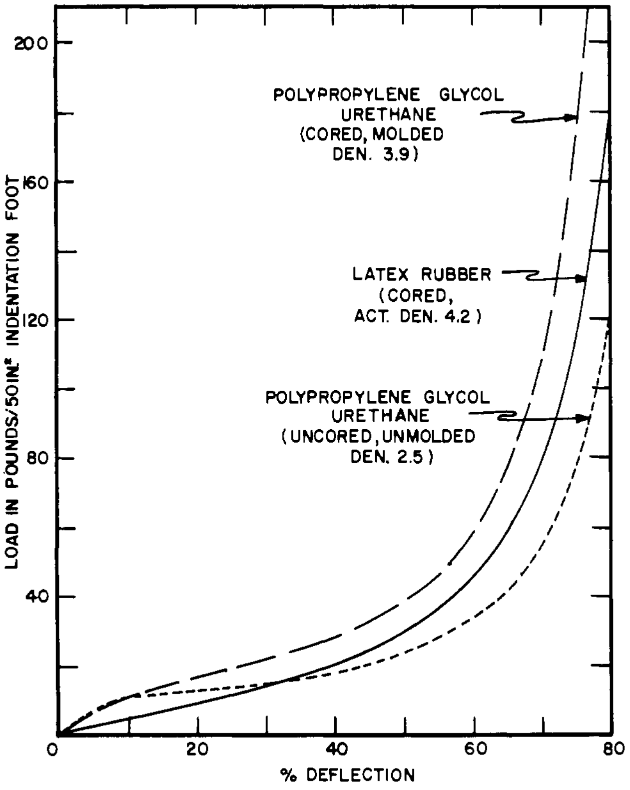

Figure 6. Indentation characteristics of auto topper pads

of these foams was greater than that of the latex cushion, giving a more stable feel in use. Figure 5 shows that the same type of formulation gives a much softer slab stock, largely because of the absence of skin in the trimmed slab.

The indentation behavior of a foam in the range of 50 to 80% deflection may be used to indicate whether "bottoming" may be expected in seating uses. To avoid bottoming, the load-bearing characteristics of the foam should increase fairly rapidly beyond about 50% deflection, and rapidly at 70 to 80% deflection. Figures 6 and 7 compare the poly(propylene glycol) and modified poly(propylene glycol) foams with latex foam in this respect. Figure 6 gives indent curves for molded commercial automotive latex topper pad, a molded and cored poly(propylene glycol) foam pad, and slab stock, as all were soft and had essentially identical behavior in the 0 to 50% deflection region. The indent curves in Figure 7 compare commercial latex cushions with molded poly(propylene glycol) foam cushions, as these two

