Molded Polyurethane Foam Durability Testing as a Response to Applied Work

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ABSTRACT

Molded polyurethane foam is subjected to a battery of material property and performance tests developed to qualify the material for its use in automotive seating. Of particular interest are those test protocols designed to ensure that the polyurethane foam in automotive seating is suitable for use throughout the lifetime of the vehicle. Due to extended warranty periods and the increased lifetimes of automobiles today, these testing protocols are called upon to provide assurance of material performance for end use conditions that were not in effect during their development. This paper examines a number of these durability test protocols and their development history with a particular emphasis on the varying amounts of work performed on the foam specimens and how it affects the final result. These considerations will be incorporated into the ongoing discussions of possible best practices relating the test protocol to the function of the material as critical vehicle seating component conducted under the auspices of the Molded Foam Industry Panel.

BACKGROUND

The modern automobile seat has become an increasingly complex structure due to the need to make provisions for a wide variety of functions. Some important considerations for the seating design engineer are to provide for passenger comfort, and to maintain the vehicle vision envelope in the interest of occupant safety. Engineering design considerations have evolved, now recognizing the role that vehicle seats play to isolate the occupants of a vehicle from the vibrations that arise from the interaction of the road surface and the vehicle in motion. Also, there is a greater awareness of the fact that vehicle seats shape the consumer's perception of the vehicle as a whole. Therefore a wide variety of materials are employed to support the multiple functions of vehicle seats. The physical properties of these seating materials must be maintained both under static and dynamic conditions in the showroom and on the road because of the ultimate role of the seat as the interface between the human being and the vehicle.

The primary choice for cushioning material in vehicle seats is polyurethane foam. In a static application, foam provides a soft, pliant surface to the touch and provides distributed pressure support when the occupant is seated. In a dynamic setting, the ability to shield the individual from, or attenuate, higher frequency (>6 Hz) vibrations is an important aspect of polyurethane foam performance. This foam property is a contributing factor to the safety and comfort of an occupant during driving [1].

One sometimes-overlooked but equally important property of polyurethane foam, both in static and dynamic use, is its ability to provide consistent performance over the lifetime of a vehicle. This is due to the remarkable ability of the foam to recover its properties when not subjected to loading (when “rested”). In fact, it is this property of polyurethane foam that led to its choice to replace previous materials of construction and perhaps has insured its dominant position in vehicle seating. Due to the importance of this performance, many test procedures have been devised to quantify long-term durability. The Urethane Foam Dynamic Fatigue (UFDF) test [2], which was derived from the Fisher Body Dynamic Fatigue Test, and the Constant Force Pounding test [3] are the best test examples. And, since their inception, these tests have been expanded to produce even more information about the performance and changes that occur in the foam during the course of these tests (i.e., in real time) [4]. Characterization of the polyurethane foam “fatigue” behavior has become relevant because it provides an indication of how foam properties change with dynamic cycling, although at exaggerated conditions chosen to reproduce the effects of a vehicle lifetime in less than a day.

The changes in properties in these test procedures are loosely referred to as fatigue. However, fatigue is a term primarily associated with failure conditions of a material to be classified. Therefore, in polyurethane foam, fatigue is the appropriate nomenclature to associate with tensile and tear strength along with elongation. However, when the applied force is compressive, catastrophic rupture failures are not often manifest in foams. Indeed, this fact is one reason that polyurethane has been chosen almost universally for automotive seating applications. There is ample work to support the supposition that polyurethane foams exhibit small, permanent changes upon initial use [5, 6]. But of particular relevance under actual use conditions are those transient changes that are recovered upon resting.

The physical properties of polyurethane foam undergo changes during its normal use in a vehicle due to the same forces that result in its remarkable durability. At a fundamental level, this behavior is dictated by the chemical structure of the polyurethane foam [9, 10, 11]. A detailed investigation of the chemical structure is unnecessary for the purpose of relating the property changes to driving conditions. This work proposes that, by careful consideration of how polyurethane foam is utilized in a vehicle, tests to consider reasonable maximum expected changes may be developed. A test method, characterized by an energy level input and duration associated with driving, is presented in which the dynamic modulus and creep characteristics of foam are measured. The preliminary reference material and dynamic testing procedure of this work will serve to produce a greater understanding of how the polyurethane foam properties in a vehicle seat respond under typical use conditions.

SURVEY OF METHODS

The following table lists the details associated with two well known test protocols for polyurethane foam durability testing for application in automotive seating.

Table 1. Polyurethane Foam Durability Test Protocols.

	Urethane Foam Dynamic Fatigue Test (UFDF)	ASTM Dynamic Fatigue Test by Constant Force Pounding (CFP)
Pre-Conditioning	24 hrs. 23^{o}C & 50% RH	12 hrs. 23^{o}C & 50% RH
Cycles	306000	A. 8000 B. 80000
Frequency	5 Hertz	1 Hertz
Cycled Loadings	As measured at 45% and 55% deflection	0 - 750 N
Conditions	23^{o}C & 50% RH	23^{o}C & 50% RH
Recovery	30 mins. for IFD, Real time for Dynamic Modulus, Hysteresis and Creep	60 mins. at 23(+/-2)^{o}C & 50(+/-5)% RH for height and hardness measurements (24 hr. option)
Measurements	1. Height Loss 2. 50% Force Loss 3. Creep 4. UFDF number 5. Dynamic Modulus 6. Dynamic Hysteresis	1. Height Loss 2. Force Loss
Specifications or Performance Classifications	UFDF Number	Height Loss < 10%
Indentor Foot	Dynamic Fatigue Testing Indentor with a swivel joint based on ASTM 3574 IFD indentor	250 mm diameter with 25 mm lower edge radius

Fisher Body Dynamic Fatigue

The Fisher Body Dynamic Fatigue (FBDF) was jointly developed by the Union Carbide Corporation and the Fisher Body Division of General Motors, specifically one V. S. Murty, in the late 1970s. At that time, the test method under consideration was a static creep type test. In the early 1980s, a dynamic durability test was developed with the advent and adoption of hydraulic universal testing machines, and the desire to perform a test that was more representative of the application. In addition to the conventional height and load loss values employed in other test protocols, a dynamic creep measurement was added to the protocol. Later, the inheritors of the Union Carbide business continued to refine and extend the test [2, 4, 7, 8].

