BDX-613-1345 (Rev.)
Distribution Category UC-25

FLEXIBLE POLYURETHANE FOAM

Published January 1976

Project Leader:
J. Salary
Department 814

Project Team:
O. A. Krueger
E. T. Walsh

PDO 6989216
Final Report

Technical Communications

Bendix Kansas City Division

DISCLAIMER

FLEXIBLE POLYURETHANE FOAM

BDX-613-1345 (Rev.), Published January 1976

Prepared by J. Salary, D/814, under PDO 6989216

Flexible polyurethane foam systems with different densities and load-bearing properties have been developed for use in packaging applications. A flexible foam formulation, Number 092674-1, has been designated BKC 45301 according to Material Standard 2170658.

WPC-JB

THE BENDIX CORPORATION
KANSAS CITY DIVISION
P.O. BOX 1159
KANSAS CITY, MISSOURI 64141

A prime contractor for the United States Energy Research and Development Administration
Contract Number AT(29-1)-613 USERDA

CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

Flexible polyurethane foam systems with different densities and load-bearing properties were developed at the Bendix Kansas City Division for use in packaging applications. Several formulation parameters such as polyol type, mix ratio, catalyst concentration, mix time, mold preheat, and cure cycle were investigated. Compression/deflection and compression-set tests were performed on foam samples prepared from the various formulations.

The test results showed compression/deflection properties for some of the foam formulations evaluated in this investigation meet the requirements of Material Standards 2170612 through 2170615 and 2170372 indicating these new formulations are suitable for packaging purposes. Adding as much as 10 percent calcium carbonate as a filler only slightly improved compression/deflection properties.

A flexible polyurethane foam derived from this investigation has been designated BKC 45301 according to Material Standard 2170658.

DISCUSSION

SCOPE AND PURPOSE

The need for flexible polyurethane foam systems continues to increase at Bendix. These materials are primarily used for packaging applications. This type application requires material having different densities and load-bearing properties.

Flexible urethane foam systems are becoming commercially available only in large quantities [1000-pound orders (453.5 kg) minimum]. This presents both a shelf life and a material storage problem at Bendix Kansas City since our need is on a much smaller scale than most commercial applications.

This project was undertaken to develop various flexible polyurethane foam systems suitable for packaging purposes. These materials could be produced in small lots in the Resin Pilot Plant to support production needs as dictated by schedule requirements.

ACTIVITY

List of Materials and Suppliers

The materials and suppliers used to prepare the formulations are listed in Table 1.

Preparing and Testing Flexible Polyurethane Foam

All foam blocks were prepared by mixing an isocyanate component and a polyol component. The isocyanate component was made by blending 80 parts by weight of polymeric isocyanate and 20 parts by weight of toluene diisocyanate. The polyol component contained a polyether polyol, catalyst, blowing agent, filler, and cross-linking agents. The two components were mixed for 30 seconds using an 82 mm Conn-type impeller fitted to a high speed, air-driven stirrer. Then quantities of materials adequate for the desired density were weighed into metal molds which had been coated with a fluorocarbon mold release. Three mold sizes were used: one was 8 by 8 by 3.25 inches (203.2 by 203.2 by 82.5 mm), the second was 4 by 6 by 12 inches (101.6 by 152.4 by 304.8 mm), and the third was 8 by 8 by 4 inches (203.2 by 203.2 by 101.6 mm). The mold preheat temperatures ranged from 70 to 80°C.

The compression/deflection tests were conducted in accordance with Material Standard 9952033 with the exception that the samples were 3 by 3 by 1 inches (76.2 by 76.2 by 25.4 mm). The tests were performed at approximately 26°C. All compression-set tests

Table 1. List of Materials and Suppliers

Polyether Polyols	Supplier
Poly-G-X802 (OH Number 38.1)	Olin Chemical Company
Poly-G-X803 (OH Number 25.0)	Olin Chemical Company
Poly-G-X804 (OH Number 26.1)	Olin Chemical Company
Poly-G-3030 (OH Number 55.1)	Olin Chemical Company
Cross-Linking Agents	**Supplier**
Pluracol 581	BASF Corporation
Quadrol-	BASF Corporation
Trimethylolpropane (TMP)	Celanese Chemical Company
Filler	**Supplier**
Calcium Carbonate ($CaCO_3$)	Fisher Scientific Company
Catalyst	**Supplier**
DABCO 33 LV	Houdry Process and Chemical Company
Isocyanates	**Supplier**
Toluene Diisocyanate (TDI)	Mobay Chemical Company
Mondur 432	Mobay Chemical Company
Polyaryl Polyisocyanate (PAPI)	Upjohn Company

were conducted in accordance with Material Standard 9952033 with the exception that the samples were 1-inch (25.4 mm) cubes.