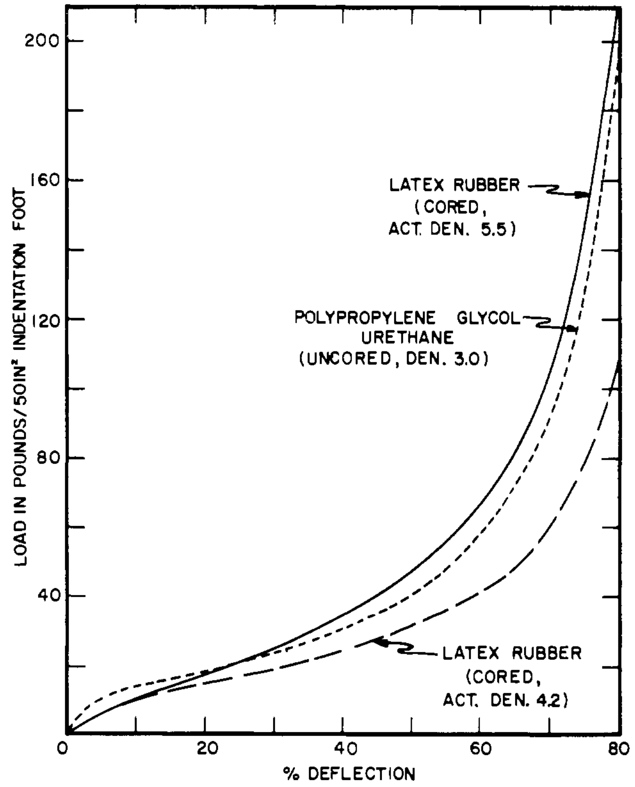

Figure 7. Indentation characteristics of molded cushions

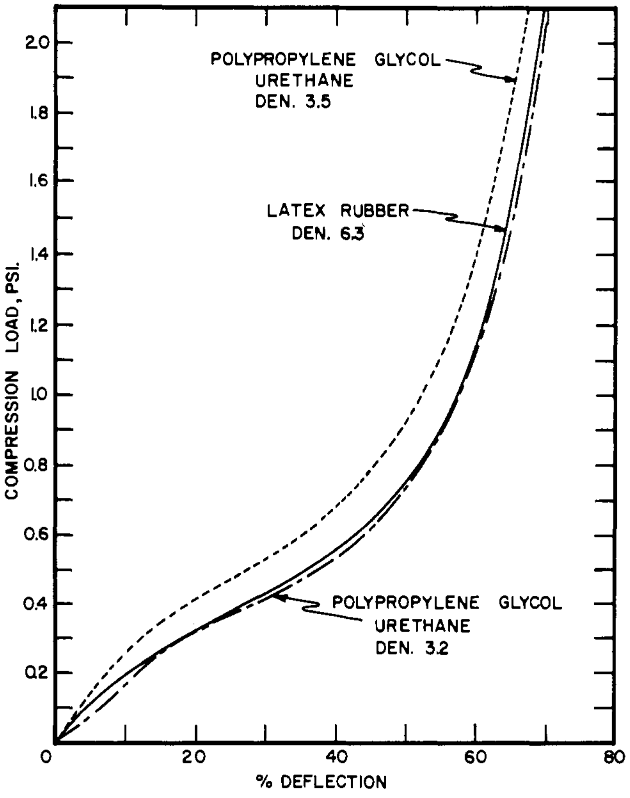

Figure 8. Compression-deflection characteristics of urethane and latex foams

2 × 2 × 1 inch block

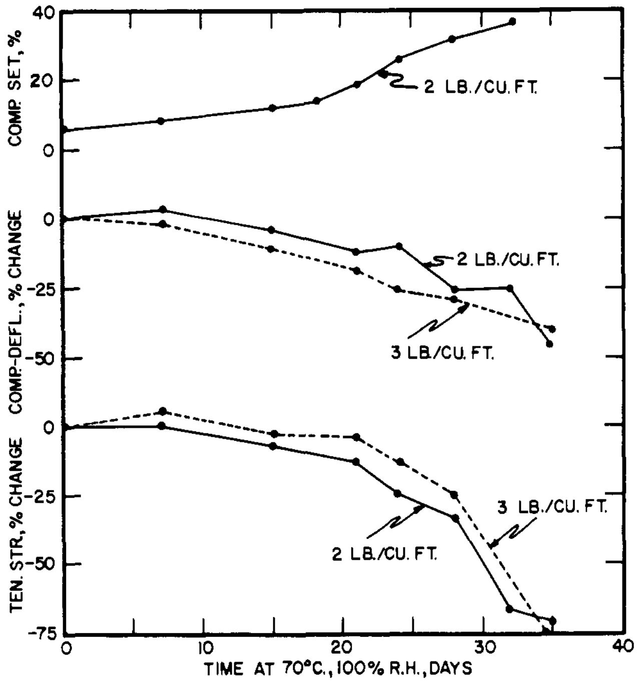

Figure 9. Accelerated hydrolysis resistance of adipic acid polyester urethane foam