The strength of this test protocol lies in the fact that the results from the laboratory method were used to develop a correlation with actual in-vehicle tests. General Motors conducted ride testing at their proving grounds to develop a subjectively scaled value for the performance of the seating foam. This value was in turn normalized, and related to a 100 point scale which used weighting factors for each value (initial and final height, h_i and h_f, & initial and final force, F_i and F_f) measured -

$$\% \text{ height loss} = (h_i - h_f) / h_i \times 100 \qquad (1)$$

$$\% \text{ force loss} = (F_i - F_f) / F_i \times 100 \qquad (2)$$

$$\text{creep} = \text{initial force deflection} - \text{final force deflection} \qquad (3)$$

$$\text{FBDF No.} = (4 \times \text{creep}) + (5 \times \% \text{ height loss}) + (1.5 \times \% \text{ force loss}) \qquad (4)$$

At the time of its development, an FBDF number of <90 was associated with the performance of an acceptable front seat cushion. General Motors was able to insure a level of performance from the foam that could be translated into final application performance. Raw material suppliers and foam manufacturers were also able, in the 25 years that followed, to characterize their products' performance in a test that could trace its basis to real world performance.

Constant Force Pounding

The constant force pounding (CFP) test [Figure 1] has existed for over 30 years. It evolved through the British Standards Institute (BSI) into DIN (Deutsches Institut für Normung) and eventually into ISO (International Standards Organization), as ISO 3385. It worked its way into ASTM (American Society for Testing and Materials) during the 1980's, where today it is ASTM D3574 Test I_3. In the test a 750 N (168 lb) indenter is raised and lowered onto a 380 x 380 x 50 mm sample at a rate of approximately 1 Hertz. Loss of thickness and force deflection (40% IFD) are evaluated generally after 80,000 cycles.

The 250 mm diameter circular indenter is intended to simulate the action exerted on to a seat cushion by an average weight person as they repeatedly sit down and get up off of the cushion. It has become the durability performance standard for many seating applications, particularly in upholstered furniture and automotive seating. Over the years there have been attempts to use the constant force pounding test as the basis for developing service classes for various applications. An example is BS 3379 (Specification for Flexible Urethane Foam for Load Bearing Applications), which outlines a series of performance classes ranging from light duty for applications like pillows and scatter cushions to extremely severe for heavy duty contract seating and transport seating. There are allowable load deflection test losses for each class over a range of initial foam hardnesses, creating performance bands for each service class. Despite some of the shortcomings of this test, the constant force pounding will continue to be used as a durability measurement for cushioning applications.

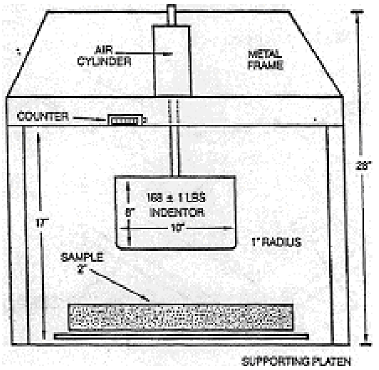

Figure 1. *ASTM Constant Force Pounding Apparatus.*

Other Durability Test Protocols

There are many other durability tests that have been developed for various particular reasons. The majority of these durability test variants are specific to the vehicle manufacturers (Original Equipment Manufacturers or OEMs). Some of these test protocols are point by point duplicates of the ASTM or ISO CFP standards. Others, such as the Japanese Repeated Compression Set (Constant Deflection Pounding, or CDP) exhibit characteristics that mimic different aspects of the CFP and UFDF tests. Some tests, most notably the BMW Dynamic Fatigue Test, couple the applied work of cycling with stressed environmental conditions (40^{o}C & 80% RH). Fundamentally, all of these test protocols tend to exhibit the same basic characteristics. The CFP and UFDF test protocols are simply popular durability test protocols that portray different approaches to the problem of qualifying polyurethane foam durability for use in the automotive seating application.

DURABILITY TEST FUNCTIONALITY

The task of designing a particular test protocol begins with the consideration of the application and how the choices made in the laboratory relate to the in-use situation. In our case, we need to consider how the molded polyurethane foam in a vehicle seat is used today. Automotive seating foam is an important tool in the seating designers' toolbox. The intricate geometries and multiple firmnesses ("feels") of the foam provide designers with a number of options to achieve their goals, both from the standpoint of performance and appearance.

