

Auto Seating Lightweighting Using Solstice® Liquid Blowing Agent (HFO 1233zd(E))

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ABSTRACT

The lightweighting of auto components is a crucial strategy for OEMs to achieve increasingly challenging CAFÉ requirements. Research from MIT has found that every 10% reduction in passenger vehicle weight reduces fuel consumption by about 7%. Since fuel economy requirements have already increased by 18% from MY 2012 to 2017, the weight savings strategies that are easiest to implement have largely been exhausted. Seating is the largest interior component by weight, but the foam is often overlooked from lightweighting consideration due to the perception that higher weight, higher density seating is an important aspect of the vehicle's comfort. It has become almost a truism that the physical properties associated with seating comfort -- load bearing, resilience, durability - are directly related to foam density. A new auxiliary blowing agent known chemically as HFO 1233zd(E) is commercially available as Solstice® LBA. Using 2 -4 parts per hundred polyol has been found to lower weight in molded seating foam by 10 to 20%, while maintaining properties related to comfort and durability. This hydrofluoro olefin (HFO) is liquid near room temperature (b. p. = 19C), non-ozone depleting, with GWP of 1, non-flammable (ASTM E-681), VOC-exempt by the EPA. Safe working conditions, well below the exposure limit of 800 ppm (TWA/TLV), can be maintained with the air exhaust systems commonly in-use in auto seating foam manufacturing. In VDA 278 testing, no residual Solstice LBA has been detected in the foam. In addition, Solstice LBA lowers the viscosity of the liquid polyurethane blend, improving foam flow in the mold. Better mold-flow assists intricate parts to be filled with less foam, providing a second pathway to weight reduction. Using small amounts of Solstice LBA with little or no reformulation can provide weight savings in intermediate sized autos of 1.1 to 2.1 kg.

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INTRODUCTION

The CAFE (Corporate Average Fuel Economy) standard was first established in 1975 for MY1978 at 18.0 mpg for passenger cars and 17.2 mpg in MY1979 for light trucks. It was modified in 2007 to increase future fuel economy and to take into account vehicles of different sizes or "footprints". New rules were finalized by the U.S. NHTSA with agreement from the auto industry in 2012. The final rules for fuel economy from MY2017 to MY 2025 by the NHTSA were combined with rules by the EPA to control greenhouse gas emissions (GHG) by autos and light trucks. This is known as the National Program [1]. This resulted in the passenger vehicle fleet average increasing from 27.5 mpg in MY2010 to 34.1 mpg in MY2014, or 24%. Under these rules the passenger fleet average is due to increase to 54.1 mpg by MY2025. Light trucks are expected to increase fuel economy from 26.3 mpg in MY2014 to 39.3 mpg by MY2025 [2] [3].

There is compliance flexibility built into the program by allowing credit banking on models that outperform the standard, credits for reduced CO₂ equivalents from air conditioning improvements and the factoring-in of the performance of hybrid/electrical vehicles. Even so, compliance with the CAFE standards between MY 2017 and MY 2025 has necessitated that the auto industry examine every known

method to improve fuel efficiency. It has already implemented many of the cost-effective improvements such as substituting lighter weight aluminum for steel and other lightweighting design changes discussed below.

Lightweighting is the term being applied to the removing of mass from the vehicle. This is the next most effective strategy for improving fuel economy after improving engine and drive-train efficiencies. Two key strategies for achieving mass reduction are changing the body design to require less material and substituting lighter-weight materials for heavier ones. Re-designing the vehicle's body structure to use less material or substituting a lighter weight material are risky, expensive and take several years to complete. The quicker and less risky approach involves taking mass out of nonstructural areas such as interiors. But, the most apparent methods for lightweighting such as substituting plastic and glass reinforced sheet molding compound (SMC) for non-structural interior metal parts have been already accomplished [4].

However, seating foam is the largest non-structural part in the vehicle. The average mid-size vehicle contains 11.4 kg of seat foam. Usually it is not considered a candidate for lightweighting due to the

current “truism” that heavier, higher density foam provides more comfort and durability to the seating. Recent research shows this may no longer be true.

A new auxiliary blowing agent known chemically as HFO 1233zd(E) is now commercially available as Solstice LBA. Our research shows that it can be added to existing molded seating foam formulations at just 2 to 4 parts per hundred polyol (pphp) to reduce foam weight by 10%. This can be accomplished with no change to the polyurethane foam chemistry while the foam retains the key physical properties that are measured to predict comfort and durability. A further foam weight reduction of up to 20% is possible with small formulation modifications to preserve these key foam properties. This can result in weight savings of 1.1 kg to 2.2 kg per vehicle. In light of the fact that with lightweighting, “every gram counts” [5], reducing seating foam weight without reducing comfort and durability is now possible.

