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MATERIAL AND PROCESS DEVELOPMENT
OF POLYURETHANE FOAM, FY71-4

PDO 6984191, Quarterly Report

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Published September, 1972

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FY71-4

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Quarterly Report

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MATERIAL AND PROCESS DEVELOPMENT OF POLYURETHANE FOAM,
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Prepared by J. R. Fender, D/834, under PDO 6984191

During FY71-4 Olin Corporation's BC 1220 polyurethane foam material was analyzed to determine how changes in cure temperature alter shrinkage and compressive properties of the foam.

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SUMMARY

Stafoam BC 1220 material has been reviewed this quarter as a part of a continuing study to more thoroughly characterize polyurethane foam materials.

This study has shown that material shrinkage characteristics are changed by the material cure cycle and not greatly altered by mold preheat temperatures. Compressive strength characteristics, however, are altered much more by mold preheat than by cure temperature.

During the next quarter data from CPR 1040-10 will be analyzed and reported.

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DISCUSSION

SCOPE AND PURPOSE

The purpose of this project is to characterize current and newly developed polyurethane foam systems. Additional goals are to develop processing limits and techniques, stabilization procedures, and shrinkage data required in using the systems for making rigid polyurethane foam products.

PRIOR WORK

Work during this fiscal year has included characterization of CPR 1040-10 (CPR Division of the Upjohn Company), Stafoam BC 1220 (Olin Corporation),* and BX 6003-2.5A (Bendix Corporation) with special emphasis placed upon the effect of cure cycle changes.

ACTIVITY

Continuation of the cure cycle study during this report period involved additional sample preparation and testing of CPR 1040-10 and statistical analysis of the test data obtained on BC 1220.

Study of BC 1220 was conducted on 6- by 6- by 1-inch-thick test blocks poured as nearly as possible to give 0.5 g/cc (31.25 lb/ft³) test specimens. Twenty-five different mold preheat and cure temperature combinations were selected to study how mold preheat and cure temperature changes alter compressive and shrinkage characteristics of the foam system. Selected for study were 77, 90, 105, 120, and 135°F mold preheat temperatures and four-hour cure cycles of 165, 200, 235, 270, and 305°F.

ACCOMPLISHMENTS

A complete report of the statistical analysis is included in the Appendix. The conclusions from this report are as follows.

- The cure temperature has no statistically significant effect on compressive properties investigated at room temperature and 165°F.

*Now supplied by Expanded Rubber and Plastics Corporation.

- Mold preheat has a strong influence on compressive strength and modulus results with the highest preheat of the study--135°F--producing the highest values.
- BC 1220 is not a high temperature material and loses most of its compressive strength when tested at 300°F. Higher results were obtained, however, from samples having the highest preheat and cure temperature.
- Mold preheat does not have a marked influence on block shrinkage characteristics.
- Cure temperature has a pronounced effect on finished part size. Higher cure temperatures result in higher shrinkage levels. This conclusion is consistent with data from other materials studied.
- Shrinkage versus time graphs show 0.5 g/cc density BC 1220 foam to be a very dimensionally stable material.

FUTURE WORK

Data from the cure cycle studies of CPR 1040-10 will be reviewed by Statistical Quality Control.

A study to expand compressive strength data of current and newly developed foam systems is in work and initial data should be available for inclusion in next quarter's report.

Appendix

STAFOAM BC 1220 DATA ANALYSIS

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May 4, 1971

S. L. DeGisi, D/814

J. H. Carder, D/416

STAFOAM, BC 1220

A study was performed on Stafoam, BC 1220, to determine how changes in the mold preheat and cure temperatures altered the compressive and shrink characteristics of the foam system. Twenty-five different mold preheat and cure temperature conditions were selected for the study. The mold preheat temperatures selected were: 77°F, 90°F, 105°F, 120°F and 135°F. The test blocks were cured for four hours at either 165°F, 200°F, 235°F, 270°F or 305°F. The characteristics studied were:

1. Compressive Strength - Measured at 6% and 10% strain;
2. Modulus - Determined from the straight portion of the load-deflection curve; and
3. Shrink - Measurements were recorded on 6" x 6" x 1" test blocks using check fixture FC 1442855.