Because of the role it plays in supporting the vehicle occupant, seat cushions are of special interest when considering durability testing. The seat cushion generally supports more than 80% of the occupants' mass. Automotive OEMs specify that the H-point requirements must be met and have an expectation that the durability of the seat will insure this performance during use. The foam employed in seat backs is not normally subject to the loading conditions of the cushion foam. For durability testing, the cushion is therefore of primary concern, and as the natural extension, sitting pressures will need to be considered. Durability tests account for sitting pressure directly (750 Newtons in CFP) or indirectly, by the designed deflection (50% for the UFDF). In both durability test protocols, the force or deflection choices are somewhat extreme. A force of 750 Newtons on the CFP indentor is not quite twice the 99% percentile male force and the typical design deflection today is closer to 35% rather than 50%.

Another consideration is the dynamic use of the foam. Previous references cite vibration frequencies of 1 to 2 Hertz as those transmitted from the interaction of the road, tires and vehicle suspension system to the seat or floor of the interior [1, 12]. Foam itself exhibits resonance frequencies of 3 to 6 Hertz under various vibration transmissibility testing protocols [13]. The CFP test frequency is in line with vehicle resonance frequencies, while the UFDF employs a cyclic frequency more in keeping with that of the polyurethane foam.

The final consideration is concerned with time. How long is the foam under load? How long is the foam rested? Generally, under commute conditions, the foam is loaded between 0.5 and 1 hour, rested for 8 to 9 hours, and the load applied again. Overnight, the foam can rest again for up to 12 hours. In both durability test protocols the foam is under load, without rest, for a far greater time period.

Therefore, we can identify three characteristics that define a durability test – the limits of the cycle, the frequency of the cycling, and the cycling time. When these three characteristics are considered together, the applied work, or energy, is defined. The following sections consider basic attributes of one or the other of the two durability test methods under consideration such as how the primary property losses, height and force, change with time/cycling, the statistical variation of the results, and how the control scheme and test setup may influence the variation in results between different laboratories. Once the issue of test control scheme is introduced, the influence of applied work and its manifestation, the temperature increase of the foam, must then be addressed. Finally, we can discuss the test methods, their functionality and the opportunities for improving the test protocol.

MOLDED POLYURETHANE FOAM SAMPLES

The following experimental foams, characterized by overall densities and ASTM 50% IFD [Table 2], were produced to study various aspects of the two primary test protocols employed to qualify polyurethane foam durability. Foam specimens utilized for characterization were produced utilizing a state of the art high pressure metering machine and a 400 x 400 x 100 mm laboratory block mold. These densities and firmnesses span a wide range of foam grades. The foam samples were allowed to cure for at least one week at ambient conditions after manufacture and prior to 24 hour preconditioning at standard laboratory environmental conditions (21°C and 50% R. H.).

Table 2. Foam Samples.

Identity	Density (kg/m^3)	50% IFD (Newtons)
2MM857	30	269
2MM854	50	441
2MM849	70	605

DURABILITY TEST CONSIDERATIONS

Property Losses versus Cycling - Constant Force Pounding

In ASTM D3574 the constant force pounding test lists two possible test cycles, 8000 cycles or 80000 cycles. In a recent study performed by the Molded Foam Industry Panel, foams [Table 2] were subjected to both cycles for comparison purposes with an intermediate test cycle of 20000 cycles. In each case, the foams were subjected to the first 8000 cycles and then they were tested for losses after one hour recovery. The foams were then put back on to the tester until the total was 20000 cycles and 80000 cycles respectfully, with the losses measured each time. The thickness and IFD losses for each test cycle are shown below [Figure 2]. The results indicate that 50% or more of the losses occur in the first 8000 cycles and as much as 75% of the losses will be administered in the first 20000 cycles. From this data it would seem reasonable for one to be able to use one of these shortened cycles as a quick check for the foam's relative durability.

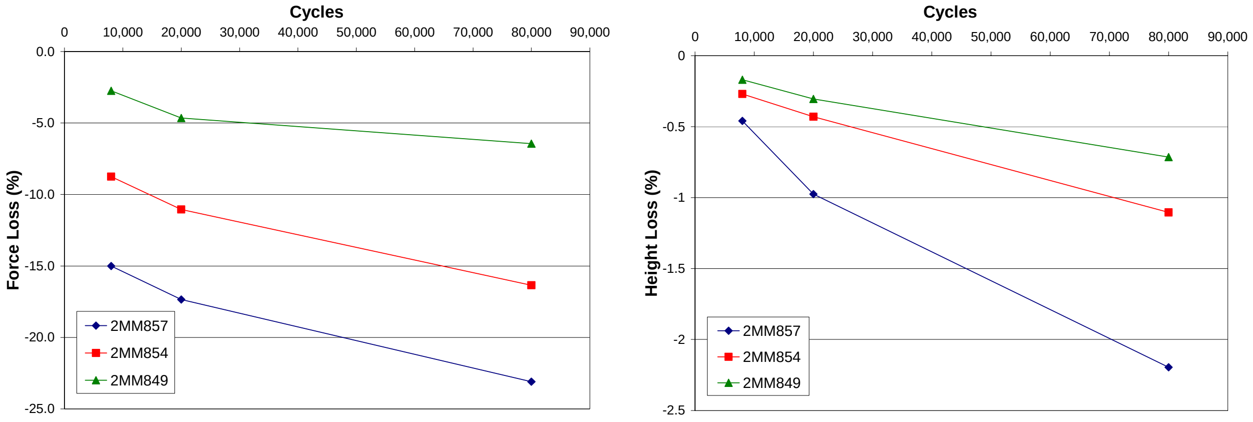

Figure 2. *Force Loss & Height Loss as a Function of Constant Force Pounding Cycles.*

Test Precision & Variation - Constant Force Pounding

Precision for this test method is based on a round robin study conducted by the Polyurethane Foam Association in year 2000 in accordance with ASTM Practice E 691. For the study, three materials were carefully selected to cover the range of properties expected in commercially available products. The number of labs was 7. The samples were distributed by one lab, but individual specimens were prepared at the labs performing the tests. Each laboratory obtained six test results for each material. Precision, characterized by repeatability (S_r and r) and reproducibility (S_R and R) have been determined as shown in the individual tables.

