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Dynamic Response of Flexible Urethane Foam after Stress-Relaxation

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An interesting comment appeared in the Consumers Union Report on mattresses in October 1962; "My overall impression was that the polyurethane mattress seemed to have some sort of delayed reaction as I moved around on it, as though it were calculating the various weights I was applying here and there and, after calculation adjusting for it. Once having made the calculation, it seemed to be bottomless, giving me the nervous impression that I was suspended by some sort of magic in mid-air".

Less dramatically, the same concept has been expressed by the automotive industry as pocketing. Other terms used to describe the effect include stress relaxation, pocket stress, bottoms out, and change in "H" point. The driver after a few hours finds himself sitting in a depression. The thickness of the foam has decreased along with the comfort and durability. Many reasons have been advanced for this unacceptable response for load bearing applications and they include;

1. The heat warmth of the body softens the foam.
2. The moisture from the body softens the foam.
3. Urethane foams are really urea (made with high levels of water) foams and exhibit high levels of creep.
4. Urethane foams have poor fatigue properties compared to coil spring and latex foam.
5. Urethane foams have low storage modulus and high dynamic modulus.
6. Urethane foams are visco-elastic and behave as expected.

There has been no simple apparent and easy test or combination of tests that could be used to measure this property and predict performance.

We have conducted stress-relaxation studies in tension and compression. The tension studies were conducted at 50, 75, and 90 percent of rupture stress. The results could not be related to any group of recognized parameters.

Compression creep studies were conducted under constant stress and under constant strain. The specimen sizes were as small as .32 dm^2 to as large as 3.2 dm^2. The results were expressed in one or all three of the normal graphic forms, a) Isometric-stress against log time, b) creep curves-strain against log time and c) isochronous-stress against strain. The stress-relaxation data along with 25 other physical properties and the chemical recipes and processing variable were calculated and found to be nearly unmanageable. A very few general conclusions were made.

ABSTRACT

This paper describes the development of a mechanical test apparatus for measuring the dynamic response of flexible foams after extended stress relaxation. Additional items discussed are creep, pocketing and fight back.

1. Creep testing in tension or compression is time consuming and may require expensive test apparatus.

2. Test conditions such as humidity and temperature must be controlled.

3. The age of the specimen and previous preflexes and storage conditions must be accurately known to obtain meaningful results.

4. Creep testing is a poor quality control-type test.

Additional conclusions were:

1. It is difficult, if not impossible, to measure the contribution of cell size, cell distribution, cell porosity on stress relaxation measurement.

2. Urethane foams with higher density, made with low water, give the best results apparently independent of polyol structure and composition.

3. Literature and references give little help because the polymer tested were solid where the volume does not change in compression or tension (bulk modulus).

FIGHT BACK TESTER - Several years ago the term "fight back" was applied to the behavior of cellular urethane that exhibited stress-strain pocketing. This term, fight back, is used to describe the inability of the foam to push back to help a person get out of the depression. Several attempts were made to measure this property. Falling ball resilience was measured on compressed samples, compression set recovery rates were determined, hysteresis was measured between 20 and 50% deflection before and after creep. These studies like the one on stress-relaxation, did not yield the information necessary to select foams for load bearing application.

It was in the course of this work that the Fight Back Tester was proposed, developed and used.

MECHANICAL FIGHT BACK TESTER - The mechanical Fight Back Tester consists of a hinged lever arm with an attached indenter foot, a release trigger and a small holder containing a 9.5 mm. diameter steel ball. The indenter foot is forced into the foam, the steel ball is placed into the holder and when released, the recovery push or fight back of the foam forces the lever arm through an arc causing the ball to free fly to a flat surface marked off in cm. The distance traveled is a measure of the fight back force of the foam. The original distance the ball traveled is determined and the foam is then compressed for varying periods of time and the reduced travel is determined and the decrease in travel was calculated as a percentage value. Figures 1 and 2.

PROCEDURE - An indentation load deflection (ILD) test size sample 38 x 38 x 10 cm. is cut into 4 specimens 19 x 19 x 10 cm. The ILD test time cycle is used, two preflexes 75 to 80% of specimen thickness and a rest period of 5 ± 1 minute. The specimen is indented to 65% for 5 minutes and the lever arm released and the distance the ball traveled is measured. The exact spot the ball landed is determined by taping a long strip of carbon-computer paper to the table top. The test is then run after 30, 60 & 120 minutes stress-relaxation on the remaining three specimens.

