

# Creep/Recovery Behavior of Open-Cell Foams

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## SYNOPSIS

Static measurements have been used to predict the dynamic response of "unbounded" open-cell noninked (dry) and inked foam materials. Creep,  $e_c(t)$ , and recovery,  $e_r(t)$ , were determined in compression from static and dynamic modes. Force measurements,  $f(t)$ , and strain decay,  $e(t)$ , were used to determine the change in creep,  $\Delta e_c(t)$ . The change in creep represents the plastic strain,  $e_{pl}(t = t_h)$ , and is uniquely defined by the recovery function,  $e_r(t = t_h)$ , where  $t_h$  is the hold time. Creep and recovery results of various classes of foam materials and nonfoam materials were found to fit a master curve of the form  $F_r(t) = \exp[-k'_r(t_h)t] = [e_r(t) - e_{00}(t_h)]/[e_0(t = 0) - e_{00}(t_h)]$  at a reduced time of  $k'_r(t_h)t[k'_r(t_h)] = C_0/(t_h)^a$  (where  $C_0$  depends on the material's "dry" or "wet" state),  $a$  is a function of the type of material, and  $e_{00}$  is the permanent set]. These empirical results are applicable to printing ink transfer and print quality. Other important factors of concern are diffusion processes within the polymer matrix and the nature of the polymer (e.g., chemical constitution, porosity, molecular weight, and solubility). © 1995 John Wiley & Sons, Inc.

## INTRODUCTION

Foam materials of varying chemical diversity and fabrication methodologies are increasingly being used to substitute conventional materials for printing applications.<sup>1-4</sup> To compliment such a transition, experimental procedures are needed to validate any theoretical or empirical predictive approaches to material performance. By understanding the mechanisms involved in the physical deformation processes of dry and fluid-filled foam systems, reliability in long-term service use of these materials is enhanced.

The cyclic mechanical behavior of a fluid-filled foam depends on the dynamics of motion within the material, creep and recovery rates, cycling loads, fluid viscosity, surface and interfacial tensions, diffusion, fluid/polymer partitioning, and fluid sorption and desorption rates within the foam structure.<sup>2,5-8</sup> The net effect of these parameters is the controlling factor in print intensity and print quality as a function of cycles or time. The mechanical integrity of a foam material in cyclic loading depends to a great degree on the changes in the elastic, delayed elastic, and permanent set of the material as a function of time,  $t$ , and the hold time,  $t_h$ , i.e., the strain may be broken into two major component parts:

$$e(t, t_h) = e_e(t, t_h) + e_{pl}(t, t_h) \quad (1)$$

where the first component on the right side of the equation represents the elastic response and the second component defines the delayed elasticity and the permanent set. Both components compliment each other, i.e., as the first component decreases in time, the second component increases.<sup>7-9</sup> In this article, it will be shown how these components are determined experimentally from recovery measurements (static) and force measurements (dynamic) of "unbounded" samples, i.e., samples with no deformation edge effects, and how parameters obtained from such results can be used to predict static and dynamic creep and recovery.

## EXPERIMENTAL\*

### Materials

Roller and pad systems were used for this investigation. The rollers were fabricated from commercial polyurethane ester (PUE; pellethane 2102-80 PF,

\* Certain commercial equipment, instruments, and materials are identified in this article in order to adequately specify the experimental procedure. In no case does such identification imply recommendation or endorsement by Pitney Bowes, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

Upjohn Co.) and nitrile rubber ([acrylonitrile/butadiene], AB; 25/75 parts-ratio) and were used for the force measurements. The o.d. dimensions (0.899 cm) of the rollers were approximately the same as that of the standard P.B. 6900 fixture.<sup>10</sup> Illbruck foam pads approximately  $5.08 \times 2.54 \times 0.254$  cm (PUE, RF-4 900Z; Illbruck, Inc., Minneapolis, MN) were used for dynamic testing in the "unbounded" state, i.e., the pads were not fitted into a tray as is done for service operation. Foamex pads (Foamex Corp., Eddystone, PA) of PUE and polyurethane ether resins were fabricated into felted/laminated systems of approximately  $5.08 \times 2.54 \times 0.508$  cm dimensions. These laminated systems were designated, respectively, as (900Z/20/.041//900Z/8/.2) and (800Z/E/20/.05//800Z/E/8/.185); for each laminated section, the designations are the type of material, compression ratio, and thickness (inches). These laminated pads fabricated at Pitney Bowes were used for static measurements and the calculated dynamic responses.<sup>11</sup>

The roller materials were characterized using permeability, stress/strain in compression (recovery), and elongation (tensile cycling)<sup>12</sup> and the Illbruck and Foamex materials were characterized from creep/recovery determinations.<sup>11</sup> The inked foam materials were prepared by impregnating with a standard Pitney Bowes (PB) red fluorescent ink using a standard PB test procedure.