ASTM D3574 Pounding Durability Round Robin
(1 hour recovery vs. 24 hour recovery)

(7 Laboratories)					
Material	Avg.	S_r [A]	S_R [B]	r [C]	R [D]
1	1.69	0.76	0.87	2.14	2.43
2	1.46	0.39	0.42	1.08	1.17
3	2.50	0.24	0.61	0.68	1.70

Pounding Durability Test, 1 hour Thickness Loss, %

(7 Laboratories)					
Material	Avg.	S_r [A]	S_R [B]	r [C]	R [D]
1	1.47	0.70	0.97	1.96	2.70
2	1.11	0.32	0.39	0.89	1.10
3	1.81	0.24	0.52	0.68	1.47

Pounding Durability Test, 24 hours Thickness Loss, %

(7 Laboratories)					
Material	Avg.	S_r [A]	S_R [B]	r [C]	R [D]
1	29.9	1.34	2.93	3.75	8.22
2	20.6	2.11	2.49	5.92	6.96
3	34.1	1.56	2.86	4.36	8.01

Pounding Durability Test, 1 hour 40 % IFD Loss, %

(7 Laboratories)					
Material	Avg.	S_r [A]	S_R [B]	r [C]	R [D]
1	24.3	2.46	3.26	6.88	9.14
2	17.2	2.09	2.53	5.86	7.09
3	27.0	1.95	3.56	5.46	9.96

Pounding Durability Test, 24 hours 40 % IFD Loss, %

A. S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations of the test results from all of the participating laboratories.

B. S_R = between-laboratory reproducibility, expressed as standard deviation

C. r = within-laboratory critical interval between two results = $2.8 \times S_r$.

D. R = between-laboratories critical interval between two results = $2.8 \times S_R$.

What does all of this mean? For starters, it is clear that there can be a great deal of variability in pounding durability results when comparing one lab’s data with another’s. This variability must be considered when developing specifications and when judging a material’s compliance with a specification. There are efforts being made by the ASTM committee and by the Molded Foam Industry Panel to revise the test method to help reduce this variability. The other thing that this data demonstrates is that much of the thickness and hardness loss attributed to this test can be recovered with time, i.e. it is temporary. Roughly 20% of these losses are recovered with 24 hours of rest.

Test Control Schemes - Constant Force Pounding

Given the absolute nature of polyurethane foam test specifications, it is important to consider opportunities to improve the expected precision of the test results. Both durability test protocols were developed before computer control was widespread. The Molded Foam Industry Panel has reviewed the intricate details of the various methods employed to perform this test. This review has uncovered differences in the test execution in various labs. One difference in particular was judged to be significant enough to warrant further investigation.

Our testing laboratories generally use two mechanical methods to perform durability testing. Some testing laboratories have access to the same general equipment setup pictured in Figure 1. In this system, a platen in accordance with the test specifications with regard to geometry and mass is actuated, typically pneumatically. The actuator alternatively drops and raises this platen at the proper rate to provide for the specified test frequency. The mass provides for the 750 N requirement and the opposing end of the stroke is typically set with a limit switch. The force of gravity is employed for the downstroke. Although there are no direct measurements of the shape of the cycle, we can imagine that it is mixture of sinusoidal and square. Other laboratories have, typically for test development purposes, access to hydraulically actuated universal testing machines (UTMs). The cycling control schemes employed by the software provided by the UTM manufacturer are normally not “mixed mode” however. This means that the cycling is either based on a pair of force settings or a pair of stroke settings. In addition, the software control attempts to reproduce an idealized sine wave shape.

Two sets of constant force pounding tests were performed on a hydraulically actuated frame where the software was reprogrammed to perform mixed mode testing. In one case, the limit was designated by zero force. In this case, as the foam experienced height loss, the platen would remain in contact with the foam specimen. The second case utilized the originally measured foam height as the stroke limit. Therefore, when the foam experienced height loss, the platen was observed to move to a position above the foam so that it was no longer in contact with the foam. The results of these tests for our sample foams are shown above in Figure 4.

These results indicate that this slight difference in test protocol can influence the final values obtained in the test. Also note that the higher density sample of the case where zero force was the control point is higher than would be predicted by a linear model. This may indicate that since the platen never left the foam, there was less opportunity for heat removal. The thermal profile of our example durability tests is examined in the next section. When the effect of the testing protocol, considered here, is coupled with the theorized difference of waveform shape between pneumatically and hydraulically actuated machines, some of the test variation can be explained. One means of improving the precision of the constant force pounding durability test is to eliminate any remaining ambiguities in the test protocol.