Analyses of Test Results

Formulation variables, even when only slightly altered, can greatly affect flexible urethane foam properties. Some of these variables are: polyol type, catalyst, surfactant, blowing agent, and filler. In addition, changes in formulation variables can also alter processing characteristics of the material. The choice as to which polyol to use in a flexible urethane foam formulation involves several considerations. Normally, polyether polyols are based on polypropylene oxide, which results in moderately reactive secondary hydroxyl groups. A process called "capping" involving the use of ethylene oxide can modify the polyol so that a large percentage of the reactive sites consists of highly reactive primary hydroxyl groups. An advantage obtained by using "capped" polyols is that rapid reactions with the isocyanate groups generating considerable heat take place and tend to shorten curing cycles, produce favorable cure, and increase load-bearing properties of the foam.[1] All polyols used in this investigation had varying percentages of capping. The average molecular weight of the polyols used ranged from 4400 to 6500 with hydroxyl numbers varying from 25 to 56.

Four foam formulations based on four different polyols were prepared (Table 2). Table 3 is a listing of compression/deflection results for some of the samples prepared from these formulations. Since the foam samples were of different densities, no comparison could be made of the effect of the various polyols on the compression properties.

Figure 1 is an illustration of the average compression/deflection for a foam sample prepared from Formulation 092374. This material meets the requirements of Material Standard 2170615; however, the data indicate the foam could have a higher load-bearing capacity and still fall within the specification range required.

Table 4 is a listing of some flexible foam formulations in which trimethylolpropane and Pluracol 581 are used as cross-linking agents and calcium carbonate is included as a filler. The filler content was varied from 1 to 10 percent based on the total weight of the formulation. Trimethylolpropane constituted approximately 4 percent by weight of the formulation, while Pluracol 581 made up 18 percent. Table 5 and Figure 2 give the compression/deflection results of foam samples based on formulations containing the cross-linking agents and filler. Figure 2 also indicates compression/deflection limits of flexible urethane foam according to Material Standard 2170613. These data show foam Formulations 101574-1, 10974-2, and 10974-3 are in the lower portion of the requirements for the Material Standard and suggest that calcium carbonate, even at the 10 percent level, improves the compression/ deflection properties of the foam samples only slightly.

Flexible foam formulations are shown (Table 6) which are based on Poly-G-X803 and Poly-G-X804 polyether polyols using trimethylolpropane and Pluracol 581 as cross-linking agents. Average compression/deflection and compression-set data of foam samples based on these formulations are also given (Table 8).

---

[1]Technical Service Report, Flexible Molded Foams, Union Carbide Corporation, Chemical Division, Research and Development Department, South Charleston, West Virginia.

As indicated (Table 7), foam Formulation 101774-1 and 101774-2 are identical; however, the foam specimens based on Formulation 101774-1 were cured for 8 hours at 80°C, while the foam specimen based on Formulation 101774-2 was cured at room temperature. Using a mold preheat of 80°C, the compression/ deflection results of foam samples based on these two formulations are shown to be basically similar (Table 8). This indicates shorter cure cycles are possible when polyols that have undergone the capping process are used in foam formulations. Table 8 also gives the compression-set results of foam samples based on the formulations given in Table 6 and 7.

Figure 3 is a plot of the load versus percent deflection for foam formulations 092674-1, 092674-2, 11774-2, and 11774-1A. These data indicate all the samples tested are within the requirement limits of Material Standard 2170614. The cross-linking agent used in these formulations, Pluracol 581, is a polyol belonging to a class of materials termed "polymer polyols." Polymer polyols are a novel class of urethane intermediates which greatly enhance the load-bearing characteristics of flexible urethane foams. These materials are conventional flexible foam polyols containing a graft dispersion of in-situ polymerized vinyl polymers. Typical vinyl monomers used in commercial polymer polyols are acrylonitrile and styrene.[2]

Information is given (Figure 4) on the average compression/ deflection results of flexible polyurethane foam samples based on Poly-G-X803 and Poly-G-X804 polyether polyols using trimethylol-propane and Pluracol 581 as cross-linking agents. The compression/ deflection limits are shown for flexible urethane foam according to Material Standard 2170372. These data suggest the foam samples based on Formulation 11574, 11874-1, 103074-1, and 11774-1 are within the specification limits established for the material standard and indicate these foams systems can be used in foam applications where Material Standard 2170372 is called out.