## Testing Procedure

### Rollers

Each roller assembly was placed into a 6900 printing fixture. The fixture was interfaced with an IBM AX computer and other electronic equipment necessary for data acquisition.<sup>7</sup> The printing fixture was designed such that two indicia impacts were performed per cycle, i.e., for each cycle,  $i$ , and the number of impacts,  $j$ ,  $j = 0, 2, 4, 6 \dots 2i$ . For dry samples, only force/time measurements were performed. For inked samples, printing was begun by the indicia at a pre-selected time to stock substrates (envelopes or paper tape), and, subsequently, force/time measurements, periodic measurements of fluorescent intensity (PMU), and roller weight loss ( $\Delta W$ ) were determined during print tests. The time dependence of these changes was determined from a print equivalence of 20 prints per minute, i.e., the no. cycles = the no. prints.<sup>7</sup>

An Instron machine (Universal Instron Tensile Tester, United Calibration Corp., Huntington Beach, CA) was used for cyclic stress/strain measurements (50 cycles) at 2.0 and 20.0 in./min on

"dry" and "inked" rollers. The hysteresis effect per cycle was analyzed from changes in the area of the enclosed loop, i.e., its cyclic integral, and is reported elsewhere.<sup>7</sup>

### Pads

Creep/recovery measurements in a compression mode were obtained with a standard laboratory press (maximum capacity 24 k lb). Dry or inked samples (some conditioned at 70°C for 1-2 weeks) were compressed to an initial compression strain,  $e_0$ , using stainless-steel "shims" to obtain a given thickness; the samples were held for a time,  $t_h$ . At the completion of the hold time, the compressive force was immediately released and the recovery strain,  $e_r(t)$ , was measured as a function of time,  $t$ , using a spring/force gauge ( $\pm 0.0015$  in.). The plastic strain,  $e_{pl}$ , and the elastic strain,  $e_e$ , were determined at  $t = t_h$ , i.e.,  $e_r(t = t_h) = e_{pl}(t_h)$  and  $e_e = e_0 - e_{pl}(t_h)$ .

The dynamic measurements of pads were performed with a Pitney Bowes dynamic tester. The compression strains were controlled by using metal "shims." After each sample was cyclicly compressed at a given frequency for a period of time, the sample was quickly removed and the creep strain measured with a spring gauge.

### Force

The time dependence of the strain,  $e(t)$ , was determined from the time dependence of the force,  $f(t)$ , i.e., as a first approximation,  $f(t) = A(e) \times M_c \times e(t) = A(e) \times S(t) = M'e(t)[A(e) = \text{the contact cross-sectional area as a function of strain; } S(t) = \text{the stress; } M_c = \text{the compression modulus; and } M' = A(e)M_c]$ . The strain,  $e(t)$ , may be empirically represented as<sup>1,2,7</sup>

$$e(t) = e_0 \exp(-k_0 t) \quad (2)$$

where  $k_0$  is a constant. The results for  $k_0$  and  $f(t)$  are shown, respectively, in Table I and Figures 1 and 2 for PUE and AB foam materials.

The change in creep,  $\Delta e_c(t)$ , and the creep,  $e_c(t)$ , can be determined from eq. (2) as follows:

$$\Delta e_c(t) = e_0 - e(t) = e_0[1 - \exp(-k_0 t)] \quad (3)$$

or

$$\begin{aligned} e_c(t) &= 2e_0 - e(t) \\ &= e_0 + \Delta e_c(t) = e_0[2 - \exp(-k_0 t)] \quad (4) \end{aligned}$$

The calculated creep change results for PUE and

**Table I Proportionality Constants for PUE and AB Rollers as Determined from Force/Time Measurements**

Foam Material	$(k_0)^a$			
	Dry	Correlation Coefficient	Ink	Correlation Coefficient
Polyurethane ester (PUE)	0.001760	-.8634	0.004082	-.8898
Acrylonitrile/butadiene rubber (AB)			0.001503	-.9765

<sup>a</sup> As determined from eq. (2).

AB materials in Figures 4 and 5 were determined from Eq. (3).