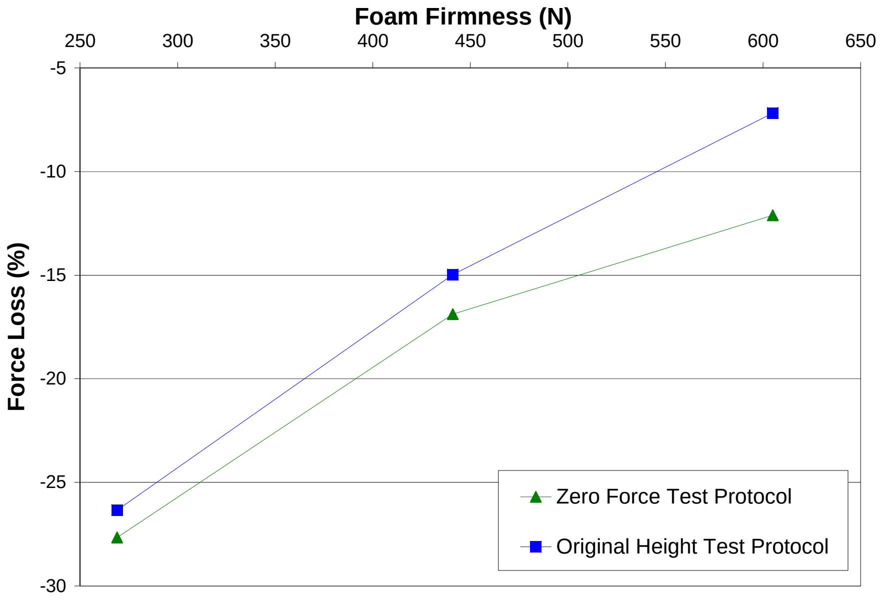

Figure 3. *Force Loss as a Function of Foam Firmness for Two Test Protocols.*

ENERGETICS

The following tests were conducted in order to better understand and illuminate the fundamental differences between the CFP and UFDF type tests. In terms of the variables employed in durability testing, these experiments consider the choice of frequency and basis for the cycle limits.

Experimental

Both tests were implemented using a hydraulically driven actuator mounted in the vertical direction on a crosshead to provide linear motion and a load cell connected to the base of the load frame to provide force feedback. MTS Systems Corporation of Minneapolis, Minnesota manufactured the hydraulic load frame and the Testware SX Dynamic Characterization software (MTS Systems Corporation) module was used in conjunction with the Teststar IIs digital control system to interface with and control the action of the hydraulic load frame.

The UFDF test was conducted in the accepted fashion, but there were some deviations in this instance of the CFP test. The foam tested remained as molded and was not cut to the height specified by ASTM. In this manner the results of the two tests are not complicated by geometric considerations. In addition, the height and load loss was measured in accordance with the UFDF test to again permit direct comparison.

Results

Table 3 summarizes the height and force loss results for the two tests. The immediate observation is the extreme differences in the force loss results as a function of firmness. The CFP results are more discriminating than those of the UFDF. The reason for the difference in the results is illustrated in Figure 5, which depicts the imputed energy for each test protocol as a function of the foam firmess.

Table 3. Force Loss and Height Loss Results.

Identity	UFDF Force Loss (%)	CFP Force Loss (%)	UFDF Height Loss (%)	CFP Height Loss (%)
2MM857	20.8	27.0	4.5	4.8
2MM854	15.7	10.0	2.7	2.7
2MM849	9.8	2.7	1.9	1.4

The applied energy for the UFDF test scales as a function of firmness due to its test protocol. This test protocol is based on the original assumption that the cushion foam was designed to be deflected approximately 50% and that the transmitted vibration of the road would result in 5% deflection deviation from this design point. This choice of protocol “normalizes” the severity of the test with foam firmness, which is one of the primary factors considered in specifying foam. In the case of the firmest foam, from the 2MM849 series, the cycles are executed between approximately 430 and 720 N, while for the softest foams, from the 2MM857 series, approximately 170 N and 330 N are the cycle limits. This normalization of the energy input relative to the foam firmness could be considered a positive aspect of this test protocol from a material science point of view since it permits durability performance comparisons for foams of differing firmnesses. However, it must be noted that utilizing this test assumes that foams are properly specified with respect to the foam firmness for use in an automotive cushion.

In the case of the CFP test protocol, regardless of the foam firmness 750 N is the controlled deflection force. As a result, the deflection employed to reach this point changes, but has less effect on the energy input. As a result, the CFP force loss values reveal a strong bias with respect to firmness and density. In terms of test functionality, the low density back foam is behaving as expected with regard to a test that was created to qualify cushions and exhibits an extreme response in force loss. But if one wished to discriminate between the performances of firmer cushions, there is so little deflection to reach the 750 N target that the height and force loss are minimal.

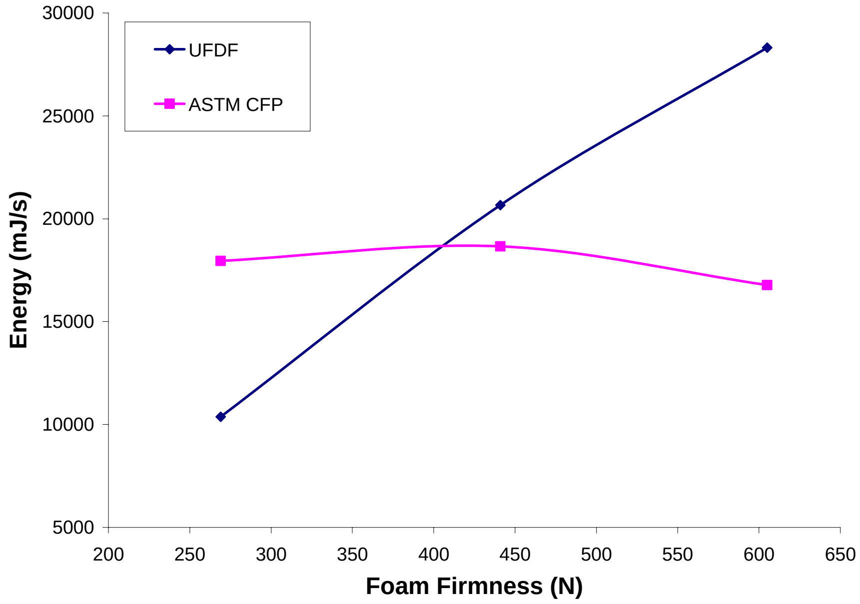

Figure 4. *Applied Energy for UFDF and CFP Durability Tests as a Function of Foam Firmness*.