ACCOMPLISHMENTS

Several different flexible polyurethane formulations have been developed. Compression/deflection results for some of the foam samples based on the formulations investigated show they are within the limits established in Material Standards 2170612 through 2170615 and 2170372, indicating these materials are suitable for packaging purposes. Calcium carbonate filler only

---

[2]F. E. Critchfield, J. V. Koleske, and D. C. Priest, "Polystyrene Copolymer Acrylonitrile) Polyols. Modulus Enhancing Polyols For Urethane Polymers," Rubber Chemistry and Technology, Volume 45, July, 1972, p 1467.

Table 2. Flexible Polyurethane Foam Formulations Based on Different Polyether Polyols

	Formulations (in Grams)			
Materials	080674	081274	082974	092374
Poly-G-X802	94.00			
Poly-G-X803			70.00	
Poly-G-X804				70.00
Poly-G-3030		99.00		
Trimethylolpropane	6.00	1.00		
Pluracol 581			20.50	20.50
Quadrol	4.50	4.50	9.50	9.50
DABCO 33 LV	0.80	0.80		0.80
Distilled water	0.80	0.80	0.80	0.80
Mondur 432/TDI (80/20)		35.9	34.8	42.10
PAPI/TDI (80/20)	44.40			

slightly improves the compression/deflection properties of the foam even at a 10 percent loading level.

A flexible foam formulation (Formulation Number 092674-1), developed as a part of this investigation, has been designated BKC 45301 according to Material Standard 2170658.

Table 3. Average Compression/Deflection Results for Flexible Polyurethane Foam Based on Different Polyether Polyols

Formulation	Density (lb/ft^3)*	Deflection 10 Percent (psi)**	30 Percent (psi)**	50 Percent (psi)**
082974	12.42	11.8	15.5	29.6
082974A	16.60	17.8	28.5	45.9
082974	17.41	13.7	25.9	58.9
081274	19.59	18.9	37.8	77.4
092374	24.44	25.9	33.3	60.0

Data were derived from an average of three 3- by 3- by 1-inch (76.2 by 76.2 by 25.4 mm) samples machined from molded foam blocks.
*1 lb/ft^3 equals 16.01 kg/m^3
**1 psi equals 6894 Pa

Table 4. Flexible Polyurethane Foam Formulations Using Trimethylolpropane and Pluracol 581 as Cross-Linking Agents and Calcium Carbonate as a Filler

Material	Formulation (in Grams) 10974-1	10974-2	10974-3	101174	101574-1
Poly-G-X803	70.00	70.00	70.00	94.00	94.00
Trimethylol-propane				6.00	6.00
DABCO 33 LV	0.80	0.80	0.80	0.80	0.80
Distilled Water	0.80	0.80	0.80	0.80	0.80
Calcium Carbonate	6.80	13.60	1.36		
Pluracol 581	20.5	20.50	20.50		
Quadrol	4.50	4.50	4.50	4.50	9.50
Mondur 432/TDI (80/20)	34.25	34.25	34.25		
PAPI/TDI (80/20)				41.70	50.40

Table 5. Average Compression/Deflection and Compression-Set Results for Modified Flexible Polyurethane Foam

Formulation	Density (lb/ft^3)*	Deflection: 10 Percent (psi)**	Deflection: 30 Percent (psi)**	Deflection: 50 Percent (psi)**	Compression-Set (Percent)
10974-1	12.20	12.2	15.5	27.4	5.1
10974-2	11.69	12.9	17.8	28.9	7.7
10974-3	12.11	10.7	13.7	22.6	6.9
101174	16.87	7.2	12.6	22.2	3.4
101574-1	17.06	9.2	15.9	32.6	4.9
101574-1	24.02	20.0	35.5	85.2	4.1

Data were derived from an average of three 3- by 3- by 1-inch (76.2 by 76.2 by 25.4 mm) samples machined from molded foam blocks. Compression-set data were derived from 1-inch (25.4 mm) cubes also machined from these foam blocks.

