

# The Effect of Visible Light on the Variability of Flexible Foam Compression Sets

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## **ABSTRACT**

The photochemistry of polyurethanes has been of interest to academics and in the area of coatings. Relatively little work has been done on polyurethane foams, apart from numerous patents or a few papers teaching means to minimize the surface yellowing, has been reported for polyurethane foams. It is generally accepted that exposure to visible light has minimal impact on the physical properties of foam. The application of modern statistical methods to some recent observations in several labs has demonstrated that exposure to light can affect the variability of some physical property test results. Increasing exposure time and/or light intensity during the storage of foam samples under ambient laboratory conditions increases the amount of permanent set induced in some compression set tests. Variability resulted from uncontrolled light exposure of cut samples prior to being compressed. Other foam properties are not substantively affected. All types of flexible foam can react in a similar manner. This paper will describe the experiments and data which demonstrate the above phenomena, some theories about the mechanism of the effect and recommendations to decrease the variability of foam testing.

## **INTRODUCTION**

Polyurethanes, especially those made using aromatic isocyanates, contain chromophores which interact with light [1,2,3] This is of particular interest in the area of polyurethane coatings, where light stability is a critical factor and is the main reason that aliphatic isocyanates are used in making polyurethane coatings. The photochemistry of polyurethane foam, which is almost exclusively made using aromatic isocyanates, has received considerably less attention. The yellowing of PU foam [4] on exposure to light is a well known phenomenon, and it has been generally accepted that apart from yellowing, ambient light has little effect on foam properties [5,6,7]. Academic studies on the effect of higher-energy UV radiation have shown that irradiation promotes chemical reactions in foam, some of which are detrimental to the foam structure [3].

During a meeting of the Molded Foam Industry Panel, whose broad mandate is to improve foam testing, data was shown indicating that exposure to ambient laboratory lighting affected some testing results, specifically compression sets. Light intensity and length of exposure to laboratory lighting of cut foam samples affected compression sets, and since there are no testing guidelines for these factors, the variability of the results was higher than expected. Some members of this Industry Panel had made similar observations, but the majority had not. Thus a systematic study to examine the effects of light exposure was instigated.

Existing data was contributed by Panel members and experiments were conducted to demonstrate the effect of light on compression sets and to investigate its impact on other commonly measured foam properties.

## EXPERIMENTAL

Foam samples were cut from either molded foam blocks or slab foam which had been made in the course of normal R&D activities. No foam was specifically made for this work. All samples were cut and conditioned as described in ASTM D3574 [8].

Apart from the accelerated exposure study, foams were only exposed to normal laboratory fluorescent lighting. No effort was made to alter the lab routine, i.e. lights were left on or turned off as usual. All labs were at standard conditions of temperature ( $23\pm 2^\circ\text{C}$ ) and humidity ( $50\pm 5\%$  RH) for foam test labs. Samples were placed on bench tops, either singly or stacked, as noted, or placed in partial shade (under a shelf) or protected from light exposure by being stored in a lightproof container.

Accelerated aging was conducted in a Q Panel chamber. The Q Panel testing was conducted per ASTM D4329 Cycle A [9] with UVA 351 lamps. UVA 351 lamps simulate sunlight through glass. The D 4329 Cycle A is 8 hours light at  $60^\circ\text{C}$  followed by 4 hours of dark at  $50^\circ\text{C}$ .

After exposure to light (or not), the samples were tested according to ASTM D3574. All measurements were done on triplicate specimens of each foam type examined.

## RESULTS

The results in this paper come from three labs and are presented separately for clarity.

### Lab #1

The initial work used historic data for the sample-to-sample variability of 90% dry compression set ( $C_d$ ) results for slab foam. Sets of three samples had been cut from each foam type and the three samples stacked such that sample #1 was always on top (greatest light exposure) and sample #3 was always on the bottom (least light exposure). The results shown in Figure 1 are the coefficient of variability (%COV) for the three samples taken from each of more than 3000 foams. The "X" axes in Figures 1 and 2 are sample ordinals.

$$\%COV = [(100)(s) / \bar{X}]$$

Where "s" is the standard deviation and  $\bar{X}$  is the mean.