All the foams in this study had a density above 29 Kg/m^3, the highest being latex at 72 Kg/m^3. The data demonstrates the usefulness of this approach in measuring the dynamic response after stress-relaxation. Slab-4 retained the highest percentage of dynamic response and could be ranked best. Also, these results in conjunction with other physical test results could be used to select foams for specific applications.

The rate of change of recovery of the dynamic response was also investigated. The Fight Back Distance (FBD-Distance ball travels in cm.) was determined on a 40 Kg/m^3 slab foam. It was stress-relaxed for 30 minutes and the FBD determined. After only 90 seconds rest, the FBD was re-determined.

	FBD
Instant	140
30 minute stress-relaxed	49
After 90 seconds rest	107

After 30 minutes, the FBD decreased from 140 to 49 cm., 39% retention and after only 90 seconds rest, the samples recovered to 76% of the initial FBD. Other foams in this study showed similar rapid recovery of resilience.

The effect of layer position in a large bun was investigated by the Fight Back Tester. It is well known that density and other properties may vary between the top and bottom of a large free rise bun. Layer A was cut from the top of the bun, Layer B & C from the center and Layer D from the bottom.

Sample	Layer	FBD
1	A	43
	B	109
	C	93
	D	26
2	A	146
	B	143
	C	157
	D	144

Sample 1 showed a wide variation from top to bottom of a 70 cm. high bun. The best values were obtained in the middle where the exotherm was the highest. Other properties effected by cure also vary from top to bottom in a large bun. Sample 2 had good uniformity from top to bottom in a 70 cm. high bun.

The effect of roller shear fatigue and static fatigue, per D1564, on the FBD was also investigated. As would be expected, the FBD

A = Sample 7-1/2 x 7-1/2 x 4 inch
B = Electrical Release
C = Lever 40 cm.
D = Steel Ball 8.8 grams
E = Hinge
F = Flight of Ball Original
G = Flight of Ball Final
H = Carbon Paper
I = Indentor Foot 7.5 cm. Diameter

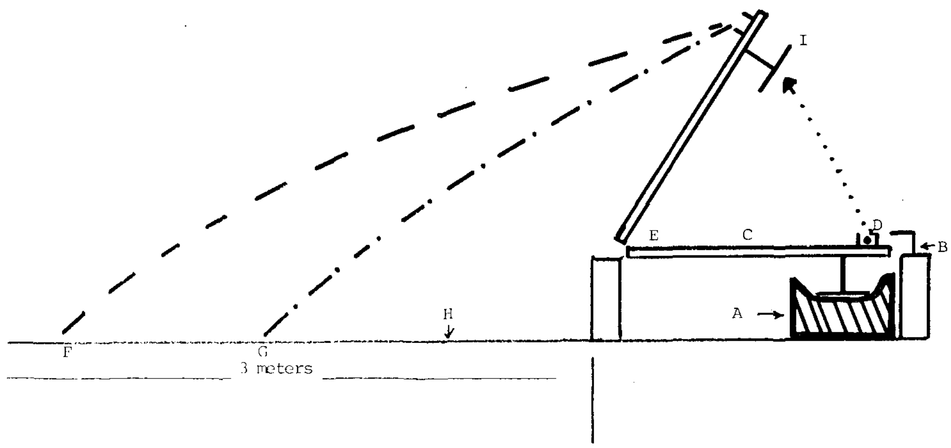

Fig. 1 - Diagram of mechanical fight back tester

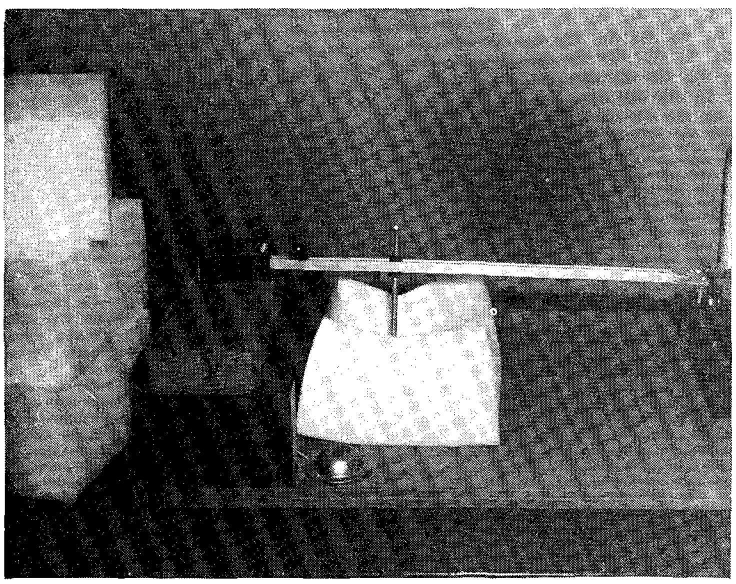

Fig. 2 - Photograph of mechanical fight back tester

MECHANICAL FIGHT-BACK TEST
(Typical Results)