This exercise to quantify the energy input into foam is instructive because it aids our understanding of how the test results, reported as height and force loss, relate to the choice of test protocol. The UFDF test provides material property type performance values for any foam, regardless of its firmness. The CFP test is functional in the sense that the pressure exerted by the vehicle occupant on the foam is fixed. The choice of a 50 mm foam specimen and 0 to 750 N of force in the CFP test protocol would seem to cover "worst case in vehicle" scenarios.

THERMAL EFFECTS

When energy is lost in the foam, heat is generated. Figure 5 depicts the temperature increase experienced by the foams detailed in Table 2.

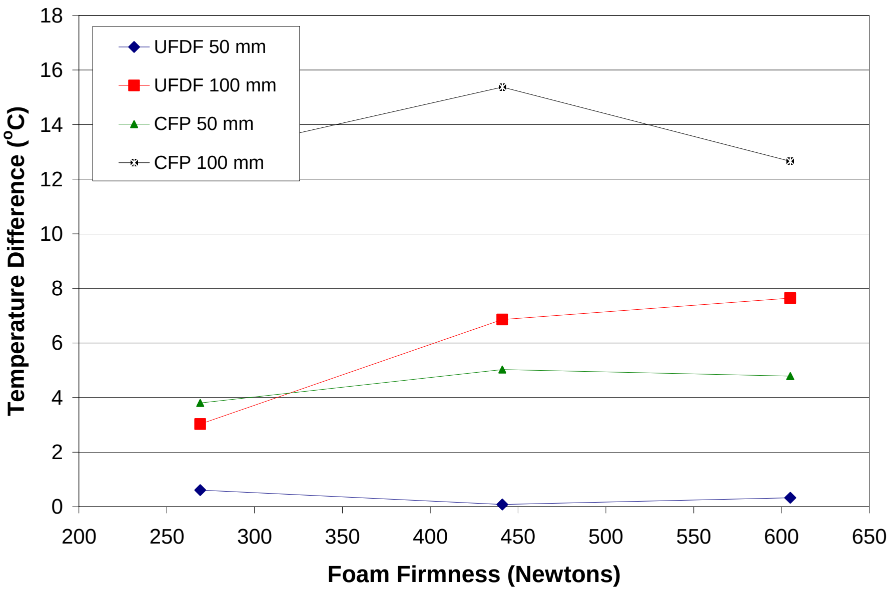

Figure 5. *Maximum Temperature Increase as a Function of Foam Firmness* **.**

The CFP temperature increase at the same foam thickness is greater than that of the UFDF test protocol. This could be due to the stroke distance of the CFP test versus the limited distance traveled in the UFDF test. When the shape of the temperature response for the normally employed 100 mm thick UFDF samples and the 50 mm thick CFP samples is compared, the shape mimics that of the applied energy curves. These curves have been generated just to provide an impression of the temperature increase for these particular tests.

Of additional interest would be the question of whether these temperature increases could influence the final force measurement results. Figure 6 depicts the CFP temperature difference as a function of 1 hour recovery time. This indicates that, for this set of foams under normal CFP conditions, there is a minimal effect of temperature. This foam data set is limited, however, to foams that are of expected air flow and other properties. One could imagine changes in foam composition and morphology that would produce foams that would exhibit greater temperature increase during cycling and therefore not be expected to return to ambient temperature conditions within an hour.

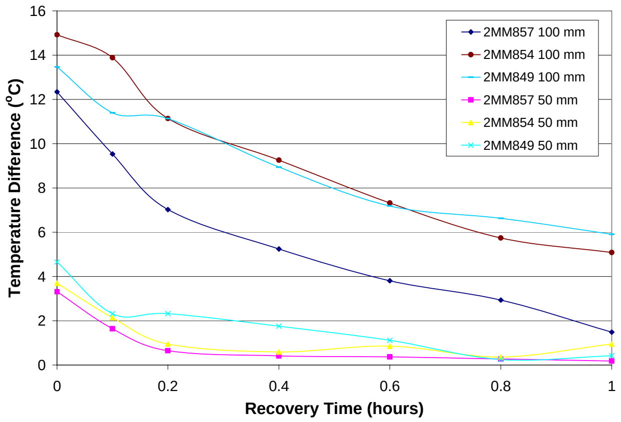

Figure 6. *Temperature Difference as a Function of Recovery Time.*

LONG TERM RECOVERY

The ability of polyurethane foam to recover its properties is an important reason why this material has become the defacto standard material for automotive seating. This ability insures that during normal day-to-day use the product will perform at essentially the same level as when produced over the lifetime of the vehicle. The durability tests considered in this paper are, by design, accelerated, or extreme when compared to everyday use conditions. We would expect the ultimate recovery of the foam after being subjected to these tests to represent worse case conditions.

The following graphs represent the CFP recovery results for a set of foams of densities that range from 31 to 62 kg/m^3 and a corresponding firmness range. The foams' recovery is measured for weeks after CFP cycling. The results are depicted in Figures 7, for force loss and height loss. After five weeks, the force loss is less than 2% and after 1 day the height loss is less than 0.5%, which seems to be the limit of resolution for this measurement.