Solstice LBA, unlike previously available auxiliary blowing agents, is non-flammable (ASTM E681), VOC-exempt by the EPA, liquid near room temperature (b. p. = 19C), non-ozone depleting, and has a GWP of 1. Safe working conditions, well below the exposure limit of 800 ppm (TWA/TLV), can be maintained with the air exhaust systems commonly in-use in auto seating foam manufacturing. In VDA 278 testing, no residual Solstice LBA has been detected in the foam.

Table 1. Physical Properties of Solstice LBA (HFO 1233zd(E))

Chemical Name	Trans- 1-chloro-3,3,3-trifluoropropene
Molecular Formula	(E)CF ₃ -CH=CClH
CAS Number	102687-65-0
Molecular Weight [g/mol]	130
Atmospheric Life	26 Days
GWP	1
ODP	~0
Boiling Point	19 °C / 66 °F
Flash Point	None
Vapor Flame Limits	None
UN Number	UN 3163
US DOT Hazard Class	LIQUEFIED GAS, N.O.S.
TLV/TWA	800 ppm
U.S. EPA Ground-level ozone VOC	Exempt Compound

EXPERIMENTAL

Seat Foam Testing

During the early 2000’s a technical working group was formed from both the auto and foam industries. Their mission was to develop a standardized series of test methods from those already in use that characterize the comfort and durability properties of flexible seating foam. The result is ASTM D3574. It defines 18 test methods and 6 appendices [6]. Of these, four tests are primarily used to initially characterize the foam: density - overall and core, 50% compression set (50°C/95% RH), resilience and indentation force deflection (IFD).

For samples too small to run IFD, compression force deflection (CFD) is typically substituted. During foam development, blocks of foam instead of seats are molded so that testing is more comparable between formulations. However in seat foam manufacture, certain properties such as density and IFD are purposely varied within certain parts of the seating pad to improve support and comfort.

Density is typically the initial property of the foam to be measured. The contrast between the overall density of the block and the core density shows the relative amount of cell compaction at the surface or “skin”. The industry often uses density as a surrogate for defining the quality of the foam.

Tensile and elongation are measured together in a test that pulls apart a standard dumbbell-shaped foam piece. The results of this test, especially elongation are influenced by the cell size (smaller is better) and uniformity of foam. As the foam is stretched, the tensile strength approaches maximum near the modulus of the polyurethane. Irregular or large cells will tear at this point. Smaller celled, more uniform foam will continue to stretch at the modulus point another 20 to 40 percent with little increase in the tensile strength. Thus machine-made foam - with more uniformity and smaller cells, will have higher elongation than hand-mixed foam.

The feeling of hardness/softness or “load-bearing properties” of the foam is measured by IFD, Indentation Force Deflection (sometimes called ILD - Indentation Load Deflection) using ASTM D3574 Test B1. In this test, a flat circular indenter, 200 mm (~8 in) in diameter is pushed into the foam sample at 50 mm/ min. The resistance of the foam (Newtons of force) to the indentation force is typically measured at foam deflections of 25% and 65%. Typically the sample is 380 mm x 380 mm x 100 mm. For comparison purposes, smaller samples can be tested as long as they are all similarly sized, larger than the surface area of the indenter, and the size of the sample is reported.

Compression Force Deflection (CFD) ASTM D3574 Test C is measured on foam samples that are smaller in surface area than the indenter. The typical sample size is 50 mm x 50 mm x 25 mm. The entire sample is compressed to 50% of the original thickness. The force (N) to compress the foam is measured. As a surrogate for IFD testing for smaller samples, 25% and 65% compression can also be measured. The surface area is also measured, and the results are reported as force per unit of surface area in kPa (psi).

The Support Factor, Comfort Factor or SAG Factor are different names for the same property. They are reported using the results from either IFD or CFD by dividing the 65% deflection by the 25% deflection result. Typically using IFD will result in more consistent and realistic Comfort Factor ratios than CFD.

Hysteresis (ASTM D3574 Appendix X6) is a measure of the short-term memory loss of the foam. It is useful as a predictor of the durability of the foam. A procedure similar to the IFD test is run with energy of indentation as the initial or “loading” energy. As the indenter rises off or “unloads” from the foam, the energy of the foam pushing against the indenter is also measured. The percent difference in the areas under the loading minus the unloading curves is determined as % hysteresis of the foam.

Resilience is another measure of foam memory. It is also known as a “ball drop” test. A 16 mm diameter steel ball is dropped through a clear tube onto a 50 mm thick piece of flexible foam. The distance that the ball returns on the bounce as a percentage of the original drop height is measured as the foam resilience.

Long-term durability is simulated by Dynamic Fatigue by Constant Force Pounding (ASTM D3574 Test I3). A constant force of 750 N (167 lb) of indentation is cycled into the foam 80,000 times, usually at 70 cycles per minute. Before and after the pounding test, two properties are measured: IFD at 40% and foam thickness. The difference is measured either an hour after the completion of the cycles, or after 24 hours, depending on the customer’s spec.