The compression results were tested at room temperature, 165°F, and 300°F.

Results

Analysis of variance techniques were used to determine if mold preheats and cure temperatures had a significant effect on the compressive results. These results are summarized in Table 1, Addendum I. An equation of the form:

$$Y = a_0 + a_1X_1 + a_2X_2 + a_{12}X_1X_2 + a_{11}X_1^2 + a_{22}X_2^2$$

was used to explain the results. Figures 1 through 9 illustrate the surfaces described by these equations.

Addendum II contains tables and figures summarizing the shrink data. A plot of the average shrink per inch vs time is shown for each of the mold preheat and cure temperature conditions. A table of the plotted values is shown on each plot.

Room Temperature Tests: The equations for compressive strength at 6% and 10% strain are listed on Figures I-1 and I-2, respectively. These figures show the effect that the mold preheat and cure temperatures have on the responses.

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The analysis of variance results are shown in Table I-1. The cure temperature has no apparent effect on the compressive strength. However, the mold preheat and mold preheat-cure temperature interaction make significant contributions to the responses, with the mold preheat temperature being the strong variable. The compressive strength will increase with increases in preheat temperatures and slightly lower cure temperatures (See Figure I-1 and I-2).

Figure I-3 shows the relation of mold preheat and cure temperature to the modulus. The equation for this plot is listed on the figure. The mold preheat, cure temperature, and mold preheat-cure temperature are significant with the mold preheat making the largest contribution. The modulus increases as the cure temperature decreases and the mold preheat increases.

The compressive strength and modulus have higher values at cure temperatures between 200°F and 235°F and a mold preheat of about 135°F.

165°F Tests: Results for compressive strength at 6% and 10% strain are listed on Figure I-4 and I-5, respectively. These figures illustrate the effects that mold preheat and cure temperature have on the responses. The analysis of variance results (Table I-1) show that the mold preheat, cure temperature, and mold preheat-cure temperature interaction make significant contributions to the responses. The compressive strength will increase with increases in the mold preheat and cure temperatures. The interaction term results in the compressive strength being higher for slightly lower cure temperatures as the mold preheat increases. The equation and plot of the modulus results are shown on Figure I-6. The cure temperature has no apparent effect on the modulus. The mold preheat and mold preheat-cure temperature interaction make significant contributions to the response. The modulus increases with an increase in preheat temperature and a slight decrease in cure temperature.

The compressive strength and modulus have higher values at mold preheats of about 135°F and cure temperatures between 235°F and 270°F.

300°F Tests: The equations for the compressive strength at 6% and 10% strain and the modulus are listed on Figure I-7, I-8 and I-9, respectively. These figures show the effects that the mold preheat and cure temperatures have on the responses. The analysis of variance results (Table I-1) show that the mold preheat, cure temperature and mold preheat-cure temperature interaction make significant contributions to the responses. The compressive strength at 6% and 10% strain and modulus will increase with increases in the cure and mold preheat temperatures. These compression properties have higher values at a mold preheat temperature of 135°F and a cure temperature of 305°F.

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Shrink: The average shrink per inch vs time is plotted for each of the mold preheat and cure temperature conditions (see Addendum II). The change in shrinkage per inch is relatively small after the initial change. This initial change occurs soon after the test block is poured (see Plots in Addendum II). Table II-1 lists the average shrink per inch, parallel and perpendicular to foam rise, for each set of conditions. The mold preheats have no apparent effect on the average shrink per inch (see Table II-2 and Figure II-1, Addendum II). There are differences in the shrink per inch for the different cure temperatures (see Table II-3 and Figure II-2, Addendum II).

Summary

The mold preheat has a strong influence, on the compressive strength and modulus readings, on the room temperature and 165°F tests. The mold preheat temperature of 135°F (the highest in this study) produced the highest values. The cure temperature was not significant for all of the compression properties investigated. However, the mold preheat-cure temperature interaction was significant in each case. It is a combination of the significance of the interaction and the significant cure temperatures that indicates a cure temperature of about 235°F for the two tests (that is, room temperature and 165°F) is best.