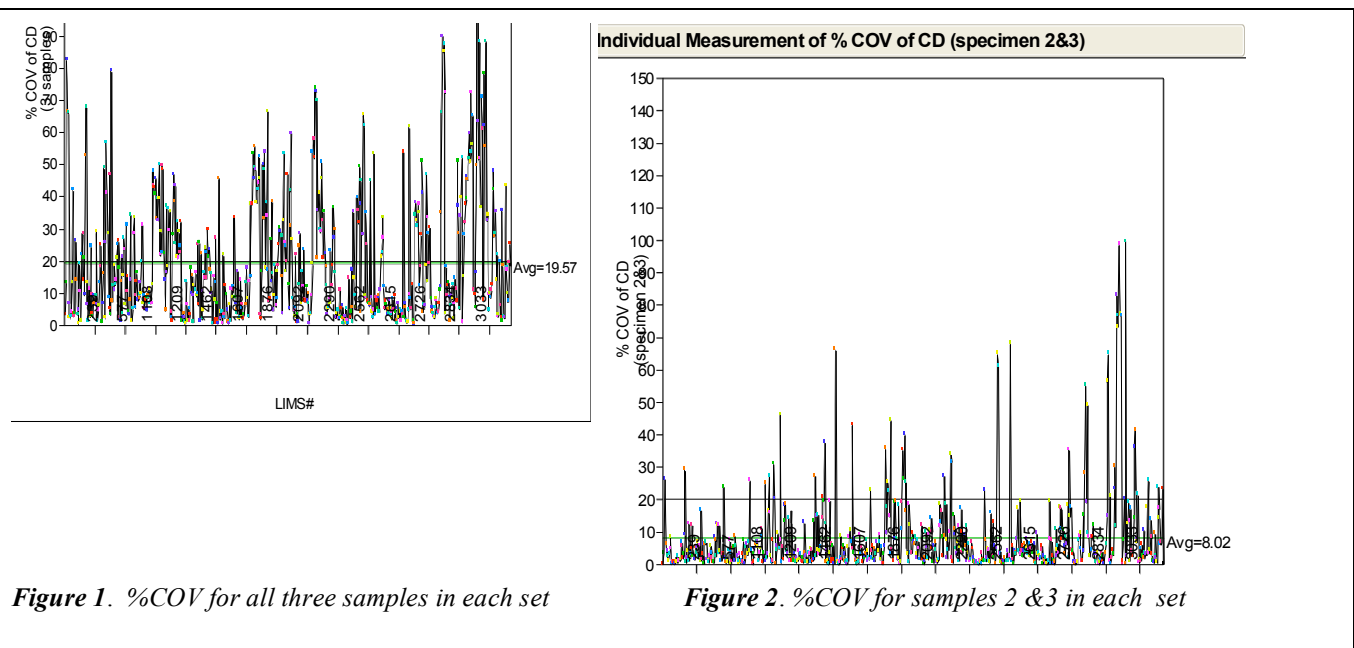
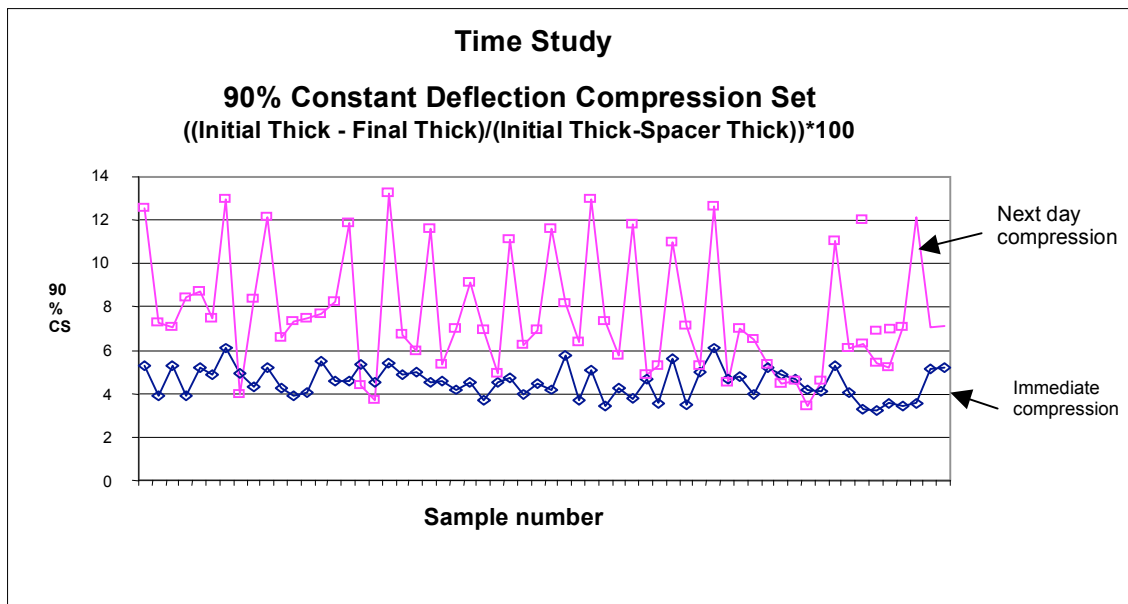


