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BDX-613-1750

HIGH LOAD BEARING FLEXIBLE URETHANE FOAMS

PDO 6985002, Final Report

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Published November 1977

Prepared for the United States Energy Research and Development  
Administration Under Contract Number EY-76-C-04-0613 USERDA



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Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche \$2.25  
Paper Copy \$3.50

BDX-613-1750  
Distribution Category UC-25

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## HIGH LOAD BEARING FLEXIBLE URETHANE FOAMS

BDX-613-1750, UNCLASSIFIED Final Report, Published November 1977

Prepared by B. G. Parker, D/814, under PDO 6985002

The load bearing properties of flexible urethane foam as a function of the formulation variables were investigated. Varying levels of a polystyrene-acrylonitrile-polyol were added to the foam systems to increase the load-bearing capabilities of the resultant materials. The formulation water level and fluorocarbon blowing agent level were also varied to provide flexible urethane foams covering a wide range of density and compressive properties. The compression set/compression deflection properties, hydrolytic stability, and aging characteristics of these foam systems were determined.

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A prime contractor with the United States  
Energy Research and Development  
Administration under Contract  
Number EY-76-C-04-0613 USERDA

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## SUMMARY

This project was initiated to characterize the effects produced by formulation variables on the load-bearing properties of flexible polyurethane foam. Compression set, compression deflection, hydrolytic stability, and aging properties of several foam systems were determined as a function of the formulation variables such as the levels of polymer polyol, water, and fluorocarbon blowing agent.

The polymer polyol can be used to increase the load-bearing properties of a foam system without changing the foam density. The use of the polymer polyol, however, results in an increase in the compression set of the foam. Increasing the formulation water or fluorocarbon level results in reduced density and load-bearing properties. These foams showed excellent hydrolytic stability and aging characteristics.

From the data generated, a foam system can be easily formulated to meet particular density and load-bearing requirements eliminating much of the time and testing required in the previously used repetitive formulate and test procedure.

## DISCUSSION

### SCOPE AND PURPOSE

The purpose of this project was to develop suitable flexible polyurethane foam for packaging delicate electronic items and other manufactured parts. These materials must meet dimensional and load-bearing requirements specified by the Design Agencies. Molded-to-size parts can be produced by these foam systems instead of the present machined-to-size parts thus resulting in a cost reduction.

### PRIOR WORK

An initial development effort entitled *Flexible Polyurethane Foam* (PDO 6989216) described the feasibility of producing flexible polyurethane foam. This previous effort demonstrated the capability of producing flexible urethane foam suitable for packaging applications. The project did not, however, define formulations covering a wide range of physical properties or investigate the long-term aging and hydrolytic stability of the foams.

### ACTIVITY

#### Preparation of Foam Samples

The initial portion of this project was directed toward producing flexible polyurethane foam samples for testing purposes using the formulations described in Table 1.

Foam blocks (101.6 by 203.2 by 203.2 millimeters) were molded in aluminum molds and cured for 8 hours at 82.2°C. Twelve millimeters (0.5 inch) of foam were removed from all surfaces and the test specimens were machined from the remaining foam block. All data points on graphs and values in tables represent the average from five foam samples. The scatter in the data points is thought to be the result of slight differences in density of the foam samples. Although each set of samples was machined from the same foam block, there are slight density variations from top to bottom. Compression deflection and compression sets were measured parallel to foam rise. The materials used in the various foam formulations are shown in Table 2. The polyols were high molecular weight polypropylene oxide triols terminated with ethylene oxide to give highly reactive primary hydroxyl groups. The use of primary hydroxyl capped polyols resulted in a foam that can be cured in less time and at a lower temperature resulting in higher production rates while conserving energy.

Table 1. Polyurethane Foam Formulation

Material	Parts by Weight
Polyether Polyol	97.5 to 50*
Polymer Polyol	2.5 to 50
Water	1.4
Quadrol**	10
DABCO LV 33***	0.7
Isocyanate Blend†	Variable

\*Combined total of polyether polyol and polyol is 100 parts

\*\*N,N,N'N'-tetrakis(2-hydroxypropyl)-ethylenediamine, Wyandotte Chemicals Corporation

\*\*\*33 percent by weight triethylenediamine (Air Products and Chemicals Incorporated) in a polyether polyol

†80 percent by weight polymeric isocyanate and 20 percent by weight toluene diisocyanate

### Effectiveness of Polymer Polyol

Two polymer polyols, Niox 34-28 and Pluracol P581, were investigated as additives to provide increased load-bearing properties of the foams. Although there was no noticeable change in the density of the foam samples after varying the level of polymer polyol in the foam formulation, there was a noticeable change in the load-bearing properties. These two polymer polyols are copolymers of acrylonitrile and styrene prepared by in-situ polymerization in a conventional ethylene oxide capped triol. A proposed molecular structure for this material is given in Figure 1. Increasing the levels of these polymers increases the load-bearing properties of the resultant foam.

