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STATIC COMPRESSIVE TESTING OF
RIGID POLYURETHANE FOAM

PDO 6984191, Topical Report

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October 1974

MASTER

Prepared for the
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**Kansas City
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Department 834

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STATIC COMPRESSIVE TESTING OF RIGID POLYURETHANE FOAM

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October 1974

Prepared by T. E. Neet and S. L. DeGisi, D/814, under
PDO 6984191

The relationships between the compressive strength and modulus and the test temperature and density of 11 foam systems are presented. The results of the study are graphically illustrated.

THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
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SUMMARY

The design of light-weight structural supports requires knowledge of the strength versus temperature and density relationships for all materials being considered. A single source for this information on rigid urethane foams has not been available in the past. Such data have either been unavailable without testing or have been scattered throughout a number of technical publications.

Studies conducted on this project resulted in the development of the relationships between the compressive strength and modulus, the test temperature, and the density of 11 rigid urethane foams. Those materials studied were BKC Thermalthane 4003-8, and BKC Rigifoams 7004-6C, 7005-20, and 6003-6 (Bendix Corporation); CPR 1005, 1024-3C, 1056-20, and (Expanded Rubber Co.); and BX 105-C6 and BX 105-C10 (Stepan Chemical Company). The results are graphically displayed in this report.

In addition, all 11 foam systems were fit simultaneously to the classic compressive strength equation¹: compressive strength = $K(\text{Density})^\alpha$ where K and α are constants for any given foam system (Figures 1 through 32 and Tables 1 and 2). Compressive strength and modulus lines for all of the foams at four different test temperatures are shown. Also included on the graphs are the 90-percent confidence limits based on the data from the foam systems tested. Future activities will involve additional evaluation of polymeric isocyanate materials and generation of data on compressive strength and compressive modulus versus density and temperature.

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DISCUSSION

SCOPE AND PURPOSE

A definite need for strength data on structural support materials exists for some current applications. While rigid urethane foams are in general use, information on the compressive strength of foams at given densities and test temperatures has not been compiled for convenient reference. The purpose of this project was to test the foams commonly used and to distribute the data for the compressive strength and compressive modulus versus density and temperature for each material.

PRIOR WORK

The compressive properties of rigid urethane foams at various densities and temperatures have been investigated as part of numerous projects. The equipment and procedures required for these tests are available and well established. However, little effort has previously been applied to collecting systematically an entire range of data relating the compressive strength of a urethane foam to its density and test temperature.

ACTIVITY

Eleven rigid urethane foams, listed below, were tested to determine the effect of material density and test temperature on the compressive strength of the foam.

Thermalthane 4003-8;
Rigifoams 7004-6C, 7005-20, and 6003-6;
CPR 1005, 1024-3C, 1056-20, and 1040-10;
Stafoam AA 602; and
BX 105-C6 and 105-C10.

Test samples were cut from the cores of 4- by 6- by 12-inch (100- by 150- by 300-mm) billets to minimize density variations in the test samples. It had previously been established^{2,3} that other factors such as cure time, cure temperature, and direction of rise do not influence compressive strength/modulus results when core samples from relatively large blocks are tested. This assumes a packing factor of approximately 3:1. At lower packing factors, directional properties may enter into the compressive strength results.

The 1.000-inch (25.40 mm) cube test specimens were compression-tested at temperatures ranging between -65 to 500°F (-54 to 260°C). The

density of each sample was also determined. All material samples were tested at a strain rate of 0.050 inch/minute (0.13 cm/minute). The samples were tested unrestrained between rigid parallel platens on an INSTRON, Model TTC, 10,000-pound universal tester. These compressive strength data were normalized to common densities using the following equation: compressive strength (modulus) equals a constant times the density raised to a power ($C.S. = KD^\alpha$). The results for both compressive strength and compressive modulus versus density and temperature were plotted as shown in Figures 1 through 20.

In addition, data from all 11 foam systems were fed into the computer and simultaneously fit to the equation, $C.S. = KD^\alpha$. For the four test temperatures represented, the computer then yielded the coefficients K and α which provided the best fit line through all data points. The values for these constants are listed in Table 1 and are compared to previously reported constants for room-temperature foam. Figures 21 through 28 represent the composite compressive strength and modulus slopes for all the evaluated foam systems. The center slope of all graphs shows the average property while the outer slopes reflect the 90-percent confidence limits.

The data from all foams were analyzed for a possible change of slope in the compressive strength line. For this study, the K and α values at all four temperatures were determined above and below selected densities. In those cases when the incorrect discontinuity point was selected, the standard deviation of the resulting equations increased. However, when the break-point was placed near a 10-lb/ft³ density (160 kg/m³), equations for the compressive strengths were developed with equal or lesser standard deviations than those obtained when using only one predictor equation. The K and α values for these new equations are shown in Table 2, while the graphs representing the average of the data and the 90-percent-confidence limits are presented in Figures 29 through 32. No data are presented for the compressive moduli using this approach since no discontinuities in the lines were found.