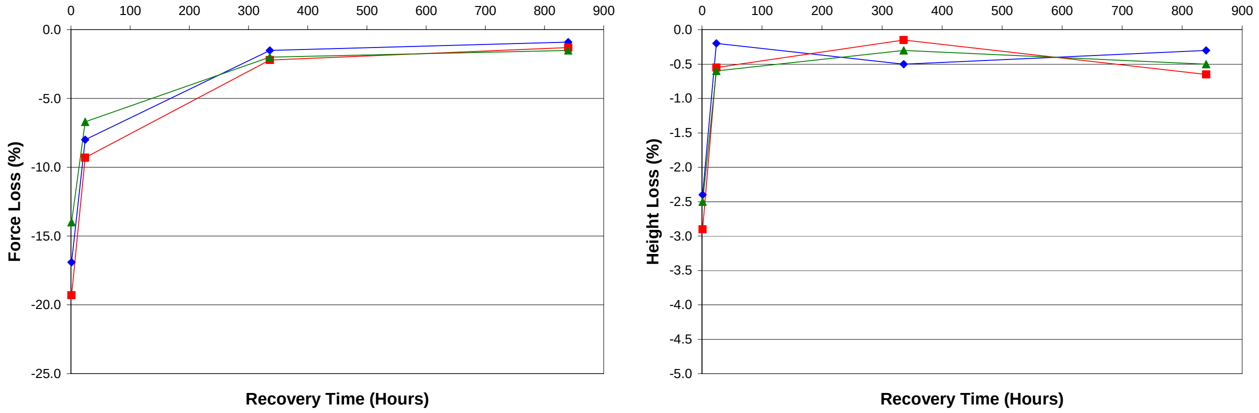

Figure 7. *CFP Force Loss & Height Loss as a Function of Long Recovery Time.*

DURABILITY TEST CORRELATIONS

Correlation of UFDF and CFP

If the general phenomena in effect during different durability test protocols are similar, one would expect to find correlations between the results of various methods. Figure 8 below is constructed from the data in Table 3 to confirm this proposition. Two aspects of this correlation are illuminated in the graph. The first idea is that the range of values for the CFP force loss is greater than that of the UFDF. Secondly, as the force loss decreases, the UFDF protocol will continue to provide discrimination of the results.

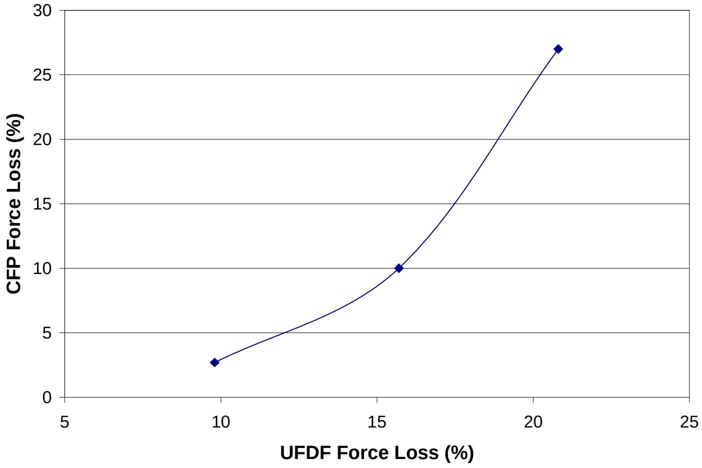

Figure 8. *CFP Force Loss versus UFDF Force Loss.*

Correlation with Other Durability Tests

There is an approximate linear correlation between the 40% IFD losses in Constant Force Pounding (CFP) and the 25% IFD losses measured after the Japanese Repeated Compression Set (or Constant Deflection Pounding - CDP) durability test. Thickness losses are about the same for both durability tests.

Hardness regains after various recovery times, e.g. 24 hours, one week or longer, are also similar for both of these durability tests. The two tests exhibit rapid regains after short recovery periods (say 24 to 48 hours) and slower regains with longer aging times. A small amount of specimen thickness and hardness do not recover even after months of aging. This may be classified as' permanent' durability testing thickness/hardness losses. In general, the permanent losses after several weeks' recovery are only a few percent. Thus well-formulated polyurethane foams recover almost all of their original properties. Repeated durability pounding on the same sample will produce cumulative height and hardness losses even after long recovery periods.

CFP and Other Physical Properties

A technical paper produced last year demonstrated that CFP results could be correlated with other physical properties that are either associated with accelerated aging (Wet Set) or energy loss (Hysteresis Loss) [14]. The correlations are depicted in Figure 9. These results demonstrate that the active phenomena of the durability tests are also present in these two tests.