The polymer polyol and polyether polyol used in the foam formulations giving the compression properties shown in Figure 2 have hydroxyl numbers and functionalities which are very similar. The increase in the load-bearing capacity of the foam is, therefore, a direct result of the additional polymer polyol in the formulation.

Table 2. Polyols and Isocyanates Used in Foam Formulations

Polyol	Manufacturer*	Hydroxyl Number	Acid Number	Water Content (Percent)
Poly-G804	Olin Chemicals	26.4	0.05	0.04
Voranol CP4371	Dow Chemical Company	46.2	0.04	0.08
Voranol CP3910	Dow Chemical Company	40.9	0.05	0.08
Voranol CP4710	Dow Chemical Company	34.7	0.03	0.08
Thanol SF5503	Jefferson Chemical Company	35	0.02	0.07
Thanol SF6500	Jefferson Chemical Company	24	0.02	0.08
Thanol TE3000	Jefferson Chemical Company	56		0.065
Pluracol P581	Wyandotte Chemicals Corporation	27		0.01
Quadrol	Wyandotte Chemicals Corporation	779		0.01
Niax 34-28	Union Carbide Corporation	28	0.02	0.04
Niax 11-27	Union Carbide Corporation	29		0.04

\*The isocyanates used in the formulations were toluene diisocyanate (80/20 isomer ratio) and Mondur M432 from the Mobay Chemical Company and Papi 901 from the Upjohn Company.

Figure 3 shows the compression deflection as a function of the polymer polyol in a foam system in which the hydroxyl number of the polyol was higher than the hydroxyl number of the polymer polyol. At first, as the level of polymer polyol increases, the compression deflection values decrease because of a lowering in the crosslink density of the resultant foam. At levels of 10 to 15 parts polymer polyol the increased load-bearing capability of this material starts to overshadow the loss in crosslink density and the compression deflection values start to increase. Again, at about 40 parts polymer polyol, the effectiveness of the additive appears to decrease.

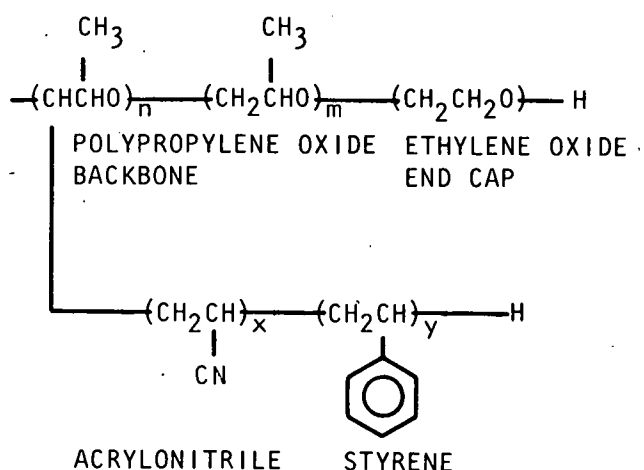


Figure 1. Proposed Chemical Structure of Polymer Polyol

There is a loss in effectiveness and also an inability to adequately predict foam compressive properties when polymer polyol is used with polyether polyols which have higher hydroxyl numbers. For this reason, the use of higher hydroxyl number polyols (higher than 30) was discontinued.

Compression set as a function of parts polymer polyol is shown in Figure 4. As the level of polymer polyol in the foam formulation increases, the compression set also increases. Therefore, there is a trade-off in the use of this material. The increased load-bearing capacity of the foam, resulting in an increase in the level of polymer polyol in the formation, can only be achieved with a corresponding increase in compression set.

#### Isocyanate Composition

The isocyanates used in the foam formulations were toluene diisocyanate (TDI), 80/20 isomer ratio, and Mondur M432, a polymeric isocyanate. Blends of polymeric isocyanate and varying amounts of TDI were used in a 1:1 to 1 NCO to OH ratio in all foam formulations. The ratio of polymeric isocyanate to toluene diisocyanate was varied from 50 to 100 percent. The effect on the compression deflection of the foam by the variation of the isocyanate composition is shown in Figure 5. As the level of polymeric isocyanate increases, the foam compression deflection also increases because of an increase in the crosslink density. No noticeable change in the tear strength or compression set was observed (Table 3).