*1 lb/ft^3 equals 16.01 kg/m^3

**1 psi equals 6894 Pa

Table 6. Flexible Foam Formulations Based on Two Different Hydroxyl Number Polyether Polyols Using Trimethylolpropane as a Cross-Linking Agent

	Material (in Grams)						
Formulation	Tri-methylol-propane	Poly-G-X803	Poly-G-X804	Quadrol	Distilled Water	Mondur 432/TDI (80/20)	PAPI/TDI (80/20)
11574*	6.0	94.0	--	9.6	0.8	--	50.4
11774-1*	1.0	--	99.0	10.5	1.3	--	45.5
11774-2*	1.0	--	99.0	10.5	1.3	46.4	--
11874-1*	3.0	--	97.0	9.5	1.3	--	49.2
11874-2*	3.0	--	97.0	9.5	1.3	50.2	--
111274-1*	5.0	--	95.0	9.5	1.3	--	54.7

*Also contains 0.8 gram DABCO 33 LV.

Table 7. Flexible Foam Formulations Based on Two Different Hydroxyl Number Polyether Polyols Using Pluracol 581 as a Cross-Linking Agent

	Material (in Grams)						
Formulation	Pluracol 581	Poly-G-X803	Poly-G-X804	Quadrol	Distilled Water	Mondur 432/TDI (80/20)	PAPI/TDI (80/20)
092674-1*	20.5	70.0	--	9.5	0.4	--	30.6
092674-2*	20.5	70.0	--	9.5	0.6	33.7	--
101774-1**	20.5	70.0	--	9.5	0.8	34.5	--
101774-2**	20.5	70.0	--	9.5	0.8	34.5	--
103074-1*	25.0	--	75.0	4.5	1.3	33.1	--
103074-2*	25.0	--	75.0	4.5	1.3	--	32.5
11774-1A***	25.0	--	75.0	10.5	1.3	--	42.7
11774-2B*	25.0	--	75.0	10.5	1.3	46.4	--
111474-1*	25.0	--	75.0	9.5	0.8	34.8	--
111474-2*	25.0	--	75.0	9.5	0.8	--	34.2

*Also contains 0.8 gram DABCO 33 LV.
**Also contains 0.8 gram DABCO 33 LV and 6.8 grams calcium carbonate.
***Also contains 0.8 gram DABCO 33 LV and 0.2 gram DC 193.

Table 8. Average Compression/Deflection and Compression-Set Results for Flexible Polyurethane Foam Based on Two Different Hydroxyl Number Polyether Polyols Using Trimethylolpropane and Pluracol 581 as Cross-Linking Agents

Formulation	Density (lb/ft^3)*	Deflection 10 Percent (psi)**	Deflection 30 Percent (psi)**	Deflection 50 Percent (psi)**	Compression-Set (Percent)
103074-1	7.72	2.0	4.3	5.0	8.9
11874-2	7.79	3.8	7.1	9.2	5.7
11574	7.80	3.0	5.4	7.4	3.9
103074-2	7.92	1.0	2.3	3.0	3.9
11774-1	8.06	2.0	3.1	4.6	3.9
11874-1	8.56	2.8	4.2	6.2	4.7
11774-2	8.59	4.0	7.2	10.6	5.7
11774-2B	13.85	16.6	33.4	46.8	14.8
11774-1A	15.38	8.8	24.2	37.2	22.1
101774-2	17.09	16.0	34.5	46.0	9.6
111274-1A	17.29	4	10.5	17.2	4.4
101774-1	17.54	14.6	33.9	46.0	11.1
111474-1	17.79	8.4	23.7	33.2	5.8
092674-1	18.27	16.4	38.7	60.2	9.4
111474-2	18.32	13.0	34.8	47.6	5.8
092674-2	20.57	13.0	37.4	54.8	10.2

The compression/deflection data were derived from an average of three 3- by 3- by 1-inch (76.2 by 76.2 by 25.4 mm) samples machined from molded foam blocks. Compression-set data were derived from an average of two 1-inch (25.44 mm) cubes also machined from these foam blocks.