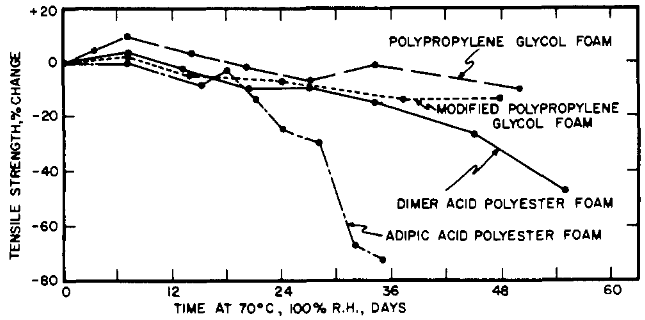

Figure 10. Accelerated hydrolysis resistance of urethane foams

2 lb./cu.ft. density

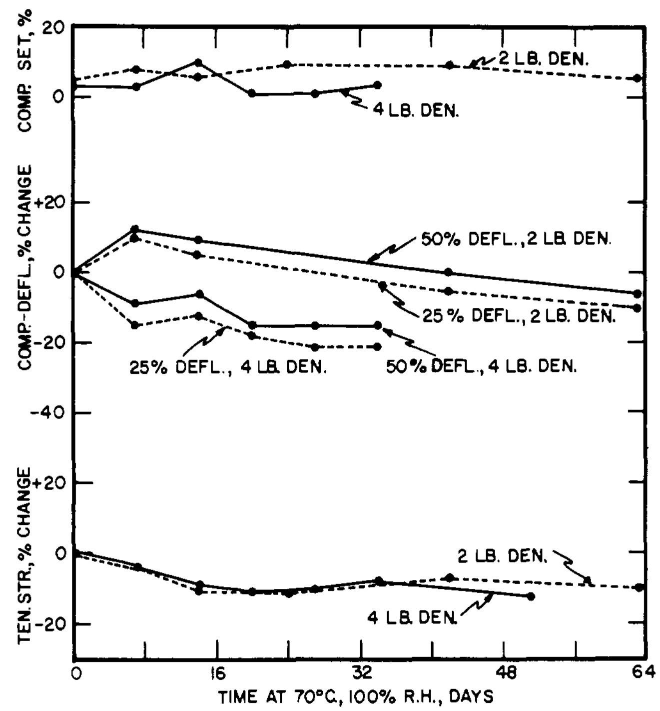

Figure 11. Accelerated hydrolysis resistance of poly(propylene glycol) urethane foam

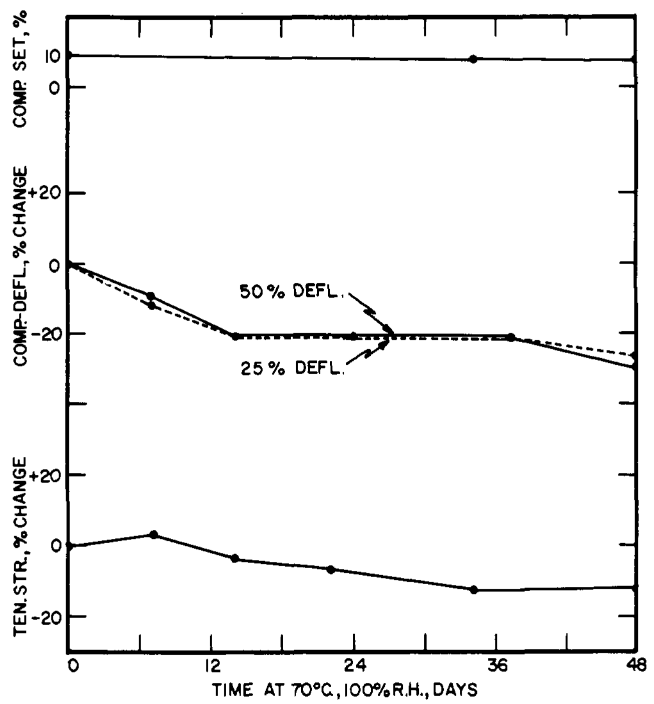

Figure 12. Accelerated hydrolysis resistance of modified poly(propylene glycol) urethane foam

2 lb./cu.ft. density

foams are similar in the 0 to 50% deflection range. Similar comparisons are made in Figure 8, using compression-deflection curves. It is readily seen that these poly(propylene glycol) foams are equal to or better than the comparable latex foams in their resistance to bottoming.

Accelerated Hydrolysis Resistance. The resistance of adipic acid polyester foams to accelerated hydrolysis conditions (Figure 9) is well known in the trade (*5*). The data given in Figure 10 compare 2-pound-per-cubic foot foam from all four systems, and show that the dimer acid polyester foams had significantly better resistance than those from the adipic acid polyester. This may be expected because of the more pronounced hydrophobic character of the dimer acid, and the lower content of hydrolyzable groups in the dimer acid polyester.

Figure 10 also shows that both polyether systems were far superior to either of the polyester foams in this respect. Additional data showing the resistance of poly(propylene glycol) and modified poly(propylene glycol) foams as measured by changes in tensile, compression-deflection, and compression set are given in Figures 11 and 12. Theoretically the pure poly(propylene glycol) foams should be somewhat more hydrophobic than the ethylene oxide-modified poly(propylene glycol) foams, and consequently slightly more resistant to hydrolysis. The small differences in the resistance of the two systems were not considered significant at this time, however.