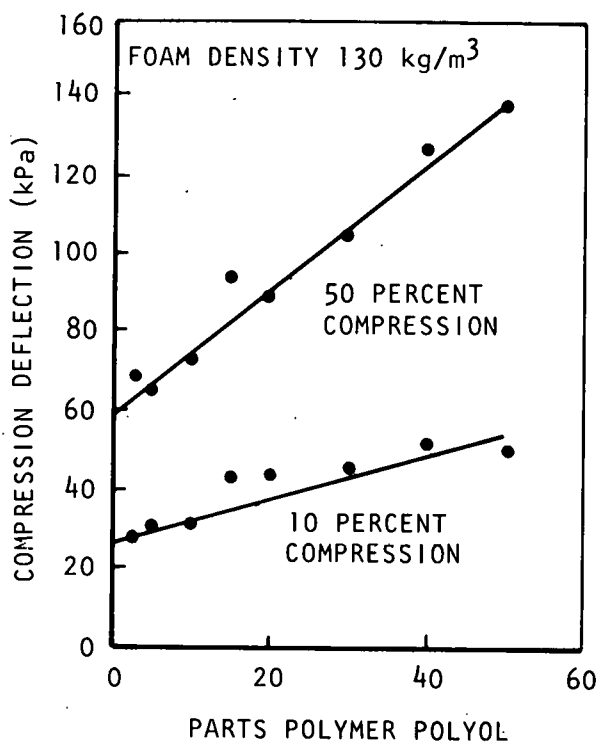


Figure 2. Effect of Polymer Polyol on Load-Bearing Properties of Poly-G804 Foam Systems

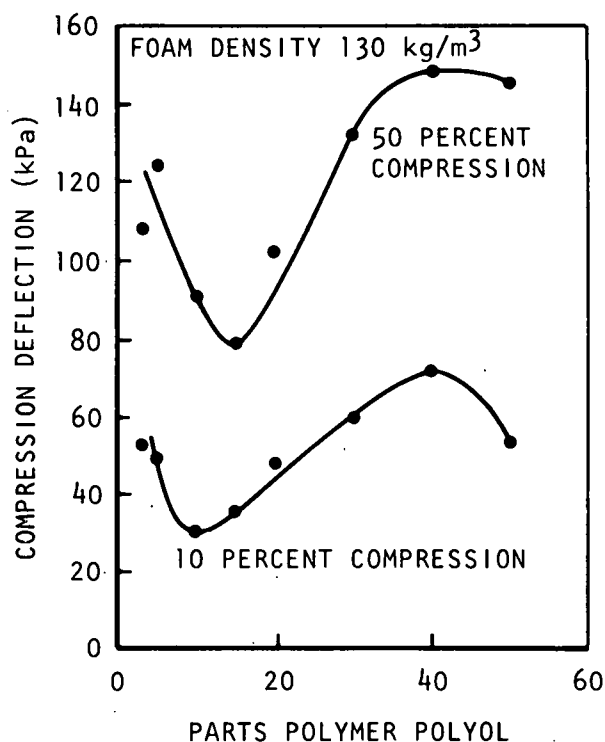
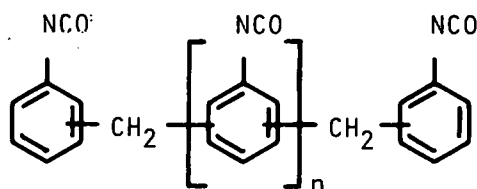


Figure 3. Effect of Polymer Polyol on Load-Bearing Properties of SF5503 Foam Systems

An attempt was made to totally remove TDI from the foam systems because of health problems associated with high concentrations of vapors from this isocyanate. However, foams prepared without TDI had excessive compression set (Table 4). For this reason, levels of 20 percent TDI and 80 percent polymeric isocyanate were chosen for the isocyanate blend and used in all additional formulations.

#### Alternate Materials

An alternate source of polymeric isocyanate, Papi 901, was also investigated. Both Papi 901 and Mondur M432 are polymer isocyanates with an average functionality ( $n$ ) of 2.3 and have the chemical structures shown in the following diagram.