**RESULTS AND DISCUSSION**

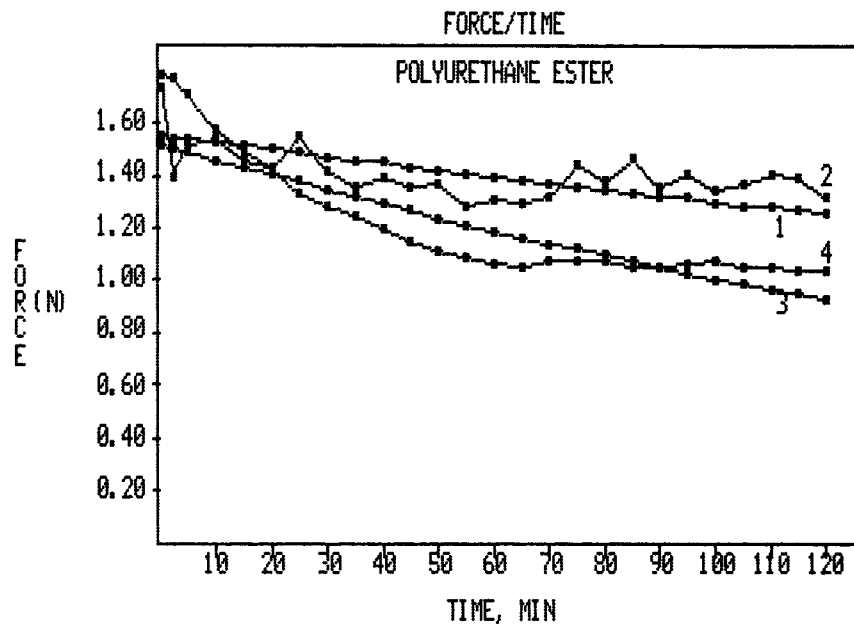
Long-term performance is of utmost concern to design engineers who must select materials for specific applications. Increasingly, the choice is made more difficult because of a tremendous rise in new engineering plastics.<sup>13,14</sup> The experimentalist often seeks test methods that simulate a priori conditions of use. To increase the reliability of a given test, the test procedure or method must be chosen very carefully, because the reliability is in direct relation to the type of test.<sup>15</sup> For printing applications, mechanical and fluid transport testing may be chosen such that materials may be selected on the basis of a limited test period, i.e., accelerated testing. In this

investigation, *in situ* dynamic force measurements and static compression testing were used to predict foam behavior under certain defined conditions, namely, open cells, no buckling of foam structure, and “free” ends of the sample.<sup>2,7</sup>

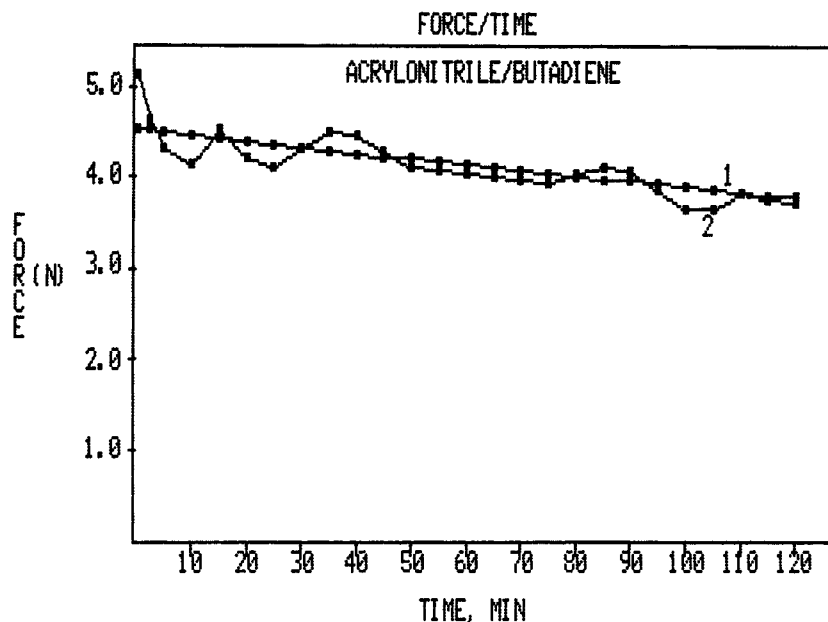
**Mechanical Testing**

Figures 1 and 2 show the force decay,  $f(t)$ , as a function of time (or cycles) for PUE and AB foam rollers (dry and inked). The calculated results were obtained from eq. (2) [i.e.,  $f(t) = M'e(t)$ ]. The exponential decay reflects the time-dependent dissipative properties of the material that is proportional to the decrease of the time-dependent elastic component,  $e_e(t)$ , at a given hold time,  $t_h$ .<sup>7,13,16,17</sup>

The magnitude of the decay in Figures 1 and 2 is influenced by the “wet” or “dry” nature of the foam material. This type of behavior has also been ex-



**Figure 1** Dynamic force measurements for PUE roller (data; calculation [calc]): (1) dry/calc; (2) dry/data; (3) ink/calc; (4) ink/data.