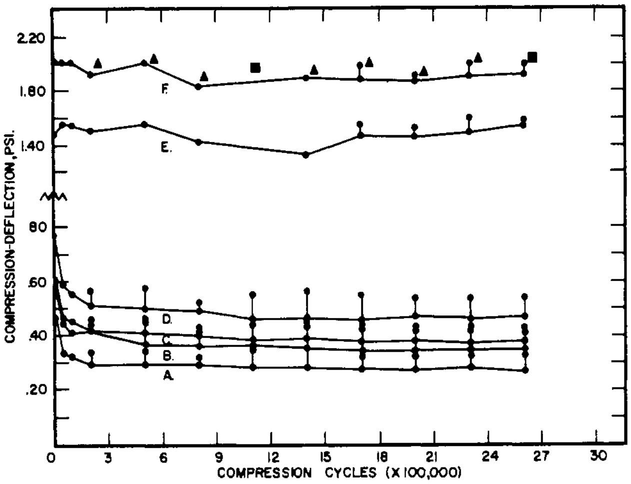

Figure 13. Flex fatigue resistance of adipic acid polyester foam

2 lb./cu.ft. density

A. 25% deflection, 1-minute rest
B. 25% deflection, no rest
C. 50% deflection, 1-minute rest
D. 50% deflection, no rest
E. 75% deflection, 1-minute rest
F. 75% deflection, no rest
▲ Measured after 18-hour recovery for each curve
■ Measured after 64-hour recovery for each curve

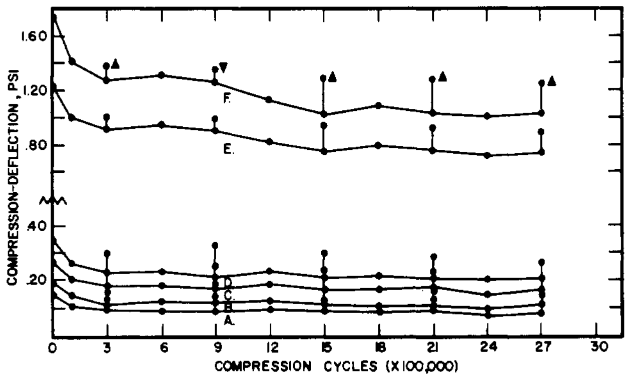

Figure 14. Flex fatigue, dimer acid polyester urethane foam

A. 25% deflection, 1-minute rest
B. 25% deflection, no rest
C. 50% deflection, 1-minute rest
D. 50% deflection, no rest
E. 75% deflection, 1-minute rest
F. 75% deflection, no rest
▲ Measured after 18-hour rest for each curve
▼ Measured after 90-hour rest for each curve

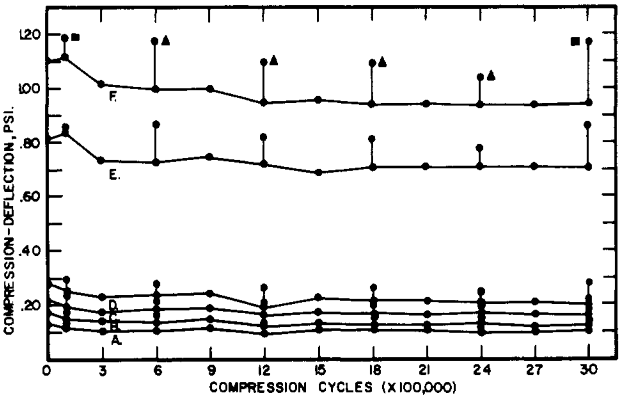

Figure 15. Flex fatigue of poly(propylene glycol) urethane foam

A. 25% deflection, 1-minute rest
B. 25% deflection, no rest
C. 50% deflection, 1-minute rest
D. 50% deflection, no rest
E. 75% deflection, 1-minute rest
F. 75% deflection, no rest
▲ Measured after 18-hour recovery for each curve
■ Measured after 64-hour recovery for each curve