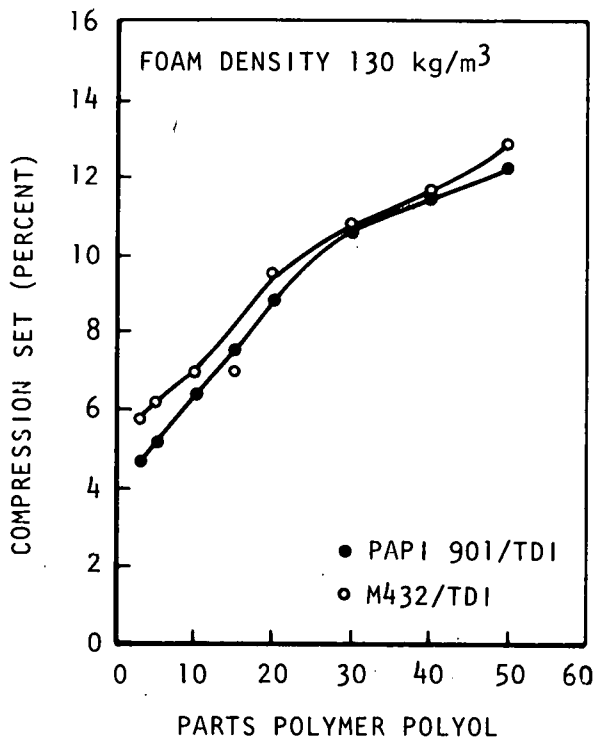


Figure 4. Effect of Polymer Polyol on Compression Set Properties

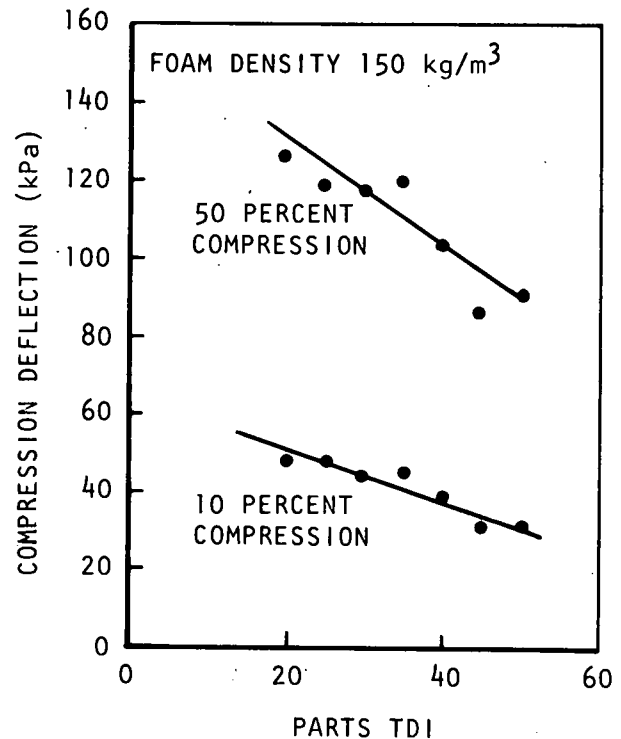


Figure 5. Effect of TDI on Load-Bearing Properties

Table 4 and Figure 6 show that the compression set and compression deflection properties of foams prepared from the two materials are essentially the same, indicating the two isocyanates could be used interchangeably.

In addition to evaluating an alternate material for the polymeric isocyanate, alternatives to the polymer polyol (Pluracol P581) and the polyether polyol (Poly-G804) were investigated. Union Carbide's Niax 11-34 was evaluated as an alternative to Poly-G804 and Niax 34-28 was evaluated as an alternative to Pluracol P581.

When comparing the two materials, the formulations given in the following tabulation were used.

Material	Parts by Weight
Polyether Polyol	80
Polymer Polyol	20
Water	1.4
Quadrol	10
DABCO LV 33	0.7
Isocyanate Blend	Variable



Table 3. Properties of Flexible Foam as a Function of Formulation TDI Level

Composition*		Compression Set (Percent)	Tear Strength (N/m)
TDI (PBW)	M432 (PBW)		
20	80	6.67	842
25	75	7.59	860
30	70	7.04	785
35	65	7.80	653
40	60	6.96	870
45	55	8.81	595
50	50	7.03	830

\*Polyol composition was 80 pbw SF5503 and 20 pbw P531. The average density was 130 kg/m<sup>3</sup>.

The level of isocyanate blend was variable because of slight differences between the hydroxyl numbers and the water content of the polyols used.

Table 5 lists the results of physical testing of the foam samples prepared from the formulations. Although there is a slight difference in the colors of the two materials, foams using the Niax 34-28 have very similar load-bearing properties to the foams using P581 but have lower compression set properties. The P581 is a white liquid while Niax 34-28 is cream-colored. Either of these two polymer polyols could be used interchangeably in foam formulations and yield essentially the same compression properties.

Replacing the Poly-G804 polymer with Niax 11-27 resulted in about a 50 percent increase in load deflection at both 10 percent and 50 percent compression. Although the two polyether polyols could not be used interchangeably, similar compression properties could be obtained using a lower level of polymer polyol in the Niax 11-27 system or using higher levels of polymer polyol in the Poly-G804 foam system.