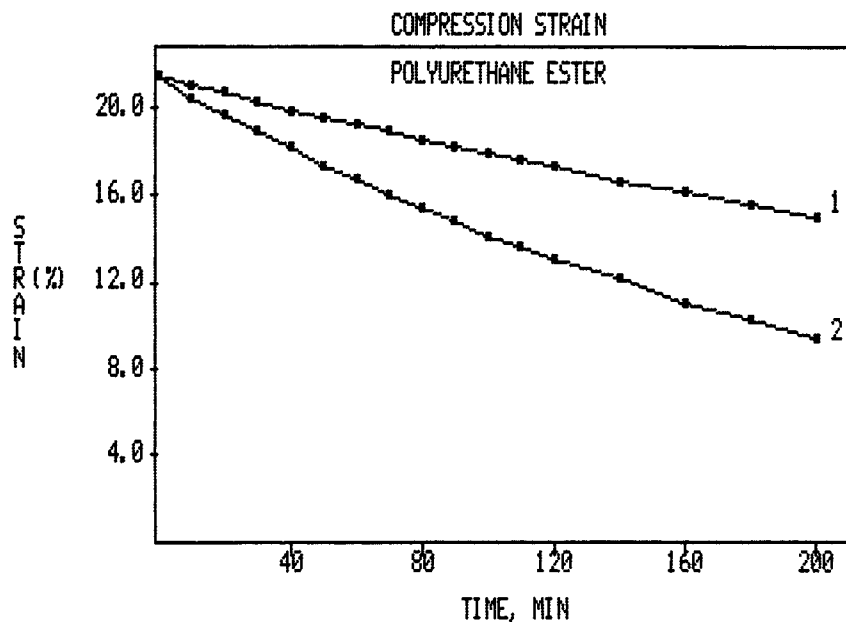


**Figure 2** Dynamic force measurements for AB roller (data; calculation [calc]): (1) ink/calc; (2) ink/data.

pressed by Throne<sup>5</sup> who asserts that the stress relaxation,  $S(t)$ , is a function of the weight percent of fluid,  $W\%$ , within the foam structure, i.e.,  $S(t) = S_0 - a_0 \ln(t)$ , where  $S_0 = S_{00} + bW\%$ . In general, time-dependent dissipative properties,  $P(t)$ , are a decreasing function of time, i.e.,  $P(t) = P_0 \exp(-kt)$ , where  $P_0$  = the initial value at  $t = 0$ .<sup>7</sup>

Other mechanical properties such as cyclic tensile testing may also be used for screening materials for

printing purposes.<sup>7</sup> Phillips and Auslander demonstrated that hysteresis effects from elastic, delayed elastic, and permanent set responses can be coupled with peak load data to assess the utility of various classes of foam materials in printing.<sup>7</sup> A ranking order of these parameters compares rather well with permeability and print performance data.<sup>7,12</sup> Such results indicate a close correspondence between the cyclic mechanical behavior (stress-strain, temper-



**Figure 3** Strain (%) for PUE roller: (1) dry; (2) ink.

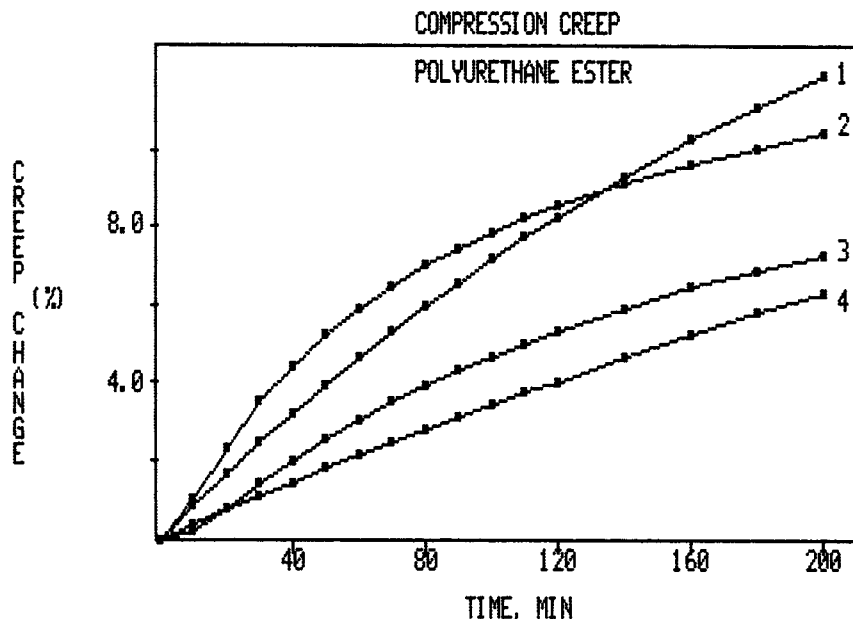


Figure 4 Change in creep,  $\Delta e_c(t)$ , for PUE roller (data; calculation [calc]): (1) ink/data; (2) ink/calc; (3) dry/calc; (4) dry/data.