Figure 1. %COV for all three samples in each set

Figure 2. %COV for samples 2 & 3 in each set



**Figure 3.** Effect of exposure time on 90% compression set

Figure 2 shows that eliminating the top, most light-exposed, sample from each data set improves the %COV by approximately a factor of two. The top sample appears to be largest contributor to the variability of this data. The best explanation for this observation seemed to be that the top sample is most affected by light (highest intensity exposure) and the length of exposure was uncontrolled. Exposure to light does not increase the variability; it is the differing exposure to light that causes the variability. If all sample sets had been exposed for the same duration to the same intensity of light, the variability most likely would have been similar for all sample sets.

The effect of length of exposure was demonstrated by cutting numerous samples from the same piece of slab foam and either measuring the 90% compression set immediately, or after 24 hours light exposure. The results are shown in Figure 3. The upper values (in red) are for the exposed samples. These samples had been stacked three high, as was usual.

The periodic variation in the results for the exposed samples is a result of the top sample having been exposed to more intense light. The 90% compression set measured for the exposed samples is both higher and has more variability than those samples cut and immediately compressed.

A simple experiment was devised to show the effect of light intensity. Samples of the slab foam used in the previous experiment were stacked three high as usual. Some stacks were left on the bench top, others were put under a shelf, while the third group was placed in a dark cabinet. 90% compression sets were measured. The results are shown in Figure 4. Exposure to more intense light had a similar effect to longer exposure in less intense light. The effect of stacking can be seen (the samples were tested such that the order top, middle, bottom, top, middle, bottom and so on was preserved).

Deformation of the foam samples sometimes occurs during compression set testing. The most common deformation is called "pillowing" or "edge-welding", in which the edges and corners of the sample have taken a greater set than the interior. Exposing foam samples to light predisposes the foam to edge-welding, as illustrated in Figure 5. Using the same slab foam and conditions as in Figures 3 and 4, samples with either longer term exposure or exposure to more intense light showed a propensity to edge-welding during compression. Samples which show edge welding can often be restored to a rectilinear shape by gently squeezing the samples. This indicates that light does not induce a major change in the chemical structure of the foam since the distortion can be reversed by crushing or squeezing the samples.