Compression set at 50% compression (ASTM D3574 Test D) is also used as a short-term test to predict long-term foam durability. Uniform samples 25 mm thick are compressed 50% between metal plates. The compression is mechanically maintained for 22 hours at an elevated temperature and humidity. When the samples are removed from the plates, they are allowed to decompress for 45 minutes at room temperature. The difference between the original thickness and the final decompressed thickness expressed as a percentage is known as the Compression Set percentage.

This test is often used in combination with humid pre-aging of the foam in a steam autoclave at either 105C for 3 hours or 120C for 5 hours. Alternatively the entire test can be run in a chamber capable of maintain high humidity at various temperatures. Typically, 50C is used at 95% relative humidity. The use of this test as a durability predictor comes from several angles. Historically, seating foam has prematurely aged in vehicles located in hot-humid climates such as the southeastern U.S. Secondly even in other parts of the country, auto interiors heat up considerably during the summer. The addition of a person compressing the seat and adding body moisture is simulated by these tests. If these in-use compression conditions cause the seating foam to change its shape, it would negate the comfort expected by the original seat design.

Laboratory Foam Production Methods

Foam samples made for this work are either free-rise foam or molded foam. Both types of foam are hand-mixed by a rotary mixer at approximately 3000 rpm for 8 seconds. The method used for hand-mixed foam is the following:

1. Pre-weigh the polyol blend
2. If applicable, add the pre-determined amount of Solstice LBA, being careful to spin the material from the mixer back into the container. Add back LBA to the polyol blend that evaporates during mixing.
3. Pre-weigh the MDI material. Add it to the polyol blend using the timing method described in the Honeywell SOP: BRLTS005 [7].
4. Immediately start the mixer and place the combined material under the mixer for 8 seconds.
5. Immediately pour the mixed material into the open mold for free-rise foam or closed mold for molded foam, depending on the experiment.

RESULTS AND DISCUSSION

One of the purposes of this work is to examine the truism that lowering molded foam density worsens its durability and comfort properties, and to show this no longer is true.

The usefulness of this idea has been due to the nearly-exclusive use of water/CO₂ as the only foam blowing agent in molded seating foam. As water reacts with diisocyanate it forms CO₂ and concurrently adds a urea group into the polyurethane polymer. As the density is decreased by adding more water, the amount of polyurethane in the struts of the foam is expected to decrease as the urea content increases. Also, importantly, the percentage of urea to urethane in the foam increases substantially. These changes lower resilience and elongation and increases hysteresis. The foam can acquire a “boardy” feeling. Increasing urea also tends to hurt foam durability as measured by wet compression set and constant force pounding tests.

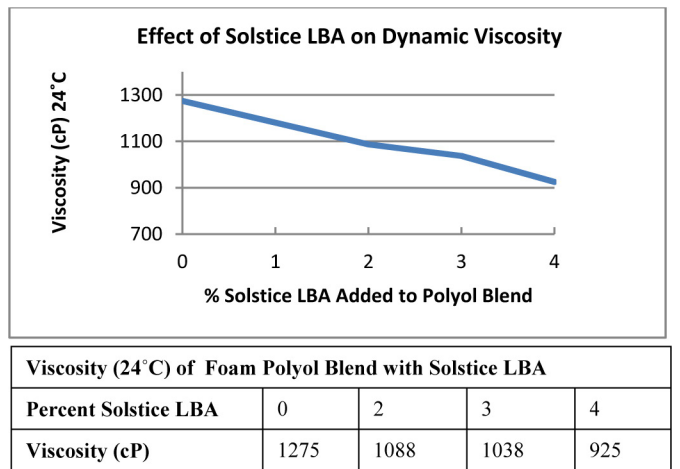
Effect on the Viscosity of Polyol Blends

In the reaction of polyol, water and diisocyanate to make polyurethane foam, the build-up of urea groups occurs quickly, causing a rapid increase in foam viscosity. When attempting to use more water/CO₂ to lower foam density, the additional urea groups cause the foam viscosity to increase so quickly and to so great of an extent, that the foam no longer fills complex molds.

In contrast, Solstice LBA is a physical foam blowing agent. It is used as an auxiliary blowing agent to water/CO₂. In its liquid state Solstice LBA solubilizes into the foam components. Since Solstice LBA does not react with the diisocyanate it lowers the viscosity of the initial foam blend. Depending on the formulation, the viscosity can be decreased by 20-25% with a dosing of 2% of the total foam.

Table 2 shows the effect of various amounts of Solstice LBA on the viscosity of the polyol blend.

Table 2. Effect of Solstice LBA on Polyol Dynamic Viscosity



During the foaming reaction, the exotherm created vaporizes the Solstice LBA. In the gaseous state, it adds pressure to the CO₂ forming from the water/diisocyanate reaction. Depending on the foam molding conditions, this additional gas pressure can be utilized to