ature, and time) of a foam material in compression and properties of the foam (porosity, morphology, chemical constitution, etc.) and properties of the fluid (viscosity, surface and interfacial tensions, shear and concentration dependence, temperature, etc.). The correlation of the mechanical behavior and the dynamics of fluid motion within a compressed foam has been attempted through Darcy's

law.<sup>2,18</sup> As a first approximation, this law applies to a foam structure with an average pore unit.<sup>2</sup> If the mechanical response of a foam material depends on inequalities in the pore size, i.e., a distribution, then deviations from Darcy's law is observed.<sup>18</sup> Another concern in dynamic testing of foams is the "bounded" or "unbounded" restraints, i.e., the influence of edge effects to alter the fluid dynamics

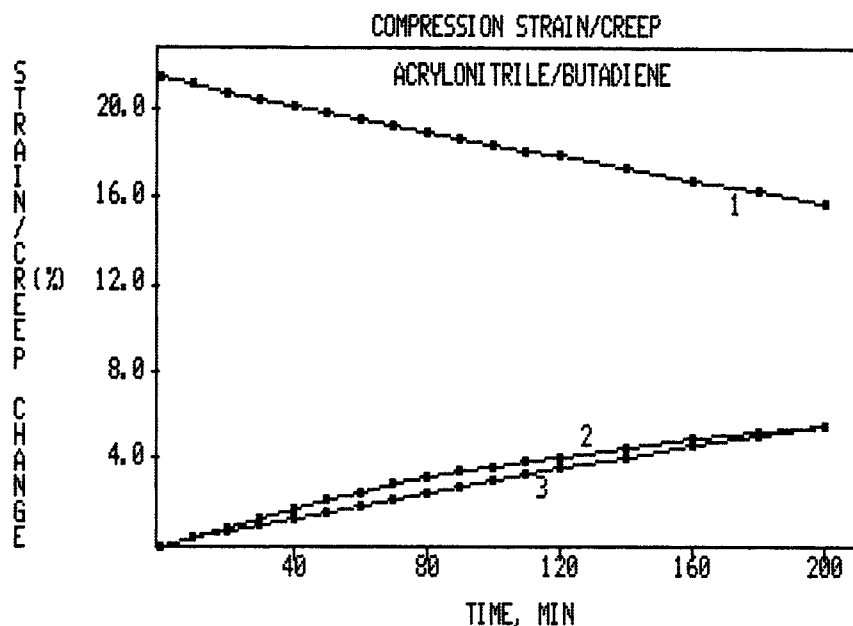


Figure 5 Strain (%) and change in creep,  $\Delta e_c(t)$ , for AB roller (data; calculation [calc]): (1) ink/strain data; (2) ink/creep-calc; (3) ink/creep data.

within the foam structure. The neglect of such considerations may produce unreliable calculations of the mechanical responses, if these restraints are present.

### Creep and Recovery

Figures 3-5 show the strain and creep change results for the PUE and AB foam materials. The strain and change in creep were, respectively, calculated from eqs. (2) and (3). It has been demonstrated that the recovery function<sup>7-9,19,20</sup> may be used to calculate the creep of a material, i.e.,

$$e_r(t) = (e_0 - e_{00}) \exp[-k'_r(t_h)t] + e_{00} \quad (5)$$

where  $e_0$  = the initial compression strain,  $e_{00}$  = the set strain, and  $k'_r(t_h)$  is a function of the hold time,  $t_h$ , and is defined as follows:

$$k'_r(t_h) = C_0/(t_h)^a \quad (6)$$

where  $C_0$  is a constant that depends on the dry or wet nature of the material and  $a$  depends on the type of material.<sup>7</sup> By setting  $t = t_h$ ,  $B = e_{00}/e_{pl}$ , and  $X(t = t_h, t_h) = X'(t_h) = \exp[-k'_r(t_h)t_h]$ , eq. (5) may be rearranged to give the change in creep,  $\Delta e_c(t = t_h)$ :

$$e_r(t = t_h) = e_{pl}(t_h) = \Delta e_c(t_h) = [e_0 X'(t_h)]/[1 + BX'(t_h) - B] \quad (7)$$

where  $B$  represents the fraction of the initial plastic deformation that is irrecoverable and is approximately independent of  $t_h$  (note Table II).<sup>8</sup> The calculated change in creep curves for Figures 4 and 5 were determined from eq. (7).

The creep in Figures 4 and 5 represents the elastic, plastic, and set strain behavior of the PUE and AB foam materials. The immediate response to the time-dependent dynamic force is the elastic component and the slow recoverable part is the plastic and set or the delayed elasticity ( $e_{pl} - e_{00}$ ). This response to an imposed strain,  $e_0$ , and an excitation or hold time,  $t_h$ , has been described by a two-network hypothesis of entangled networks by Tobolsky.<sup>10,16,21,22</sup> There are other networks of similar morphological definition that behave as entangled structures, e.g., crystalline regions connected to amorphous regions of a semicrystalline polymer exhibit time-dependent conformational readjustments from an unstressed state to a stressed one. Such elastic, delayed elastic, and permanent set behavior have been found to be universal in nature in which  $\approx 61\%$  of the recoverable deformation,  $e_{pl} = e_{00}$ , is recovered in a time  $t = t_h$ .<sup>7,8,23</sup> By rearranging eq. (5), a reduced recovery function,  $F_r$ , may be obtained as follows:

$$F_r = [e_r(t) - e_{00}]/[e_0 - e_{00}] = \exp[-k'_r(t_h)t] \quad (8)$$

A plot of  $-\ln(F_r)$  vs.  $k'_r(t_h) \times t$  generates a master curve for different types of materials. Figure 6 shows