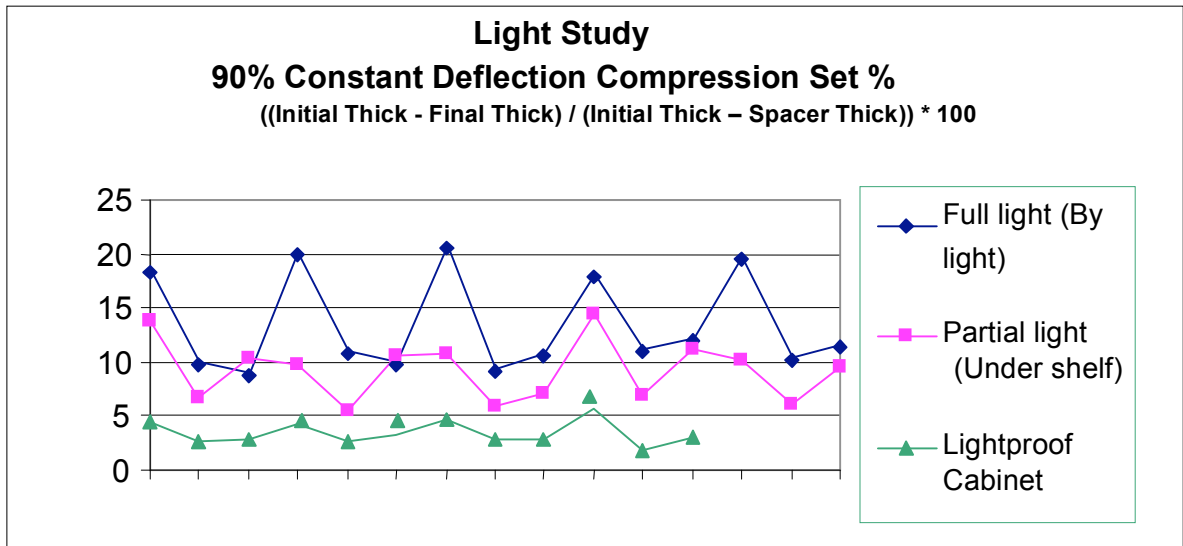


Figure 4. Effect of exposure time and light intensity on 90% compression set

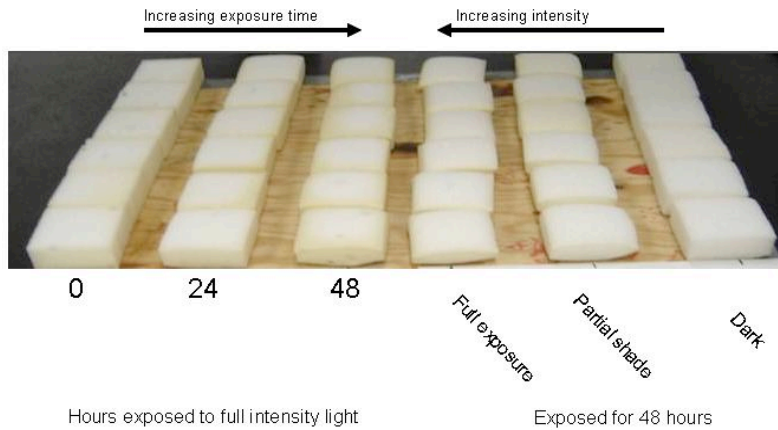


Figure 5. Illustration of the effect of light on foam deformation after 90% compression

It must be noted that the slab foam used in this study was prepared as part of a research program on a semi-production scale, continuous foam machine and may not be representative of commercially produced foam. However, we do believe that the effect of light on compression set results is a general phenomenon: the magnitude of the effect likely varies from foam to foam.

Much of the historical data and all of the preceding exploratory work involved slab foam subjected to 90% dry heat compression set testing at 70° C. Additional work was done, expanding the scope of the study to molded foam and other testing procedures.