	Distance in cm. Original	Fight Back Distance & Percent of Original After 30 min.		60 min.		120 min.	
		FBD	%	FBD	%	FBD	%
Latex Foam	115	12	10.4	9	7.8	8	7.0
HR Molded-1	190	43	22.6	37	19.5	29	15.3
HR Molded-2	126	12	9.5	11	8.7	0	0
Slab-1	178	26	14.6	20	11.2	3	1.7
Slab-2	168	19	11.3	15	8.9	0	0
Slab-3	155	50	32.3	46	29.7	21	13.5
Slab-4	129	59	45.7	52	40.3	30	23.3

was reduced after fatiguing indicated that the foam suffered a loss in dynamic properties.

Four HR type slab foams did give some unusual and interesting results; in fact the opposite of what was expected. The FBD actually increased after roller shear fatiguing.

Foam	FBD Original	FBD Roller Shear Fatigued	FBD Static Fatigued
A	10.0	38.5	8.0
B	35.0	76.3	24.6
C	46.8	123.5	38.5
D	49.0	116.8	39.0

The FBD after roller shear fatiguing, increased substantially. All the other physical properties appeared normal for this type of foam.

The reason for this increase in FBD was investigated. It was found that the original air flow, per D1564, for these four foams were low, but typical for HR foams. The air flow was run on the fatigued samples and a large increase was measured.

	AIR FLOW, CFM		
Foam	Original	Roller Shear Fatigued	Static Fatigued
3	1.6	4.3	1.9
4	1.7	3.6	1.8
5	2.3	4.1	2.5
6	1.5	3.2	1.6

As expected, the roller shearing action ruptured cells increasing the porosity. It was apparent that two preflexes immediately after manufacturing and two preflexes immediately before testing was insufficient to fully open the cell structure. The load deflection tests are run at a low rate of loading and the effect of nearly closed and leaky cells is not detectable.

It was further postulated that the percent falling ball resilience should increase as the porosity increased. This assumption proved to be correct.

FALLING BALL RESILIENCE, %

Foam	Original	Roller Shear Fatigued	Static Fatigued
A	43	46	38
B	50	55	53
C	52	64	56
D	47	59	58

The falling ball resilience confirms that the low air flow indicated that the foams acted in a damping manner and the roller shear action opened up the cells so the true contribution of the polymer phase could be discovered.

The unusual response of this type of HR foam to dynamic response can be explained in mechanical terms of a pneumatic disphragm effect. The response of foam to ILD, CLD, compression set, and fatigue is the result of two overlapping considerations; part of this response can be attributed to the contribution of the polymer phase of the foam and part to the pneumatic diaphragm effect. The true contribution of the polymer phase cannot be determined until the other effects are accurately ascertained.

DISCUSSION - In a classical stress relaxation experiment, the specimen is deformed a fixed amount, and the stress required to maintain this deformation is measured for a period of time. The maximum stress occurs as soon as the deformation takes place and the stress decreases gradually with time from this maximum value. If the stress is divided by the strain, the relaxation curve gives the variation of the relaxation modulus as a function of time. Thus, stress relaxation experiments give the variation of the modulus with time in the same way the creep experiments give the time dependence of the compliance. The compliance is obtained by dividing the strain at any time by the stress. The compliance gives an apparent reciprocal modulus which changes with time.

With the BWC Fight Back Tester Apparatus, the strain was set at 65%, the bottoming out deflection of the ILD test, and the stress response was determined by measuring the distance the ball traveled. The performance of the foam was determined by measuring the fight back distance after stress relaxation. It should be recognized that this test with a fixed 65% deflection at a single temperature generates a single value. For each temperature and for each percent deflection, a separate value will be generated, in short, for a full description of the stress relaxation character of a polymer a whole family of values is needed.

SUMMARY - The fight back tester is a simple mechanical device for measuring the dynamic response of flexible urethane foams after stress relaxation. The dynamic response is not only dependent upon the polymer structure but also on the porosity of the foam. Continued investigations should demonstrate its usefulness in selecting foams for load bearing applications.