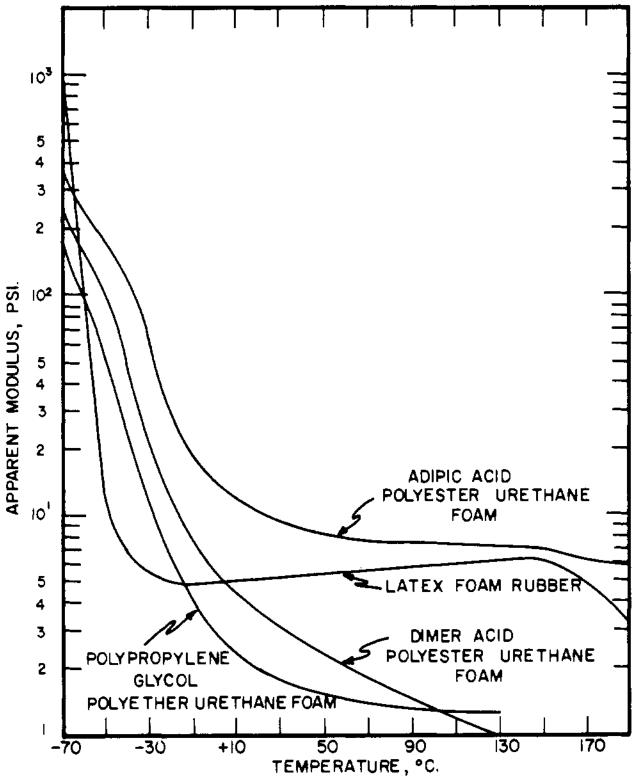

Figure 16. Clash-Berg torsional stiffness properties of flexible foams

Flex Fatigue Resistance. The resistance of all four types of foam to flex fatigue was good (Figures 13, 14, and 15). When flexed for 30 cycles per second at 0 to 70% or 30 to 80% deflection all types showed moderate softening after 50,000 to 300,000 cycles. Little or no additional softening occurred during the remainder of the tests, which ran to 2,700,000 to 3,000,000 cycles. When samples were permitted to relax for 18 to 90 hours, they regained all or a portion of the lost strength. The height loss of all samples at the end of the tests was only 0 to 8%, and there was no increase in compression set.

The polyether foams were superior to the polyester foams in that they showed extremely little effect during this test. As poly(propylene glycol) foam and the modified poly(propylene glycol) foam showed similar behavior in this test, data are given for only one (Figure 15).

Other tests were run similarly on adipic acid polyester foams at 0 to 50% deflection at 30 and 1 cycle per second. Tests were also run at 45 to 55% deflection and 30 cycles per second to simulate low amplitude vibrations which might be encountered in aircraft seating applications. In all experiments the effect was even less than that at 0 to 70% deflection reported above.

Table V. Solvent and Chemical Resistance of Urethane Foams

Solvent or Chemical	Change in Tear Strength, % Wet	Change in Tear Strength, % Dry	Change in Tear Strength, % Swelling	Change in Tensile Strength, % Wet	Change in Tensile Strength, % Dry	Change in Tensile Strength, % Swelling
	Foam System. 3 Lb./Cu. Ft. Adipic Acid Polyester Foam			System. Modified Poly(propylene Glycol)		
Linseed oil	−20	Unchanged	Slight	...	...	...
Turpentine	−45	Unchanged	Slight	−73	0	Heavy
Ether	−40	Unchanged	Slight	−5	0	Heavy
Gasoline	−55	Unchanged	Slight	−64	+8	Heavy
Mineral oil	−50	Unchanged	Slight	+6	0	Slight
Benzene	−80	Unchanged	Heavy	−30	−4	Heavy
Chlorobenzene	−90	Unchanged	Heavy	...	...	...
Carbon tetrachloride	−75	Unchanged	Heavy	−37	+7	Heavy
Ethyl acetate	−90	Unchanged	Heavy	−27	−15	Heavy
Acetone	−75	Unchanged	Heavy	−63	0	Heavy
Ethyl alcohol	−85	Unchanged	Heavy	−90	−10	Heavy
Water	−35	Unchanged	None	−47	−8	None
Sea water	−40	Unchanged	None	...	...	...
Salt, 10%	−35	Unchanged	None	−43	−8	None
Detergent solution	−30	Unchanged	None	−40	+5	None
Soap solution	−30	Unchanged	None	−43	0	None
Sodium carbonate, 10%	...	...	...	−36	+5	None
Sodium hydroxide, 10%	...	...	...	−35	0	None
Nitric acid, 10%	...	...	...	−43		None

Low and High Temperature Flexibility. The low and high temperature flexibility of the foams was measured in terms of the Clash-Berg torsional stiffness (Figure 16). The modulus calculated from this test should represent a qualitative basis for comparison of other properties, such as indent characteristics. The adipic acid polyester foams were found to begin stiffening significantly at about −10° to −25°C. The dimer acid foam stiffened gradually, but in the temperature range of −10° to −30°C. it reached any given modulus at a temperature about 15° to 20° lower than the adipic acid polyester foam. The poly(propylene glycol) foam showed an additional advantage of about 10°C.—e.g., reached an apparent modulus of 2000 pounds per square inch at −40°, compared to −30° for dimer acid and −10° for adipic acid polyester foam. The latex foam reached this modulus at −53°C. Modified poly(propylene glycol) foams gave essentially the same results as poly(propylene glycol) foams.