## Lab #2

Historical data from a lab which typically tested a greater proportion of molded foam from commercial production lines did not show the same clear trends seen in Figures 1 and 2. There were indications that differing levels of light exposure as a result of stacking samples increased the set taken when the samples were compressed by 50% and 75%.

A preliminary study using short (24 hour) exposure time supported the effect of light on compression sets. A longer study involving three different molded foams and four levels of exposure (normal stacking on bench top, covered by a sheet of cardboard, exposed to sunlight through a window and enclosed in a black plastic bag). This study was done over a vacation period in which the total elapsed time was 19 days, but lab lights were on for 7.5 days. The results are shown in Table 1 with each number being the average of three separate measurements.

*Table 1. The effect of light on 75% compression sets of molded foam*

|   | Exposure                                | Foam #1 | Foam #2 | Foam #3 |
|---|---|---------|---------|---------|
| 1 | Normal stacking                         | 19.9    | 6.1     | 6.0     |
| 2 | Cardboard covered                       | 19.4    | 5.8     | 5.7     |
| 3 | Near window                             | 19.5    | 6.5     | 6.2     |
| 4 | Black bag                               | 16.7    | 5.1     | 5.0     |
| 5 | Average Rows 1-3                        | 19.6    | 6.1     | 5.9     |
|   | Relative difference Between Row 5 and 4 | 20%     | 16.5%   | 15.5%   |

These results show little difference among those samples exposed to some light, but a significant difference between these samples and ones completely protected from light (black bag). Samples protected from light exposure had compression sets 15 to 20% lower compared to samples with some light exposure.

A more extensive study was conducted using the same foams evaluated in Table 1 above. Samples were either tested immediately after cutting or they were left exposed to lab fluorescent lighting on the bench top (total time 168 hours with lights on for 112 hours). All measurements were done in triplicate and the numbers given are the average of those three values with the range given in parentheses. The results are shown in Table 2. Three different deflections were used in the dry compression set measurements (50%, 75% and 90%), wet set at 50% deflection (50 WS in Table 2), and humid aged compression sets (HACS) were done at 50 and 75 % deflection. The last three columns are the difference between the measured compression sets, with a positive value indicating that exposure to light caused an increase in compression set.

*Table 2. Effects of light on various types of compression tests*

| % Deflection | Immediate Compression (IC) |           |           | Light Exposed    |          |           | Difference (LE-IC) |         |         |
|--------------|----------------------------|-----------|-----------|------------------|----------|-----------|--------------------|---------|---------|
|              | Foam #1                    | Foam #2   | Foam #3   | Foam #1          | Foam #2  | Foam #3   | Foam #1            | Foam #2 | Foam #3 |
| 50 CS        | 16.9(0.8)                  | 5.0(0.2)  | 4.9(01)   | 19.8(06)         | 6.0(0.2) | 5.89(0)   | 2.9                | 1.0     | 0.9     |
| 75 CS        | 21.5(1.2)                  | 6.4(02)   | 6.2(03)   | <b>43</b>        | 8.2(0.4) | 7.9(0.1)  | <b>22</b>          | 1.8     | 1.7     |
| 90 CS        | 26.2(1.1)                  | 7.3(0.2)  | 7.3(0.2)  | <b>46</b>        | 8.6(0.1) | 8.5(0.9)  | <b>20</b>          | 1.3     | 1.3     |
| 50 WS        | 26.0(1.3)                  | 10.2(0.6) | 9.8(1.1)  | <b>28.8(2.4)</b> | 12.1(05) | 10.8(1.0) | <b>2.8</b>         | 1.9     | 1.0     |
| 75 HACS      | 36.6(3.0)                  | 10.2(0.2) | 10.1(0.6) | 33.4(08)         | 9.8(07)  | 10.1(0.1) | -3.2               | -0.4    | 0.0     |
| 50 HACS      | 36.1(1.1)                  | 12.0(0.4) | 14.9(0.6) | 36.4(07)         | 12.7(13) | 15.5(11)  | 0.3                | 0.7     | 0.6     |

Foam #1, after exposure to light and compression at 75%, 90% (dry) and 50% (wet), exhibited edge-welding as described in the work from Lab #1 and shown in Figure 5. This deformation makes the measured values (in bold) unreliable and the numerical results should be treated accordingly.