*1 lb/ft^3 equals 16.01 kg/m^3

**1 psi equals 6894 Pa

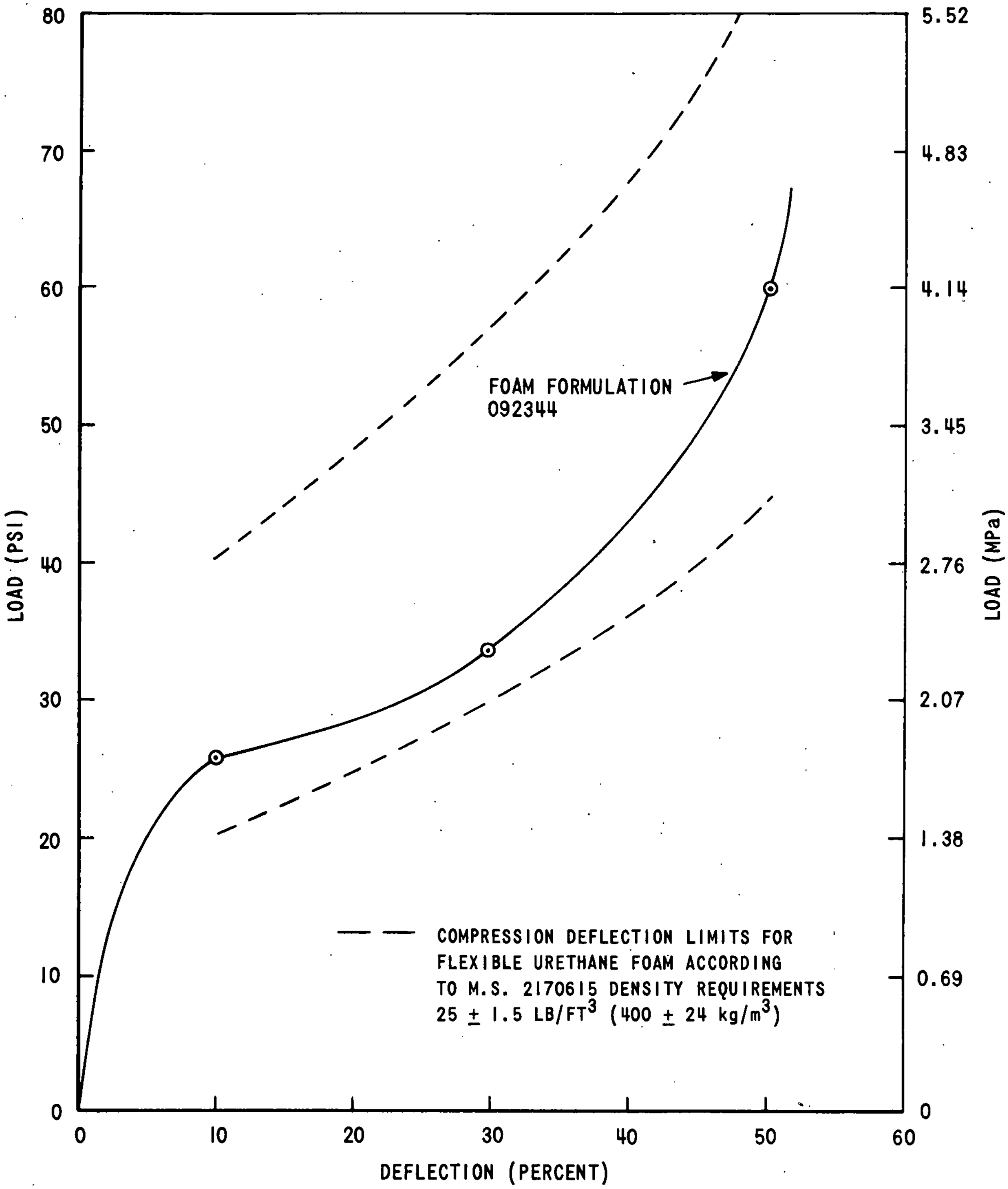

Figure 1. Average Compression/Deflection Results of Foam Samples Prepared From Formulation 092374