Similar experiments at higher temperatures showed that adipic acid polyester foams changed very little in modulus from 30° to 195°C. The dimer acid polyester foam slowly but continually softened as the temperature was raised to 130°C. The poly(propylene glycol) foam changed little from 30° to 140°C., but was beginning to soften noticeably as 140°C. was reached. The latex foam was constant over the range −30° to 160°C.

Solvent and Chemical Resistance. The solvent resistance of the adipic polyester and modified poly(propylene glycol) foams (Table V) was roughly equivalent, although the latter underwent greater swelling. After drying, both types of foams regained their original strength. The poly(propylene glycol) foams were similar to the modified poly(propylene glycol) foams. (Dimer acid foams were not tested.)

Solvents such as hydrocarbons and linseed oil caused little swelling of the polyester foams, whereas aromatics, chlorinated solvents, esters, ketones, and alcohols caused severe swelling. Water and aqueous solutions did not swell these foams. The polyether foams were swollen by ether, gasoline, and turpentine, in addition to the aromatics, chlorinated solvents, esters, ketones, and alcohol. Aqueous solutions caused no swelling of the polyether foams.

Oxidation and Ultraviolet Resistance. The ultraviolet resistance of all types of foams was evaluated using a Fade-Ometer (Figure 17). The modified poly(propylene glycol) foams were affected slightly less than the others, followed by dimer acid, adipic acid, and latex foams in

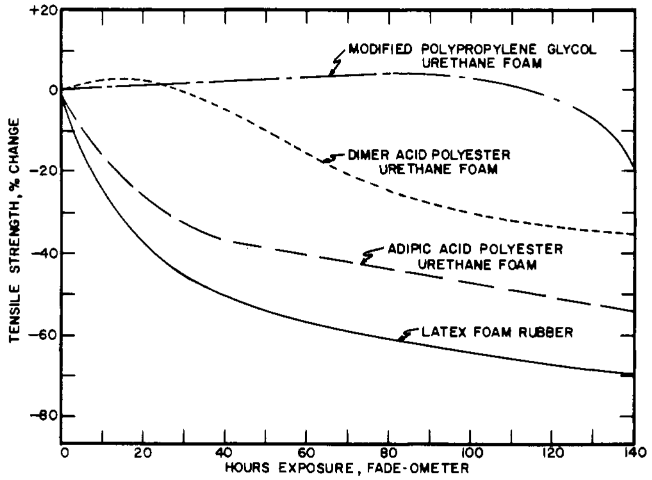

Figure 17. Ultraviolet resistance of flexible foams

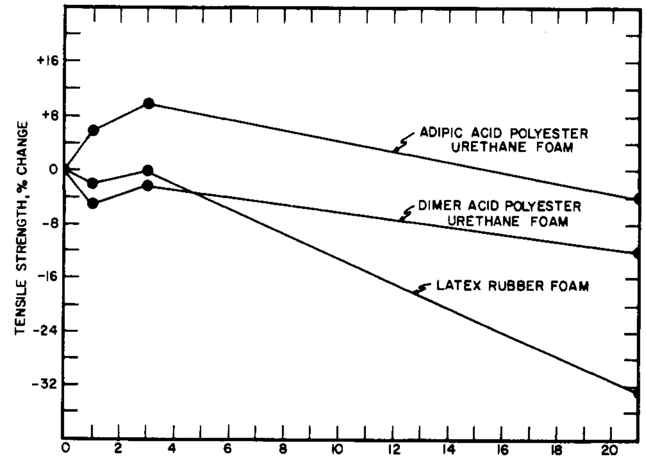

Figure 18. Oxidation resistance of flexible foams

that order. The latex foams showed a very early formation of a heavy crust, which did not appear in any of the urethane foams. All urethane foams showed a surface effect, in that all samples eventually became friable on the surface. It is believed that small changes in tensile strength in this test are not significant, primarily because the effect was largely a surface one. The uniformity and size of foam cells might be expected to exert a considerable influence on the rate of penetration of this effect into the foam.

Oxygen bomb test data on the polyester foams were also obtained at 70° C. and 300-atm. oxygen pressure (Figure 18). The polyester foams showed very little effect in 500 hours, whereas the latex foam showed a significant loss of strength. [The poly(propylene glycol) and modified poly(propylene glycol) foams have not yet been tested.]

None of the urethane foams used in these tests contained an oxidation or ultraviolet stabilizer.