These results show that light exposure can affect the results for the three deflections used in dry compression set testing and also for 50% deflection wet set testing. The effect on HACS is so small and variable as to be insignificant.

Deeply colored foam (colorant intentionally added) was used in the same experiment as described immediately above. Exposure of this type of foam to light had no significant impact whatsoever on any of the compressive tests. This clearly demonstrates that it is light alone which causes the foam to have different compression set values. The internal colorant acts like “sun block”, protecting the foam from the effect of the visible radiation.

The surprising effect of light on compression sets led to the question “Are any other foam properties affected by exposure to light?” The following work was intended to provide the answer.

## FOAM HARDNESS

The same three foams used in the earlier work in Lab #2 were either exposed to normal light or protected from light. The averages of three CFD (in kPa) measurements for each foam and deflection are presented in Table 3. There is essentially no effect of light on foam hardness.

*Table 3. Effect of light on foam hardness as measured by CFD*

| kPa            | Protected from Light (P) |         |         | Exposed to Light (E) |         |         | Difference (E-P) |         |         |
|----------------|--------------------------|---------|---------|----------------------|---------|---------|------------------|---------|---------|
| Deflection     | Foam #1                  | Foam #2 | Foam #3 | Foam #1              | Foam #2 | Foam #3 | Foam #1          | Foam #2 | Foam #3 |
| <b>25% CFD</b> | 14.4                     | 4.6     | 8.2     | 15.1                 | 4.6     | 8.5     | 0.7              | 0       | 0.3     |
| <b>50% CFD</b> | 20.6                     | 6.8     | 12.5    | 21.5                 | 6.8     | 12.9    | 0.9              | 0       | 0.4     |
| <b>75% CFD</b> | 33.3                     | 11.0    | 20.8    | 34.5                 | 11.2    | 21.5    | 1.2              | 0.2     | 0.7     |

## RESILIENCY (BALL REBOUND)

Three different density foam samples were selected to study the effect of light on ball rebound. For each foam, one set of samples was stored in black plastic bags while the other set was exposed to light on the lab bench top. Ball rebound was measured for each set of foams at intervals up to 33 days. The results are shown in Table 4. There is essentially no effect of light on foam resiliency.

*Table 4. The effect of light on foam resiliency as measured by ball rebound*

| Time (days) | Foam 37 kg/m <sup>3</sup> |         | Foam 45 kg/m <sup>3</sup> |         | Foam 70 kg/m <sup>3</sup> |         |
|-------------|---------------------------|---------|---------------------------|---------|---------------------------|---------|
|             | Protected                 | Exposed | Protected                 | Exposed | Protected                 | Exposed |
| <b>1</b>    |                           |         |                           |         | 67                        | 67      |
| <b>3</b>    | 33                        | 34      | 35                        | 33      |                           |         |
| <b>13</b>   | 35                        | 36      | 35                        | 35      | 66                        | 66      |
| <b>33</b>   | 36                        | 36      | 34                        | 34      | 65                        | 66      |

## FOAM SWELLING

Samples used in the Foam Hardness (CFD) work, after 33 days elapsed time, were immersed in petroleum ether. All the foams immediately swelled. There was no observed difference in swelling of the samples as a result of light exposure.

## MICROSCOPIC EXAMINATION

Foams from the Compression Set and Resiliency work were examined using a 75X optical microscope. Structure of the skin and internal cells did not show any effects of light exposure (except for some yellowing).