**Table II Summary of Constants for the Calculation of  $k'_r(t_h) = C_0/(t_h)^a$  and  $B = e_{00}/e_{pl}(0)$  [ $e_0$  is the Initial Strain at  $t = 0$ , i.e.,  $e_0 = e(t = 0)$ ; and  $e_{pl}(0) = e_{pl}(t = t_h)$  and  $e_{00} = e(t = \infty, t_h)$ ]**

System	$C_0$ [min <sup>-1</sup> (a - 1)]			a	$e_0$	B
	Dry	Inked	Vapor			
Polyurethane ester (PUE)	12.6	9.4		1.35	0.214	0.69
Acrylonitrile/butadiene (AB)		10.0		1.30	0.214	0.57
Illbruck (PUE; RF-4 900Z)		5.5		1.30	0.62	0.50
Foamex <sup>a</sup> : [900Z : 900Z]	4.4			1.05	0.47	0.50
Foamex <sup>a</sup> : [900Z : 900Z]		3.6		1.05	0.35	0.50
Foamex <sup>b</sup> : [800Z/E : 800Z/E]	5.1			1.05	0.48	0.50
Foamex <sup>b</sup> : [800Z/E : 800Z/E]		5.3		1.05	0.34	0.50
Foamex <sup>c</sup> : [900Z/C-8/.3]		4.0		1.05	0.36	0.50
PVF <sub>2</sub> /EtAc <sup>d</sup>	2.15		2.01	1.04	0.280	0.80
LDPE/EtAc <sup>e</sup>	3.16			1.10	0.290	0.50
LDPE/EtAc <sup>e</sup>	2.05		1.39	1.07	0.54	0.50

<sup>a</sup> Laminated systems at different felt ratios (Note Ref. 11).

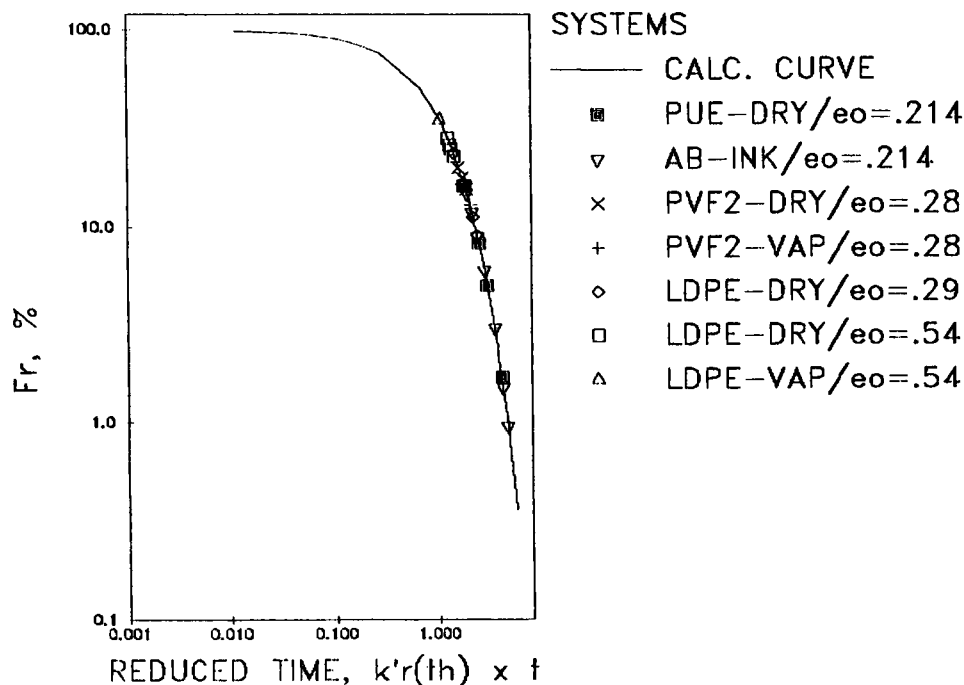
<sup>b</sup> Laminated systems at different felt ratios (Note Ref. 11).

<sup>c</sup> "Virgin" pad material with a thickness of 0.76 cm.

<sup>d</sup> Determined from data in Ref. 9.

<sup>e</sup> Determined from data in Ref. 9.