Table 4. Effect of Isocyanate Composition on Compression Set

Polyol Composition		Compression Set		
Poly-G804 (PBW)	P581 (PBW)	M432/TDI (Percent)	Papi 901/TDI (Percent)	M432 (Percent)
97	3	4.7	5.8	12.0
95	5	6.2	5.1	10.5
90	10	6.4	7.0	11.0
85	15	7.6	7.0	15.4
80	20	8.8	9.5	12.8
70	30	10.6	10.8	17.5
60	40	11.6	11.0	19.8
50	50	12.2	12.9	24.8

#### Density Effects

The density of the urethane foam was changed by varying the formulation water level and by varying the level of fluorocarbon blowing agent. The effect of concentration of these two blowing agents on the free-rise density of foams prepared from the following formulations is given in Figures 7 and 8.

<u>Component</u>	<u>Parts by Weight</u>
Poly-G804	80
P581	20
Quadrol	10
Water	Variable
Fluorocarbon (Freon 11, DuPont)	Variable
DABCO LV 33	0.3
Isocyanate Blend: 80 percent by weight M432 and 20 percent by weight TDI	Variable

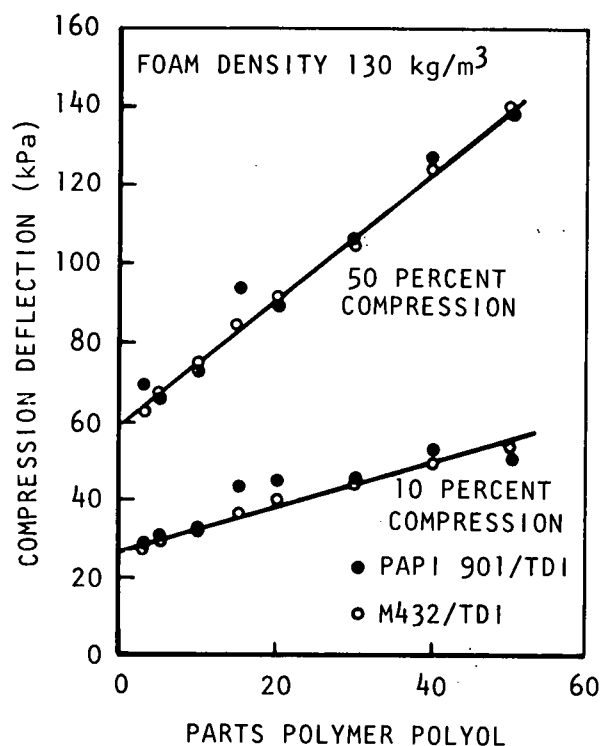


Figure 6. Comparison of Two Polymeric Isocyanates

Increasing the water level in urethane foam formulations decreases the density, but also alters the chemical structure. Water reacts with an isocyanate to produce disubstituted urea and carbon dioxide. Increasing the water level, therefore, increases the amount of carbon dioxide for expansion and increases the disubstituted urea content.

Figures 9 and 10 show the effect of density on compression deflection and tear strength. The density of these samples was varied by the addition of fluorocarbon blowing agents to the formulations. Figures 11 and 12 show the effect of water level on compression deflection and tear strength caused by variations in the disubstituted urea content. The density of these foam samples was kept constant at 110 kg/m<sup>3</sup> by reducing the amount of Freon 11 as the formulation water level was increased.

There are two opposing trends which occur when the formulation water level is increased. One trend is a decrease in compression deflection caused by a decrease in density. Another trend is an increase in compression deflection caused by an increase in disubstituted urea content. Figure 13 shows the combined effect in which the density and disubstituted urea content are both varied by the formulation water level (no fluorocarbon blowing agent).