## Lab #3

Accelerated aging studies were conducted by Lab #3 using a Q Panel chamber equipped with UVA 351 lamps, which simulate sunlight through glass. Foam samples were irradiated using conditions specified in ASTM D4329 Cycle A for 24 hours. These samples were then subjected to dry compression set at 50% and 90% deflection. Duplicate samples were used in this phase of the study and the averaged results are shown in Table 5. The range for each pair of values was quite low, as can be seen from the values given in brackets in the Table. The Relative Difference is the increase in compression set as a result of Q Panel exposure relative to the non-exposed result. The accelerated aging clearly has a more dramatic effect on compression set than ambient lab lighting; however, the very large relative differences (200-300%) are partially due to the low non-exposed compression sets.

*Table 5. Effect of accelerated aging (more intense light) on foam compression sets*

|               | Non-exposed (N) |                | Exposed (Q Panel) |                | Difference (Q panel –N) |         | Relative Difference |         |
|---------------|-----------------|----------------|-------------------|----------------|-------------------------|---------|---------------------|---------|
|               | Foam #1         | Foam #2        | Foam #1           | Foam #2        | Foam #1                 | Foam #2 | Foam #1             | Foam #2 |
| <b>50% CS</b> | 0.49<br>(0)     | 0.45<br>(0.3)  | 1.61<br>(0.48)    | 1.67<br>(0.40) | 1.12                    | 1.20    | 230%                | 270%    |
| <b>90% CS</b> | 1.12<br>(0.09)  | 0.93<br>(0.13) | 4.02<br>(0.35)    | 3.74<br>(0.20) | 2.90                    | 2.81    | 260%                | 300%    |

## TENSILE, TEAR and ELONGATION

In a second experiment performed in Lab #3, additional samples were aged in the Q Panel chamber in a similar fashion as was described above for 72 hours. 50 mm thick slices were cut off from the yellowed surface of the foams and samples were prepared for tensile, tear and elongation testing. The tensile samples were cut using the ASTM D3574 Die and the tear samples were cut from the foams with the ASTM D624 Die C. Additional specimens were cut from samples that were kept out of the light. In each case three specimens were tested and the average is reported. Table 6 shows the comparisons between samples with and without accelerated light aging. The effect of the light on elongation and tear strength were minimal. However, the foams lost about 10% of their tensile strength due to light exposure.

*Table 6. Effect of accelerated aging (more intense light) on foam tensile, tear and elongation.*

| Sample               | Tensile, kPa |      | Elongation, % |     | Die C Tear, N/m |     |
|----------------------|--------------|------|---------------|-----|-----------------|-----|
|                      | 1            | 2    | 1             | 2   | 1               | 2   |
| <b>Non-Exposed</b>   | 180          | 137  | 111           | 103 | 752             | 673 |
| <b>Exposed (QUV)</b> | 159          | 119  | 108           | 101 | 738             | 663 |
| <b>% Loss</b>        | 11.7         | 13.1 | 2.7           | 1.9 | 1.9             | 1.5 |

## DISCUSSION

Analysis of historical data (Figures 1 and 2) indicated that exposure to ambient lab light had an impact on compression set results, specifically on the variability of those results. Light exposure *per se* does not account for the variability; it is the inconsistent exposure that gives rise to the variability in the compression set results. During the acquisition of the historical data it was not recognized that light exposure had any effect on compression sets (or any other property except yellowing) and so no effort was made to eliminate this exposure, or even keep it constant. The length of time from a set of samples being cut and being subjected to compression depended on many factors: the work load in the lab, vacation and holiday schedules, prioritization of samples and so on. We now know that the topmost samples were most exposed to higher and variable amounts of light. This led to these samples having higher, and more variable compression sets.