Flame Resistance. The polyether foams had excellent flame resistance. Foams prepared with certain activator systems did not support combustion, even though no flameproofing agent was added. The foam from other activator combinations was self-extinguishing after a few seconds, comparable to adipic acid polyester foams containing 4% (based on polyester) of flame-proofing agent. The dimer acid foams supported combustion, but not so readily as latex foams.

INTERPRETATION OF PROPERTIES

The foam properties reported here give some indication of the value of these materials for many applications. In some cases factors other than those reported here may be more important and may decide the choice of materials for the specific applications.

For seating applications the properties of the two polyether foams and the dimer acid foam appear to be approximately equal, and are more favorable than those of the adipic acid polyester foams. The first three types give nearly linear indent and compression-deflection curves without coring, and have lower hysteresis, higher rebound, and better feel than the adipic acid polyester foam. This latter foam does not have a linear compression-deflection curve in slab stock, but it can be cored with pyramid- or cone-shaped cores to give such a curve. Even so, it does not have as luxuriant and comfortable a feel as the polyether and dimer acid polyester foams. All four types have good flex fatigue resistance and good compression set, essentials for good seating. The solvent resistance is adequate for cleaning purposes.

The low temperature flexibility of the polyether foams is better than that of either type of polyester foam, which will be an advantage for automotive seating applications. Although the temperature-modulus curve for the polyether foams is not so flat in the range of +25° to −25° C. as that of latex foam, the polyether foams are believed to be adequate in this respect.

The polyether foams have added advantages in their greater ease of molding and preparation of slab stock, as compared to both of the polyester foams. Mold times are short (10 to 12 minutes), and the cushions can be easily stripped from the mold for further curing (Figure 19). Slab stock may be prepared in higher blocks with the polyether foam (Figure 20) than with the polyester foam, and the polyether foam slabs can be more readily heat-formed without skin into cushions and other items (Figure 21).

For pillows and mattresses, which may require softer foams than seating applications, both polyether and the dimer acid polyester foams appear suitable, and are equivalent. The adipic acid polyester foam is believed to be too stiff for these applications unless highly cored.

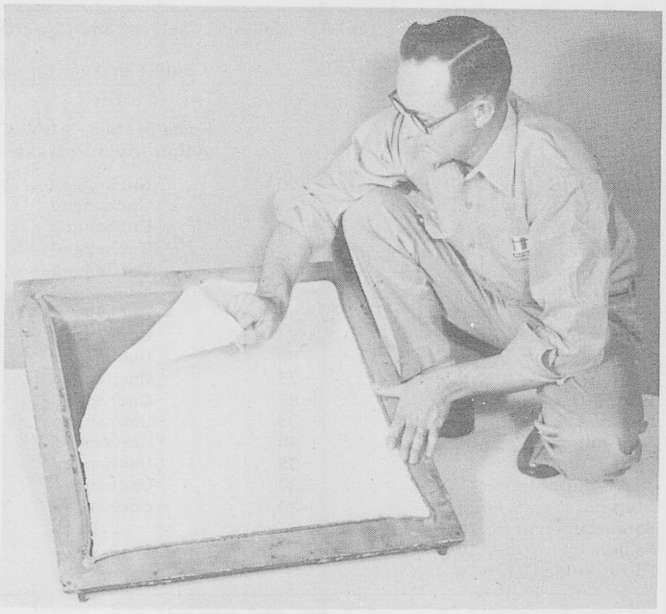

Figure 19. Molding urethane foam

Polypropylene glycol urethane foam being removed from mold after 10- to 12-minute mold time

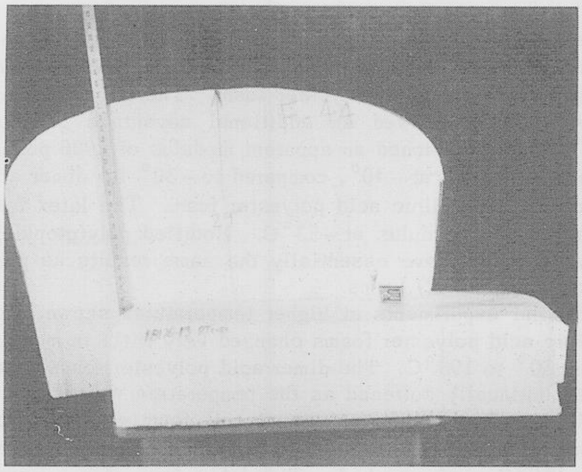

Figure 20. Comparison of slab stock block height

Experimental polypropylene glycol urethane foam blocks 28 to 30 inches high have been made, compared to normal 9- to 12-inch polyester urethane foam blocks

The adipic acid polyester foams are being widely used for clothing interliners. Their good insulating qualities, light weight, and resistance to washing and dry cleaning make them attractive for this use. The drape or feel of the thin foam sheets used for this application is very important, as well as the ease of cutting very thin sheets. The properties of the polyether foams described here indicate they may be even better than the adipic acid polyester foams because of increased softness and low temperature flexibility. The solvent resistance appears to be adequate, though they are somewhat more susceptible to swelling when wet with dry cleaning solvents. The dimer acid polyester foams should be the equal of the polyether foams, although their solvent resistance has not been determined as yet.