## REDUCED RECOVERY



**Figure 6** Reduced recovery for “dry” and “inked” PUE and AB rollers and PVF<sub>2</sub>/EtAc and LDPE/EtAc vs. the reduced time,  $k'_r(t_h)t$ , at room temperature.

the log-log results for foam materials and semi-crystalline polymers for varying conditions of strain, hold times, concentration levels, and nature of permeates. Other variations of the master curve may be obtained by performing certain transformations.<sup>7</sup>

### Temperature Dependence of Creep/Recovery

Previous data by Phillips et al. indicated that for low-density polyethylene there existed a small, but increasing dependence of the ratio  $e_{00}/e_{pl}$  on the initial elongation,  $e_0$ . Recent data<sup>24</sup> on felted laminated “porex”/neoprene samples at a given press temperature, compression cycles, and hold times,  $t_h$ , allowed an assessment of the temperature dependence of the function,  $B$ , in eq. (7). From these results, it was found that  $B$  could be expressed as

$$B = B(t_h, e_0, T_0, T) = B_0(t_h, e_0, T_0) + B_{00}\{1 - \exp[-b_1(T - T_0)]\} \quad (9)$$

where  $T_0$  and  $T$  are, respectively, the reference temperature and the measurement temperature and  $b_1$  is a constant. The function,  $B_0$ , is given as

$$B_0(t_h, e_0, T_0) = B'_0(t_h, T_0) + \{[1 - B'_0(t_h, T_0)][1 - \exp(-b_2e_0)]\} \quad (10)$$

and

$$B'_0(t_h, T_0) = [e_{00}(t_h, T_0)/e_{pl}(t_h, T_0)] \quad (11)$$

From eq. (6), the temperature dependence of  $k'_r(t_h)$  was found to be adequately represented as

$$k'_r(t_h, T) = C_0(T)/(t_h)^a \quad (12)$$

and  $C_0(t)$  is expressed by the following:

$$C_0(T) = C(T_0)\{\exp[-c_1(T - T_0)]\} \quad (13)$$

where  $C(T_0)$  is the value at the reference temperature,  $T_0$ , and  $c_1$  is a constant. For example, one of the felted/laminated “porex”/neoprene systems was reasonably represented for  $C(T_0 = 25^\circ\text{C}) = 5.20 \text{ min}^{-1}$  and  $c_1 = 0.0131 (\text{ }^\circ\text{C})^{-1}$  for static and dynamic testing.<sup>24</sup>

The set strain,  $e_{00}$ , to a first approximation was found to be linear in  $T - T_0$ , i.e.,

$$e_{00}(T) = e_{00}(T_0)[1 + c_2(T - T_0)] \quad (14)$$

where  $c_2$  is a constant and  $e_{00}(T_0)$  is the set strain at the reference temperature,  $T_0$ . Equation (14) was reasonably obeyed over the temperature range of

25°C to about 240°C for the felted/laminated “porex”/neoprene systems.<sup>24</sup>

**Dynamic Testing**

Under a load,  $S_0$ , the creep,  $e_c(t)$ , at time,  $t$ , may be represented as a function of an instantaneous recoverable component and a delayed component, i.e., the present response at  $t$  is a function of its past stress history.<sup>13,16</sup> If a material behaves in such a manner, the Boltzmann superposition principle may be applied.<sup>13,16,25,26</sup> Assuming that the foam materials in this study are linear viscoelastic, eqs. (4) and (7) may be combined to yield

$$e_c(t) = e_0 \{ 1 + [X(t, t_h)/(1 + BX(t, t_h) - B)] \} \quad (15)$$

Equation (15) may be used to predict static creep from dynamic creep and dynamic recovery. At static creep times,  $t_c$ , dynamic recovery times,  $t_r = t_c$ , and dynamic creep,  $t_d$ , the static creep is given by

$$[e_c(t_c)]_s = [e_c(t_d)]_d + [e_r(t_c)]_d \quad (16)$$

The creep and dynamic times may be defined for one inking (one impact) per cycle or for two inkings (two impacts) per cycle:

**One Impact per Cycle:**

For a contact time,  $t_0$ , frequency,  $f_0$ , and cycle,  $i$ ,  $t_c$  and  $t_d$  are, respectively, given as

$$t_c = (i - 1)t_0 + \{ (i - 1)[(1/f_0) - t_0] \} \quad (17a)$$

and

$$t_d = it_0 + \{ (i - 1)[(1/f_0) - t_0] \} \quad (17b)$$

**Two impacts per cycle:**

For cycle,  $i$ , the creep and recovery times are defined as follows:

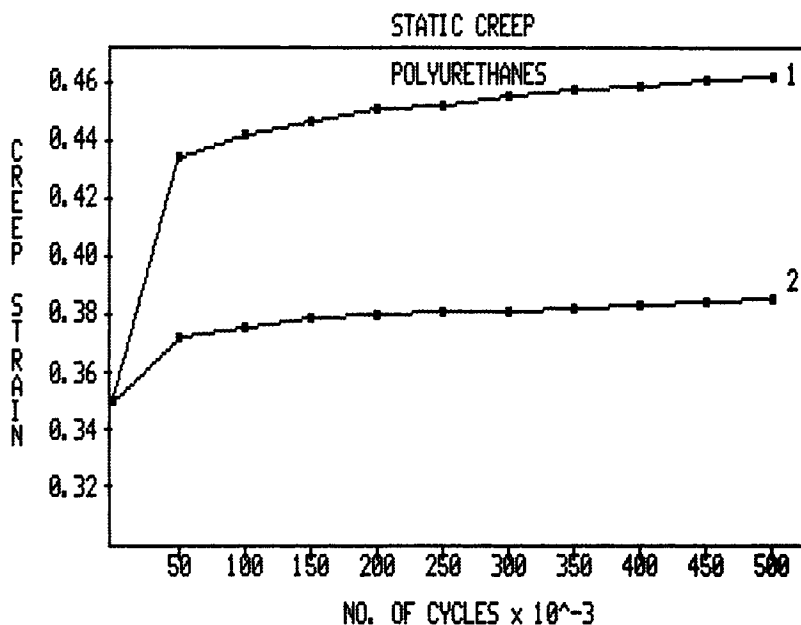
- $t_{c1}$  = time for 1st creep
- $t_{c2}$  = time for 2nd creep
- $t_{r1}$  = time between 1st and 2nd creep [1st recovery]
- $t_{r2}$  = time at end of 2nd creep/cycle [2nd recovery]

where  $t_c$  and  $t_d$  are now defined as follows:

$$t_c = (i - 1)t_{c1} + (i - 1)[t_{r1} + t_{c2} + t_{r2}] \quad (19a)$$

$$t_d = i(t_{c1} + t_{r1}) + (i - 1)[t_{c2} + t_{r2}] \quad (19b)$$

Using eqs. (5), (15), (16), (17a), and (17b) and the  $C_0$  and  $a$  values in Table II for inked Foamex 900Z: 900Z and inked Foamex 800Z/E:800Z/E,  $f_0 = 4$  cycles/s and  $t_0 = 0.01$  s, the results were calculated as shown in Figure 7. The ester structure of the Foamex 900Z:900Z apparently imparts less crystallinity to



**Figure 7** Calculated static creep from the dynamic creep and recovery (determined for a contact time  $t_0 = 10$  ms,  $f_0 = 4$  c/s,  $t_h = 1065$  min, and an initial compression strain of  $e_0 = 0.35$ ): (1) Foamex 900Z (ester); (2) Foamex 800Z/E (ether).



**Table III Static and Dynamic Testing of an Illbruck Noninked (Dry) Foamed PUE Pad (RF4-900Z)**

Time, $t$ (h)	Recovery, $e_r(t)$ ( $e_0 = 0.62$ ; $e_{00} = 0.13$ ; $t_h = 2$ h)		Dynamic Creep, $e_c$ ( $t = t_h = 2$ h)				
	Exp <sup>a</sup>	Calcd <sup>a</sup>	$t_0$ (s)	$f_0$ (c/s)	Cycles ( $\times 10^{-3}$ )	Exp <sup>a</sup>	Calcd <sup>a</sup>
0.83	0.35	0.41	1.06	0.47	3.38	0.18	0.19
2.0	0.26	0.26	0.125	4.0	28.8	0.24	0.19
2.7	0.24	0.21	0.055	9.1	65.5	0.25	0.19

<sup>a</sup> Exp = experimental. Calcd = calculated.

its chains than does the ether structure of the Foamex 800Z/E:800Z/E.<sup>13,16</sup> The variations in structure is seen as creep enhancement for the ester material. Although these results were determined for an "unbounded" or "free" specimen, they may not necessarily reflect the response of a "bounded" sample. Calculations for two impacts per cycle showed negligible differences in the static creep for dynamic recovery times of the order of the dynamic creep times ( $2t_0$ ).

In Table III, static and dynamic results are given for an Illbruck noninked pad. The static and dynamic calculated values are reasonably in agreement with the data at high  $t$  and low frequency, i.e., below a given time or above a certain frequency, experimental measurements (in this case) depend on the time for sample removal and subsequent strain determinations. During this time interval, the sample undergoes some recovery that affects the experimental results. No corrections were made for such recovery responses in the calculations.

## CONCLUSION

Foam materials may be characterized from *in situ* force measurements to give time-dependent strain and creep behavior. For well-defined boundary conditions, linear viscoelastic behavior and a properly chosen experimental setup, static measurements may be reasonably predicted from calculated dynamic creep and dynamic recovery responses of a dry or wet viscoelastic foam material. This investigation also demonstrates that a master curve may be generated from creep/recovery data that supports previous results on elasticity, delayed elasticity, and permanent deformation.

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