Numerous data, presented in Figures 3, 4 and 5 and Tables 1, 2 and 5 demonstrate the effect of controlled light exposure on compression sets. Increasing light exposure, either by increasing the duration of exposure or the intensity of the light, increased the amount of compression set measured. Protecting the foam from light by physically blocking the light (experiments involving shading the samples or putting them in light-proof containers), minimizing exposure time by processing cut foams immediately, or by limiting the effect of light at a microscopic or chemical level (experiments with foam containing a colorant) all decreased or eliminated the effect of light on compression set.

Light can have a large impact on the deformation of foam samples during compression, as illustrated in Figure 1. Light does not penetrate the foam uniformly: it is absorbed most by the outermost layers. One would therefore expect that foam in these outermost layers would be most affected by light, in this case the effect being to increase compression set. When

these outermost layers experience a significantly higher set than the interior of the sample edge-welding or pillowing results. Edge-welding is more likely to occur in foams which have inherently high compression sets.

The observation that light-exposed, edge-welded foams can be restored to rectilinear shapes and no changes in cell structure as a result of light exposure were observed with an optical microscope give some clues about the nature of the effect of light on foam. One potential explanation is that exposure to light increases the tackiness of some of the foam surfaces or otherwise predisposes the cellular structure to cell wall adhesion and thus surface-to-surface bonding. This increased tackiness would be manifested under conditions where foam surfaces were forced into contact long enough for these interactions to occur. This is what happens during compression set testing where the foam is compressed for many hours (eg 22 hours at 70°C). It is not observed in hardness testing or ball rebound since the compression experienced by the foam in these cases is transient. It is also possible that such light-induced tackiness is removed by the annealing process that foam undergoes when subject to HACS treatment. The proposed “tacky surface” hypothesis can explain most of the observations made in this work. This hypothesis would predict that properties such as tensile, tear and elongation would not be greatly affected by light exposure. The results in Table 6 show this to be essentially true, although there was some apparent loss in tensile strength due to accelerated light exposure.

We are unprepared at this point to propose a mechanism by which light could induce this tackiness. That is a subject for a more fundamental study and the authors would encourage anyone with the inclination and ability to pursue this to do so.

## CONCLUSIONS

Exposure of polyurethane foam to fluorescent light causes it to yellow, a readily and consistently observed phenomenon. Most other aspects of foam are unaffected by light exposure, including load-bearing (hardness), resiliency, and humid aged compression set. Compression sets of non-autoclaved foams were increased by exposure of the foam to light from standard laboratory fluorescent ceiling lights. The effect was positively correlated to intensity and exposure time. Edge welding or pillowing of compressed samples also increased with increased exposure to light. Foam samples containing light-absorbing material were not affected by exposure to light, as would be expected. A “surface tackiness” hypothesis has been proposed to explain the observations made in this work. Part of this hypothesis requires that the foam surfaces be brought into intimate contact at some point for the effect of light to be observed in test results.

The observed effect of light on compression set is a testing laboratory concern rather than an issue of foam durability in car seats or other applications. Variable exposure of lab samples to light can lead to increased error or even necessitate retesting of samples in cases where compression sets are close to specification limits. We recommend that samples be compressed immediately after cutting, or if that is not practical, that the cut samples be stored in lightproof containers until compression can be done.

Foam is rarely exposed to light for prolonged periods before being assembled into seats, mattresses etc and thus being covered and protected from light. Additionally, although this has not been tested, prolonged light exposure will cause the foam to yellow, making the effect of light self-limiting.

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## BIOGRAPHIES

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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 Quality Laboratory, Woodbridge, Ontario, Canada. He is now a consultant to the polyurethane industry and can be reached at ronblair@hotmail.com.

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Jim McEvoy has worked for Johnson Controls for 17 years in various roles, most recently focusing on polyurethane foam development. He received his Bachelor of Science in Chemistry from the University of Wisconsin and MBA in Managing Technology from the University of Phoenix. His entire career has been spent in either polyurethane foam manufacture or seating development.

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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.

### **Marcela Rusan de Priamus**



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### **Carol Wright**



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