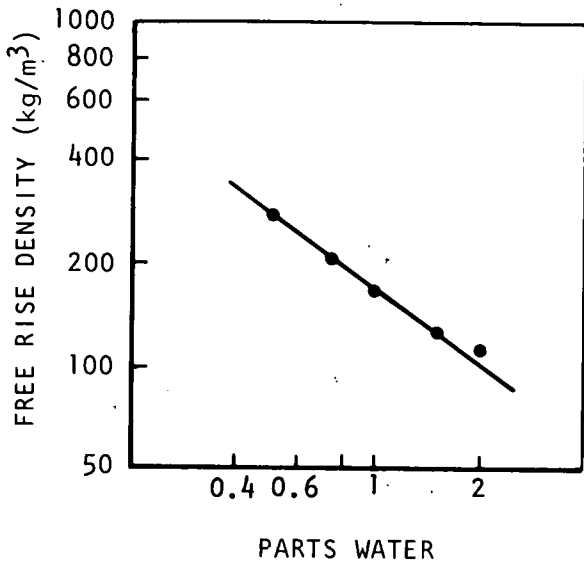


Figure 7. Effect of Formulation Water Level on Foam Free-Rise Density

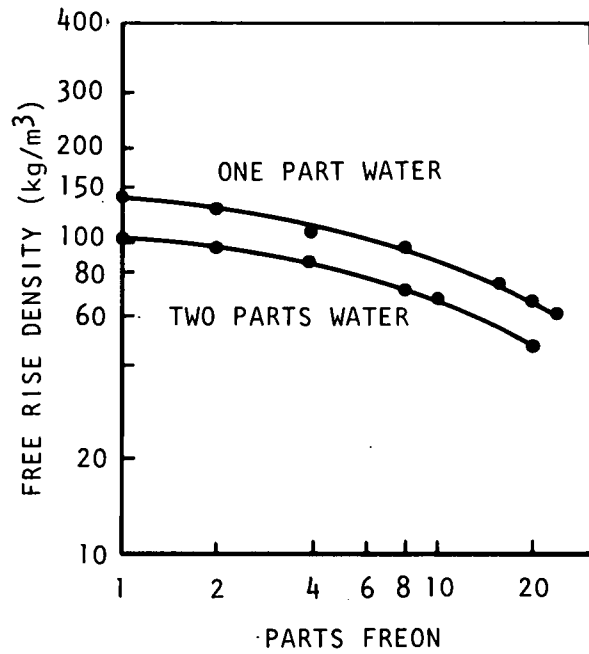


Figure 8. Effect of Freon 11 on Foam Free-Rise Density

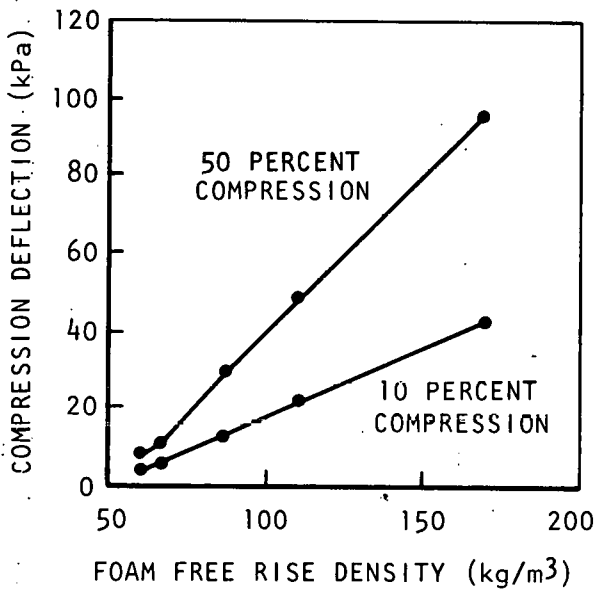


Figure 9. Compression Deflection at Constant Formulation Water Level

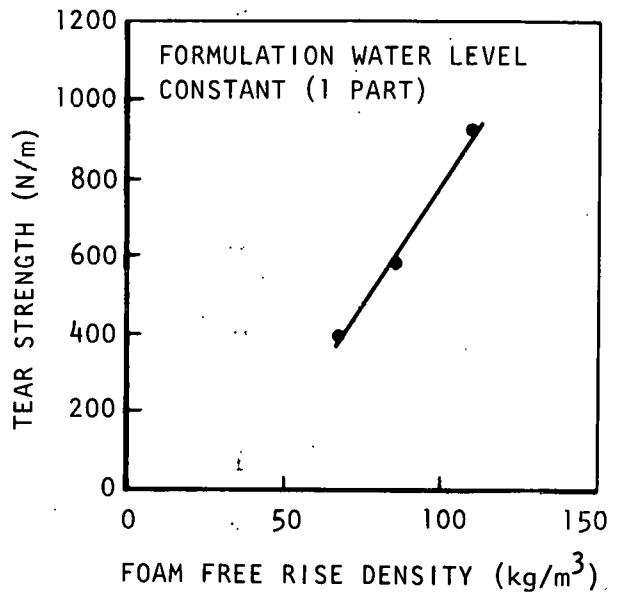


Figure 10. Tear Strength at Constant Formulation Water Level

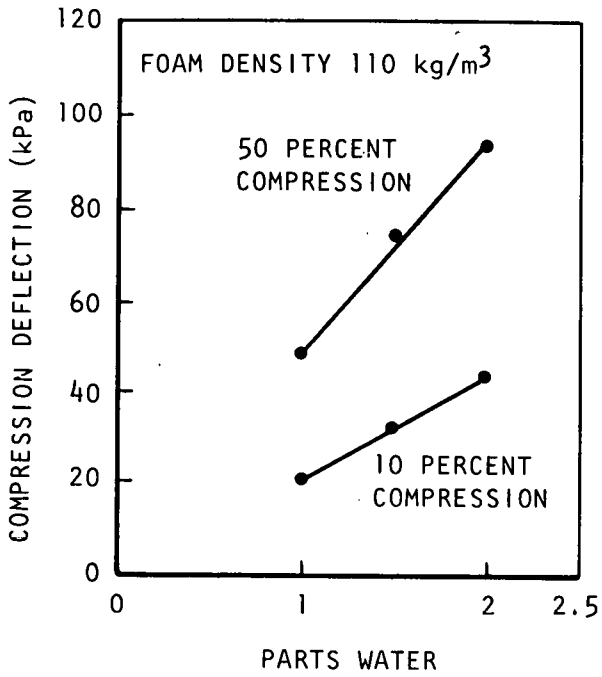


Figure 11. Compression Deflection at Constant Density

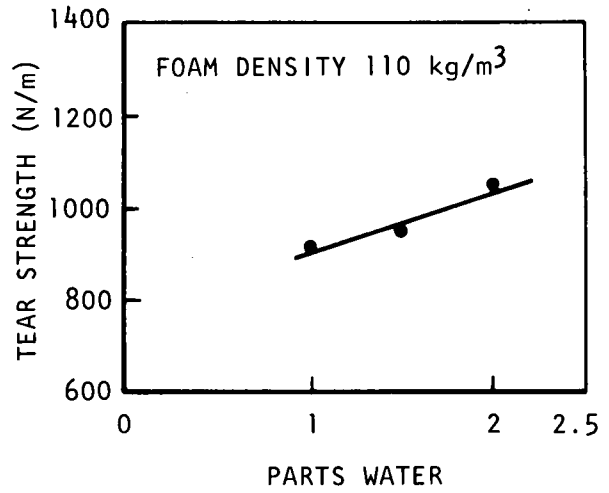


Figure 12. Tear Strength at Constant Density

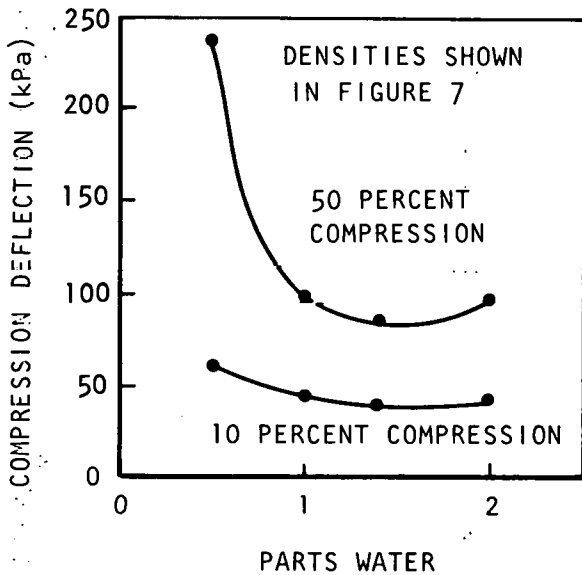


Figure 13. Effect of Formulation Water Level on Compression Deflection

Table 5. Comparison of Properties of Foams Prepared From Various Polyether Polyol and Polymer Polyol Combinations

Polyol Combinations	Compression Set (Percent)	Compression Deflection		Tear Strength (N/m)
		at 10 Percent (kPa)	at 50 Percent (kPa)	
Poly-G804 Polyether and P581 Polymer	8.8	44	90	874
Poly-Niax 11-27 Polyether and Niax 34-28 Polymer	3.98	56	130	1219
G804 Polyether and Niax 34-28 Polymer	1.34	38	87	1053
P581 Polymer and Niax 11-27 Polyether	4.29	57	133	1951

#### Aging Characteristics

The aging characteristics of the various foam systems were also investigated. The following conditions (A to E) were used to determine the compression set and compression deflection.

- A. Room temperature (24°C and 5 percent R.H.)
- B. -54°C after conditioning for 2 hours at -54°C
- C. 74°C after conditioning for 2 hours at 74°C
- D. Room temperature after conditioning for 7 days at 100°C in dry heat
- E. Room temperature after conditioning for 7 days at 74°C and 95 percent R.H.