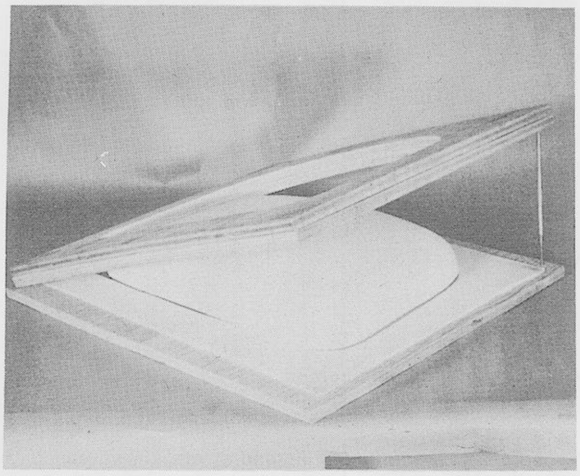

Figure 21. Heat-forming urethane foam

Poly(propylene glycol) urethane foam can be heat-formed simply and under milder conditions than polyester urethane foams

Table VI. Properties of Adipic Acid Polyester Urethane Foam Topper Pad after 2.5-Year Use

Property	Value
Thickness, mm.	28^a
Set, %	6.7
Density, lb./cu.ft.	5.6
Tensile, lb./sq.inch	23
Elongation, %	315
Compression set, 70° C., % (based on original thickness)	12
German automotive indent specifications	Pass

^{a}Original thickness, 30 mm.

Rug underlay applications are most readily satisfied by the adipic acid polyester foams at this time. The dimer acid polyester foams and the polyether foams described here are too soft for rug underlay, where a compression-deflection value of 0.8 to 1.0 pound per square inch at 25% deflection may be desired. It may be expected that stiffer foams meeting this requirement will be developed from these newer resins.

Crash pads and other applications requiring good shock absorption have been prepared most readily from the adipic acid polyester foams. The other three foams described here again are too soft for these applications, but formulations suitable for them are under development.

The oxidation resistance of all types of urethane foam under the test conditions used was superior to that of latex foam, and should be adequate for all normal uses. Further improvements perhaps will be realized by the incorporation of an appropriate oxidation stabilizer.

The hydrolysis resistance of adipic acid polyester foams has generally been considered as one of the major factors limiting the full use life of these foams. They have now been used long enough to give some indication of their actual service life. For example, an automotive topper pad was used in Europe for 2.5 years, during which time the car was driven 65,000 miles. At the end of this time the pad was in good condition and had the properties indicated in Table VI.

The exact conditions of manufacture of this pad are not known. However, it is generally recognized in the urethane foam industry that foams of 1.5 to 3 pounds per cubic foot density have better hydrolysis resistance than 5-pound foams, the resistance generally improving as the density is lowered. Consequently adipic acid polyester urethane foams of the type described in this report may reasonably be expected to give longer service life than the 5.6-pound topper pad. Hopkins has estimated 6-year service life for a 4-pound foam (*5*).

The data presented here also show that the dimer acid polyester foams should have considerably longer service life than the adipic acid polyester foams. Finally, the polyether foams should have several times the service life of the polyester foams, based on hydrolysis resistance. Walsh has estimated at least 15 to 20 years for certain polyether foams (*9*).

ACKNOWLEDGMENT

The results presented in this paper were obtained as a part of the development of urethane foams at Mobay during a 2-year period, with the valuable cooperation of Farbenfabriken Bayer. The authors wish to express their appreciation to the following chemists for the preparation of foam samples, development of test methods, and evaluation of samples: P. J. Baker, W. C. Darr, W. C. Foster, H. C. Jigargian, A. Lerner, E. Peters, G. E. Reid, H. R. Schloss, L. E. Sine, J. F. Szabat of Mobay, and H. Ebneth, G. Loew, and E. Windemuth of Bayer.

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Received for review May 9, 1957. Accepted October 25, 1957.