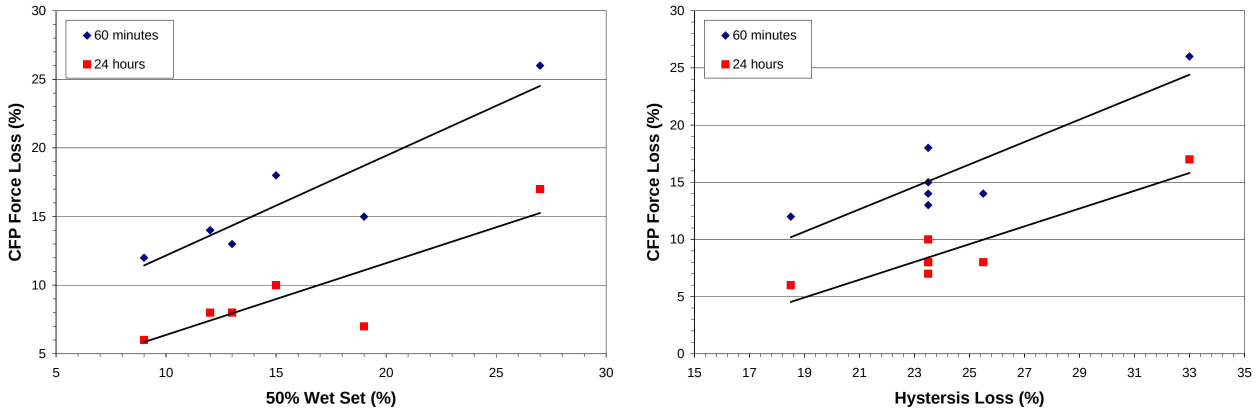

Figure 9. *CFP Force Loss versus Wet Set and Hysteresis Loss.*

DISCUSSION

Durability tests have been developed and refined/evolved to quantify the performance of polyurethane foam over time using accelerated test protocols. Force and height loss are quantified by measuring these properties before and after the imposition of work via cycling. The work performed on the foam samples results in energy lost as heat, as evidenced by the temperature increase of the foam during cycling. As with other accelerated test methods, one must insure that the test acceleration and associated temperatures do not degrade the material in a manner that will not be encountered in the field. The losses experienced by the foam are essentially recoverable.

In the case of automotive seating, two test protocols represent the fundamental approaches to testing foam. Constant Force Pounding, CFP, is a cycling protocol with a force basis with wide stroke limits executed at low frequency. Urethane Foam Dynamic Fatigue, UFDF, uses a load basis (switch to force) with a narrow stroke range executed at high frequency. Both of these automotive seating durability tests are designed with an interest in cushion performance, but differ in their philosophy. With its high force basis, greater than sitting pressures, CFP results discriminate based on firmness, with the consequence that foam grade differentiation is necessary. The UFDF test is more material characterization type in nature, normalized for force using 50% deflection basis, with results that are somewhat firmness independent. It is a more discriminating test for higher firmness foams, but there is some danger in assuming that UFDF numbers have any meaning outside of the cushion foams for which they were developed by correlation to in-vehicle results. It has been shown previously that there is a fairly good correlation between CFP test results and in-vehicle seat performance [5].

The two fundamental approaches to testing are means of imputing work/energy on the foam so that the response can be characterized, as has been done above. Since durability tests measure the response to work/energy, the results of various test protocols can be roughly correlated. A simple correlation of the two protocols is reported above, along with correlations with other durability tests and physical property measurements. Thus, the durability of foams used for seat back applications, where the imputed force is low, can be characterized by their response to thermal energy and/or hydrolytic conditions.

There is no compelling reason to dismiss either test method from a scientific point of view. In the interest of harmonizing automotive standards however, the authors propose the following recommendations for the protocol most broadly employed.

RECOMMENDATIONS

The information provided in this document provides the basis for recommending that the following work be performed to improve or redefine the CFP test to accomplish the following goals. The variation between laboratory results must be addressed using better control schemes by considering different protocols, machines, & method. The intermediate results at 8000 cycles presents an opportunity to determine if abbreviated testing provides enough information to reduce test time. Finally there is a need to integrate the two unique features of the UFDF test, real time data collection with dynamic energy loss and dynamic modulus and correlation with in-vehicle performance, within the framework of the CFP test protocol.

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BIOGRAPHIES

Brian L. Neal

Brian Neal joined ARCO Chemical Company in 1996 after earning a Ph.D. in Chemical Engineering from the University of Delaware. He joined Bayer Corporation's Polyurethanes Division in 2000, following Bayer's acquisition of Lyondell's global polyols business. In 2005, after almost three years in Leverkusen, Germany, Brian returned to Bayer Material Science's South Charleston Technical Center in West Virginia to become the leader of the automotive seating foam group, working to develop new polyols and systems for polyurethane foam applications.

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Ron Blair received his degrees in Glasgow Scotland. He continued his studies at the University of British Columbia before joining Royal Dutch Shell Plastics Laboratory in Holland. During his six years with Shell, he worked in various functions including fundamental research, plastics testing and latterly, polyurethanes. In 1976 he joined Monsanto Canada, which became Woodbridge Foam Corporation in 1978. Ron has held various processing and chemistry positions and recently retired from managing the Woodbridge Corporate P3T, Woodbridge, Ontario, Canada. Ron is currently a Polyurethane Industry consultant and can be contacted at ronblair@hotmail.com.

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Roy F. Pask

Roy Pask has been with BASF Corporation since 1968 where currently he is Supervisor of Polymer Physics in the Urethanes R&D Department. With over 30 years of foam testing experience, Mr. Pask also represents BASF on a number of industry associations including the Center for the Polyurethanes Industries, the Polyurethane Foam Association, the Carpet Cushion Council, the Society of Automotive Engineers, the Molded Foam Industry Panel and the American Society for Testing and Materials, where he serves as subcommittee chairman for cellular material and urethane raw material standards. Roy did his undergraduate and graduate studies at Wayne State University in Detroit, Michigan.

Mark Weierstall

Mark Weierstall has received an Associates Degree in General Studies from Macomb County Community College and is currently pursuing a Mechanical Engineering Degree. He has 22 years of experience in the automotive foam industry where his activities have mainly been focused on product development, physical testing, and specification development for seating and energy management foams. He currently manages Woodbridge's Corporate Comfort Laboratory, Troy, MI.