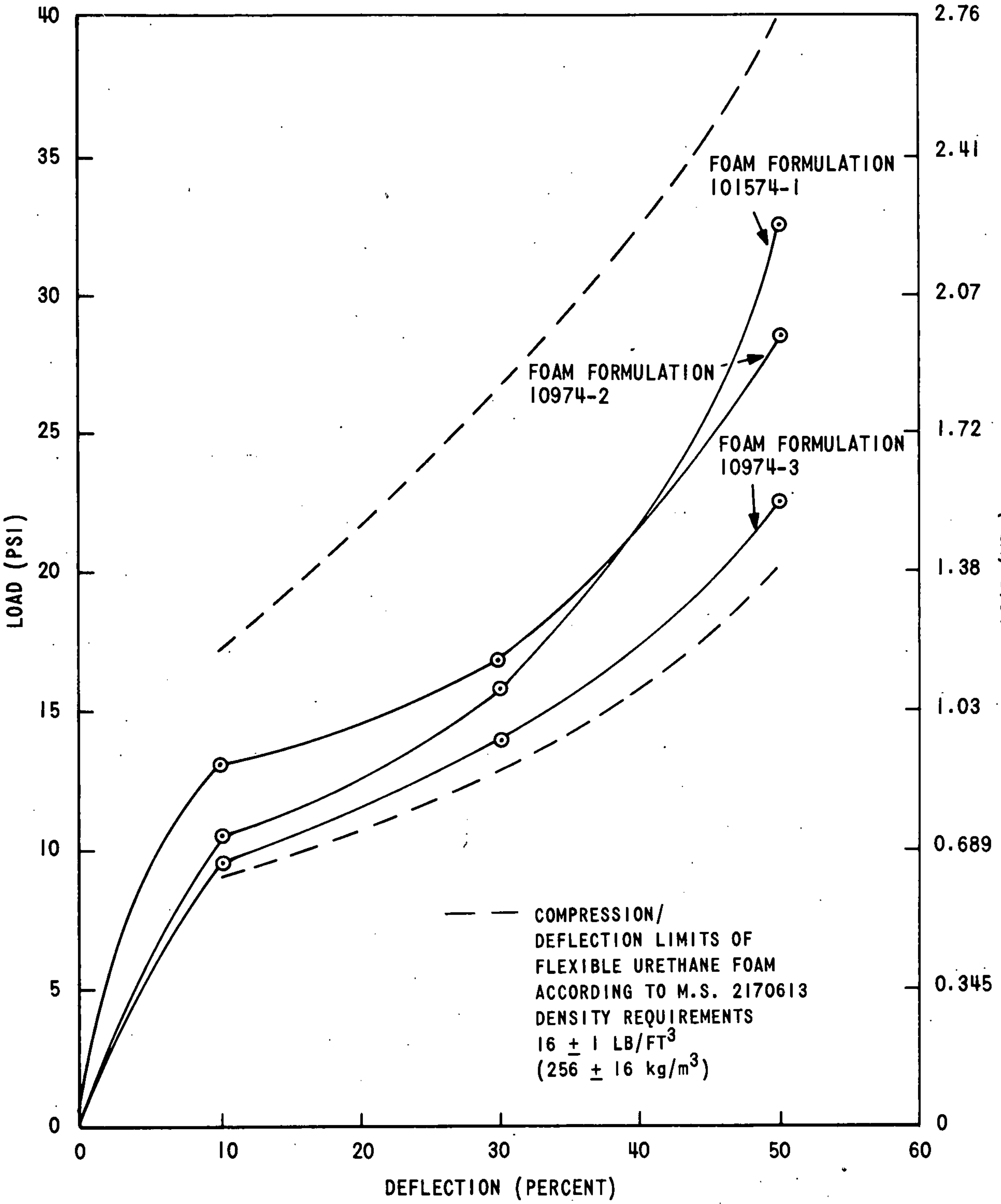

Figure 2. Average Compression/Deflection Results of Foam Samples Based on Formulations Using Pluracol 581 and Trimethylolpropane as Cross-Linking Agents and Calcium Carbonate as a Filler