Tables 6 and 7 show compressive properties of foams prepared with Poly-G804 polyol and varying amounts of Pluracol P581. Condition D of Table 6 (aging for 7 days at 100°C in dry heat) improves the compression set of the foam. This is possibly due to further

Table 6. Compression Set for Indicated Foam Systems

Composition		Condition (Percent)			
TDI/M432 (PBW)	G804/ P581 (PBW)	A	C	D	E
Poly-G804 Foam System					
*	97/3	4.7	2.4	1.5	5.1
	95/5	6.2	3.5	2.0	5.3
	90/10	6.4	3.5	3.5	6.2
	85/15	7.6	4.3	3.7	7.4
	80/20	8.8	5.4	3.2	7.4
	70/30	10.6	6.9	6.7	9.0
	60/40	11.6	7.9	7.1	12.9
	50/50	12.2	9.0	10.2	13.9
SF5503 Foam System					
20/80	**	6.7	5.9	5.5	8.2
25/75		7.6	5.0	5.0	6.8
30/70		7.0	5.0	6.0	6.2
35/65		7.8	4.6	4.1	7.5
40/60		6.7	4.5	4.1	7.3
45/55		8.8	5.4	3.5	7.0
50/50		7.0	5.2	3.0	6.6
*Isocyanate composition was 20 pbw TDI and 80 pbw M432.					
**Polyol composition was 80 pbw SF5503 and 20 pbw P581. The average density was 130 kg/m <sup>3</sup> .					

curing of the foam. Comparison of the compression set values measured under Condition A with values measured under Condition E indicates the good hydrolytic stability of the Poly-G804 foam system. The good aging characteristics of these materials are further shown in Tables 7 and 8 where only a very small difference is noted between compression deflection values measured under Condition A compared to those measured under Conditions D or E.

Tables 7 and 8 show the effects on compressive properties due to variation in the isocyanate composition. The compression set of aged specimens which were formulated with higher levels of TDI

Table 7. Polyol Poly-G804 Foam System Characteristics With Compression Deflections of 10 and 50 Percent

Composition*		Condition				
G804 (PBW)	P581 (PBW)	A (kPa)	B (kPa)	C (kPa)	D (kPa)	E (kPa)
Compression Deflection of 10 Percent						
97	3	28	166	26	28	28
95	5	30	66	26	26	38
90	10	32	97	25	28	39
85	15	43	57	37	37	41
80	20	44	74	39	43	35
70	30	45	12	38	39	35
60	40	52	37	44	55	50
50	50	50	0	56	55	59
Compression Deflection of 50 Percent						
97	3	69	383	55	63	61
95	5	66	447	57	61	59
90	10	73	425	57	66	60
85	15	94	498	75	86	87
80	20	90	481	80	94	88
70	30	106	519	90	101	97
60	40	127	643	103	124	114
50	50	138	770	113	130	125

\*Average density is 130 kg/m<sup>3</sup>.

appears to be better. Also, the samples formulated with higher levels of TDI appear to have better aging characteristics.

#### ACCOMPLISHMENTS

Several formulation parameters of highly resilient flexible foams and the resultant variation in physical properties of these materials were investigated. The data generated permits foams to be formulated which will have specific load-bearing properties at specified densities. The foam systems developed had very good hydrolytic stability and aging characteristics. Packaging materials can now be prepared which meet the dimensional and load-bearing requirements specified by the Design Agencies in a relatively short period of time.



Table 8. SF5503 Foam System Characteristics With Compression Deflections of 10 and 50 Percent

Composition		Condition				
TDI (PBW)	M432 (PBW)	A (kPa)	B (kPa)	C (kPa)	D (kPa)	E (kPa)
Compression Deflection of 10 Percent						
20	80	48		41	44	36
25	75	48		36	42	43
30	70	45		43	50	48
35	65	45		29	34	38
40	60	39		38	37	33
45	55	31		32	35	26
50	50	31		30	37	34
Compression Deflection of 50 Percent						
20	80	126	114	86	105	85
25	75	118	112	90	113	112
30	70	117	91	99	117	108
35	65	119	96	70	96	104
40	70	112	101	84	93	88
45	55	86	101	80	85	68
50	50	89	104	81	87	83

Polyol composition was 80 pbw SF5503 and 20 pbw P581. The average density was 130 kg/m<sup>3</sup>.

Several test parts were molded from these foam systems demonstrating the mold-to-size capability of the materials, thereby providing a more economical method of part fabrication than the present machined-to-size process.

Also, additional polyols and isocyanates were evaluated as alternate materials providing the foam systems with a wide degree of flexibility in formulation parameters.

#### FUTURE WORK

Although alternate materials were found for the polymeric isocyanate and the polymer polyol, direct replacements for the polyether polyol were not found. Additional polyether polyols should be evaluated as they become available as alternates for the Poly-G804 or the Niax 11-27 polyols.

The hydrolytic stability and aging characteristics of the foams tested were found to be good, however, the foams tested for aging had the same disubstituted urea content in the polymer matrix. Additional testing could determine what effects variation in the disubstituted urea content would have on the hydrolytic stability and aging characteristics of the foams.

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HIGH LOAD BEARING FLEXIBLE URETHANE FOAMS,  
B. G. Parker, D/814, UNCLAS Final, November 1977.

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PLASTICS: Urethane Foam

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