Table 3 is included as a summary of material usage recommendations, based on prior usage and the data presented here. These recommendations are intended as general guidelines and not as a substitute for technical judgment. For greater accuracy and clarity, the recommendations made are based on entire foam systems rather than on the specific formulation used for this evaluation.

ACCOMPLISHMENTS

The results presented in this report provide a relatively complete representation of the compressive properties versus temperature

and density of most of the rigid urethane foams included in current design and fabrication criteria. This information is expected to assist in the selection of alternate or new foam systems for present as well as future applications.

FUTURE WORK

The data published herein are based on results from testing ten toluene diisocyanates and one polymeric isocyanate material. Future activities will be directed toward evaluation of additional polymeric isocyanate materials. This information, plus data on new materials, as they become available, will be included in future reports.

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Figure 1. Compressive Strength Versus Density for BKC Thermalthane 4003 Core Samples at 10-Percent Deflection

Figure 2. Compressive Modulus Versus Density for BKC Thermalthane 4003 Core Samples at 10-Percent Deflection

Figure 3. Compressive Strength Versus Density for BKC Rigifoam 7004 Core Samples at 10-Percent Deflection

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Figure 15. Compressive Strength Versus Density for AA 602 Core Samples at 10-Percent Deflection

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Figure 27. Effect of Density on the Compressive Strength of Rigid Urethane Foam at 250°F (121°C)

Figure 28. Effect of Density on the Compressive Modulus of Rigid Urethane Foam at 250°F (121°C)

Figure 29. Effect of Density on the Compressive Strength of Rigid Urethane Foam at -65°F (-54°C) (Dual-Sloped Curves)

Figure 30. Effect of Density on the Compressive Strength of Rigid Urethane Foam at 77°F (25°C) (Dual-Sloped Curves)

Figure 31. Effect of Density on the Compressive Strength of Rigid Urethane Foam at 165°F (74°C) (Dual-Sloped Curves)

Figure 32. Effect of Density on the Compressive Strength of Rigid Urethane Foam at 250°F (121°C) (Dual-Sloped Curves)

Table 1. Values for K and α Constants for Compressive Strength Versus Density*

Test Temperature		Constants	
(°F)	(°C)	K	α
-65	(-54)	10.47	1.76
77	(25)	6.43	1.77
165	(74)	6.79	1.63
250	(121)	3.97	1.58
*General equation for all tested foam systems			

Table 2. Values for K and α Constants Above and Below the Slope Change-Point for Compressive Strength Versus Density*

Test Temperature		Density		Constants	
(°F)	(°C)	(lb/ft ³)	(kg/m ³)	K	α
-65	(-54)	<15	(240)	14.96	1.60
-65	(-54)	>15		6.41	1.92
77	(25)	<15		9.05	1.61
77	(25)	>15		5.28	1.84
165	(74)	<15		9.88	1.46
165	(74)	>15		5.47	1.71
250	(121)	<15		4.80	1.49
250	(121)	>15		3.89	1.59
*Dual-slope equation for all tested foam systems					

Table 3. Material Usage Recommendations

Material Designation	Material Type	Requirements		
		Percent Ash and Chlorine	Low Density 2 to 10 lb/ft ³ (32 to 160 kg/m ³)	Medium Density 10 to 20 lb/ft ³ (160 to 320 kg/m ³)
4003	1	N/R	U	A
7004	2	A	M	A-M
6003	2	A	A*	A*
1056/7005	2	A	U	A-M
1005	2	A	U	U
1024/105	2	A	A	A
1040	2	A	U	A*
AA600	2	A	A	A
Legend				
1 Polymeric Isocyanate				
2 Toluene Diisocyanate				
A Acceptable				
M Marginal				
N/R Not Recommended				
U Unknown; Insufficient Data				
* Preferred				

			Reference
High Density 20 to 40 lb/ft ³ (320 to 640 kg/m ³)	High Temperature Service (>250°F) (>121°C)	Mold-to- Size	
A	A*	A	Figures 1 and 2
A-M	A	A-M	Figures 3 and 4
A*	N/R	A*	Figures 5 and 6
A*	N/R	A*	Figures 7 and 8
A*	N/R	U	Figures 9 and 10
N/R	N/R	A	Figures 11, 12, 17, 18, 19, and 20
A	N/R	A*	Figures 13 and 14
M	M	A	Figures 15 and 16

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¹Calvin James Benning, "Chemistry and Physics of Foam Formation," *Plastic Foams*, Volume 1, Interscience, New York, 1969, p 221.

²S. L. DeGisi and T. E. Neet, "Effect of Amine Catalysts on the Physical Properties of a Rigid Urethane Foam System," *Journal of Cellular Plastics*, Volume 7, Number 4, July/August, 1971, pp 165-201.

³S. L. DeGisi and T. E. Neet, "Effect of Amine Catalysts on the Compressive Properties of Urethane Foam," *Journal of Cellular Plastics*, Volume 9, Number 4, July/August, 1973, pp 174-181.

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