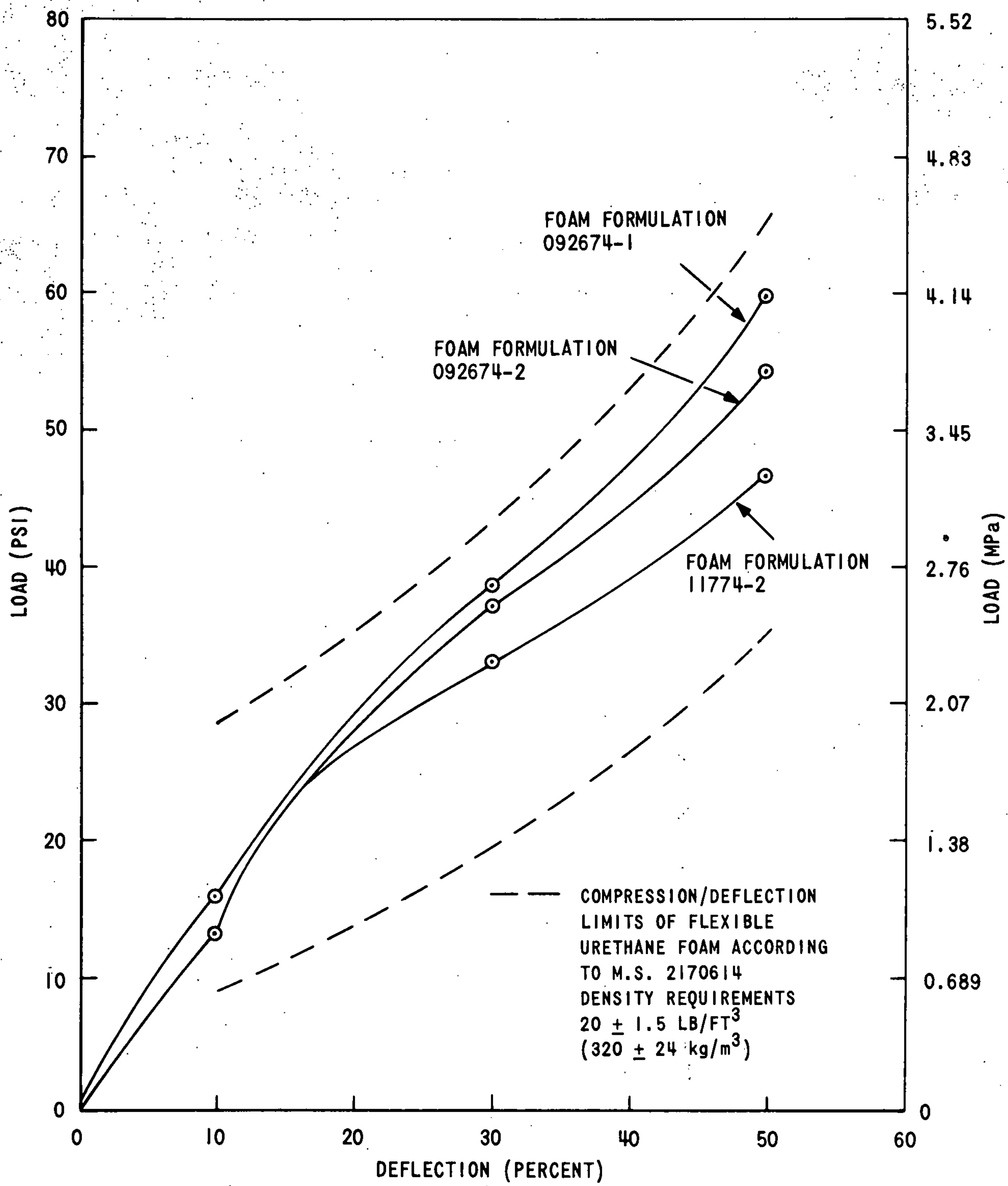

Figure 3. Average Compression/Deflection Results of Foam Samples Based on Formulations Using Poly-G-X803 and X804 Polyether Polyols With Pluracol 581 and Trimethylolpropane as Cross-Linking Agents