Those blocks tested at 300°F have compressive properties that are much lower than the room temperature and 165°F tests. The compressive strength and modulus reading increase as the mold preheats and cure temperatures increase. Therefore, a mold preheat of 135°F and a cure temperature of 305°F would provide highest values.

The shrink per inch increases as the cure temperature increases. The mold preheat does not appear to have a marked influence on the shrink per inch. For cure temperatures of 165°F, 200°F and 235°F the shrink per inch parallel and perpendicular to foam rise are nearly equal. For cure temperatures above 235°F the shrink per inch parallel to foam rise is approximately .0008 inches per inch larger than that perpendicular to foam rise.

The most desirable settings for mold preheat and cure temperature (excluding the 300°F tests which were much lower than the others) would be 135°F and 235°F, respectively. These settings would provide high compressive properties and uniform shrink per inch (approximately .0036 inches per inch).

Since the mold preheats had a strong influence on the compressive properties and these properties were still increasing at the largest mold preheat temperature studied, it is recommended that mold preheat temperatures above 135°F be investigated.

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ADDENDUM I

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Table I - 1
Analysis of Variance Results

Room Temperature Tests			
Characteristics	6% Strain	10% Strain	Modulus
Cure Temperatures	NS	NS	S
Preheat Temperatures	S	S	S
Cure x Preheat Interaction	S	S	S
165°F Tests			
Characteristics	6% Strain	10% Strain	Modulus
Cure Temperatures	S	S	NS
Preheat Temperatures	S	S	S
Cure x Preheat Interaction	S	S	S
300°F Tests			
Characteristics	6% Strain	10% Strain	Modulus
Cure Temperatures	S	S	S
Preheat Temperatures	S	S	S
Cure x Preheat Interaction	S	S	S

S - Means the different levels of the characteristic had a significant effect on the response.

NS - Means the different levels of the characteristic did not have a significant effect on the response.

Y = 6% R.T.

X1=CURE TEMPERATURE

X2=PREHEAT TEMPERATURE

$$Y = -722.129 + 7.036X_1 + 30.389X_2 - 0.009X_1X_2 - 0.012X_1^2 - 0.088X_2^2$$

SCALE 0.003

(Y+1777.245)

Figure I-1

Y = 10% R.T.
 X1 = CURE TEMPERATURE
 X2 = PREHEAT TEMPERATURE

$$Y = -567.640 + 6.739X_1 + 28.100X_2 - 0.012X_1X_2 - 0.011X_1^2 - 0.073X_2^2$$

SCALE 0.003 (Y+1791.591)

Figure I-2

Y = MODULUS R.T.

X1 = CURE TEMPERATURE

X2 = PREHEAT TEMPERATURE

$$Y = -15128.000 + 195.500X_1 + 1416.000X_2 + 0.205X_1X_2 - 0.517X_1^2 - 5.780X_2^2$$

SCALE 0.000099 (Y+ 74782.)

Figure I-3

Y = 6% 165 DEG F
 X1 = CURE TEMPERATURE
 X2 = PREHEAT TEMPERATURE

$$Y = -824.459 + 6.854X_1 + 20.712X_2 - 0.014X_1X_2 - 0.010X_1^2 - 0.055X_2^2$$

SCALE 0.004 (Y+1119.576)

Figure I-4

Y = 10% 165 DEG F
 X1 = CURE TEMPERATURE
 X2 = PREHEAT TEMPERATURE

$$Y = -696.000 + 6.433X_1 + 19.494X_2 - 0.014X_1X_2 - 0.009X_1^2 - 0.048X_2^2$$

SCALE 0.004 (Y + 1843.925)

Figure I-5

Y=MODULUS 165 DEG F
 X1=CURE TEMPERATURE
 X2=PREHEAT TEMPERATURE

$$Y = -38040.000 + 247.400X_1 + 1416.500X_2 - 0.488X_1X_2 - 0.458X_1^2 - 5.290X_2^2$$

SCALE 0.000133 (Y+ 60130.)