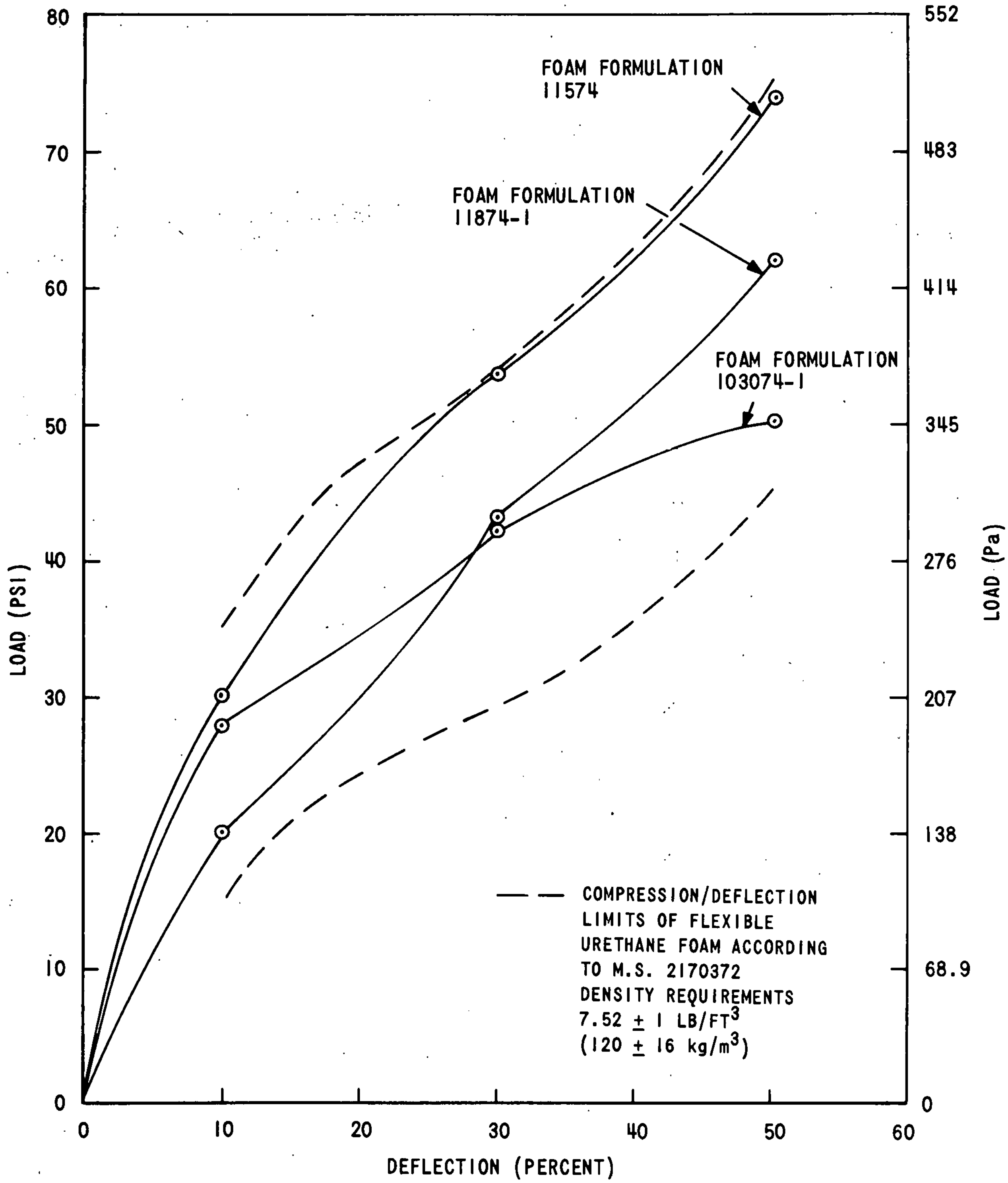

Figure 4. Average Compression/Deflection Results of Foam Samples Based on Formulations 11574, 11874-1, and 103074-1

DISTRIBUTION

	Copy
R. Bulcock, ERDA-KCAO	1
V. C. Vespe, ERDA-ALO	2
J. A. Freed, LASL	3
W. A. May, LASL	4
S. J. Buginas, LLL	5
H. G. Hammond, LLL	6
H. M. Brinkmeier, Monsanto	7
P. B. Rand, SLA	8
C. B. Frost, SLL	9
R. F. Pippert, D/100	10
J. D. Corey, D/554	11-12
L. Stratton, D/554	13-15
R. P. Frohmberg, D/800	16
W. H. Deterding, D/814	17
T. E. Neet, D/814	18
J. Salary, D/814	19
C. H. Smith, D/814	20
J. R. Fender, D/834	21
A. K. Thoeni, D/834	22
R. E. Kessler, D/864	23-25