Figure I-6

Y = 6% 300 DEG F
 X1 = CURE TEMPERATURE
 X2 = PREHEAT TEMPERATURE

$$Y = -18.482 + 0.113X_1 + 0.579X_2 - 0.000X_1X_2 - 0.002X_2^2$$

SCALE 0.132 (Y + 28.103)

Figure I-7

Y = 10% 300 DEG F
 X1 = CURE TEMPERATURE
 X2 = PREHEAT TEMPERATURE

$$Y = -19.385 + 0.131X_1 + 0.844X_2 - 0.001X_1X_2 + 0.000X_1^2 - 0.002X_2^2$$

SCALE 0.083 (Y + 45.648)

Figure I-8

Y = MODULUS 300 DEG F
 X1 = CURE TEMPERATURE
 X2 = PREHEAT TEMPERATURE

$$Y = -253.750 + 2.150X_1 + 8.360X_2 - 0.007X_1X_2 - 0.001X_1^2 - 0.022X_2^2$$

SCALE 0.008 (Y + 484.842)

Figure I-9

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Table II-1. Average Inch Per Inch Shrinkage of Cure Temperature-Mold Preheat Combinations Studied.

Mold Preheat	Cure Temperature									
	165°F		200°F		235°F		270°F		305°F	
	Para	Perp	Para	Perp	Para	Perp	Para	Perp	Para	Perp
77	.0024	.0023	.0031	.0036	.0038	.0033	.0052	.0036	.0044	.0038
90	.0022	.0020	.0032	.0030	.0033	.0034	.0042	.0035	.0041	.0039
105	.0023	.0023	.0032	.0030	.0035	.0040	.0044	.0039	.0045	.0040
120	.0022	.0020	.0031	.0025	.0037	.0032	.0041	.0038	.0049	.0040
135	.0026	.0020	.0029	.0027	.0041	.0035	.0047	.0035	.0046	.0033

Table II-2. Average Inch Per Inch Shrinkage at each Mold Preheat Temperature

Mold Temp	Para	Perp
77	.00378	.00328
90	.00340	.00316
105	.00358	.00344
120	.00362	.00310
135	.00378	.00300

Table II-3. Average Inch Per Inch Shrinkage at each Cure Temperature

Cure Temp	Para	Perp
165	.00234	.00212
200	.00310	.00296
235	.00370	.00348
270	.00452	.00366
305	.00450	.00376

FIGURE II-1

AVERAGE SHRINK PER INCH AT EACH MOLD PREHEAT

FIGURE II-2

AVERAGE SHRINK PER INCH AT EACH CURE TEMPERATURE

INCH PER INCH SHRINKAGE VS. TIME

PREHEAT 78, CURE 4 HOURS AT 165 F

▲ PERPENDICULAR
x PARALLEL

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 90, CURE 4 HOURS AT 165 F

▲ PERPENDICULAR
x PARALLEL

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 110, CURE 4 HOURS AT 165 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 120, CURE 4 HOURS AT 165 F

▲ PERPENDICULAR
x PARALLEL

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 135, CURE 4 HOURS AT 165 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 77, CURE 4 HOURS AT 200 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 89, CURE 4 HOURS AT 200 F

▲ PERPENDICULAR
x PARALLEL

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 107, CURE 4 HOURS AT 200 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 120, CURE 4 HOURS AT 200 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 135, CURE 4 HOURS AT 200 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 77, CURE 4 HOURS AT 235 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 91, CURE 4 HOURS AT 235 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 107, CURE 4 HOURS AT 235 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 121, CURE 4 HOURS AT 235 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 133, CURE 4 HOURS AT 235 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 76, CURE 4 HOURS AT 270 F

▲ PERPENDICULAR
x PARALLEL

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 91, CURE 4 HOURS AT 270 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 105, CURE 4 HOURS AT 270 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 120, CURE 4 HOURS AT 270 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 133, CURE 4 HOURS AT 270 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 79, CURE 4 HOURS AT 305 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 90, CURE 4 HOURS AT 305 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 106, CURE 4 HOURS AT 305 F

▲ PERPENDICULAR
x PARALLEL

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 120, CURE 4 HOURS AT 305 F

INCH PER INCH SHRINKAGE VS TIME

PREHEAT 135, CURE 4 HOURS AT 305 F