

Advanced Comfort™ Seating: A revolution in seating performance for the automotive industry®

Chris Skinner, Automotive Platform Manager; Christophe Ponce, Product Manager (Seating)

Huntsman Polyurethanes
Everslaan 45, B3078 Everberg, Belgium

1. Abstract

The paper will first describe a methodology for determining critical dynamic performance features defining comfort in a PUR automotive seating system and then the application of this methodology to a range of seating systems from Huntsman Polyurethanes. A range of critical tests demonstrate the performance features of versatile, HR⁺ and Advanced Comfort™ systems correlated against a broad density range allowing an effective comparison of the different systems. The data confirms that the Advanced Comfort™ System introduced by Huntsman offers a step change in performance for automotive seating systems.¹

2. Introduction

Within the European automotive market there are a number of identifiable technological and economic trends that are critical when considering a proposal to supply technology to this market.¹ In general, the listed factors are driving the current & future development of PUR technology can be summarised as:

- Requirement for improved “comfort” within vehicles (ergonomic² / acoustic)
- Requirement for enhanced safety features & improved driving dynamics within vehicles
- Requirement for continued reduction in cost / weight whilst providing enhanced technical effects
- Movement towards true modularity in design and economic efficiency
- Movement toward alternative sources of propulsion (electrical, hydrogen)
- Movement away from traditional western assembly towards eastern European based operations³
- Extending service life or MTBF

Comfort is more than ever one of the major factors of car performance that can be easily characterised by the consumer to help differentiate vehicles within a similar class. Within the framework of automotive comfort the seating systems contribute disproportionately to the individual customer’s perception of the vehicle performance.⁴ The seat also has other vital roles such as ensuring the safety of the passengers whilst provide adequate postural support and, as a consequence, it has become a significant focus of all elements of the automotive production chain. This has resulted in increasing partnership between not only car manufacturers (OEMs) and automotive system manufacturers (Tier 1 / Tier 2) but also between the system manufacturers and the raw material suppliers. It is also important to understand this requirement for improved comfort in light of the *modus operandii* of the automotive industry characterised by stringent customer requirements, particularly those of delivering performance and durability whilst systematically optimising the cost of any technical solution.

To achieve these sometimes convergent targets required by the automotive market it is important for a raw materials supplier to truly understand the relationship between the chemistry, structure, morphology and physical properties of an individual seating foam technology they intend to deliver to the market as only then can the development of relevant performance be achieved under conditions that are accepted by the automotive market. The following paper will describe the methodology developed within Huntsman to characterise and guide the development of comfort performance from automotive seating systems. The

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¹ The information and recommendations in this paper are, to the best of our knowledge, accurate at the date of publication. Nothing herein is to be construed as a warranty express or implied. In all cases, it is the responsibility of the users to determine the application of the information or the suitability of any products for their own particular purpose.

paper will then describe the relative performance of a range of generic Huntsman Polyurethane seating system technologies current positioned within the European automotive market in terms of these testing criteria.

3. How to characterise “comfort” within automotive seating

Over the past ten years through intensive research and development in combination with some of the world’s largest automotive seating system manufacturers, Huntsman has devoted major technical effort to understanding the impact that a chemical supplier can have on the creation of comfort in an automobile.^{5,6}

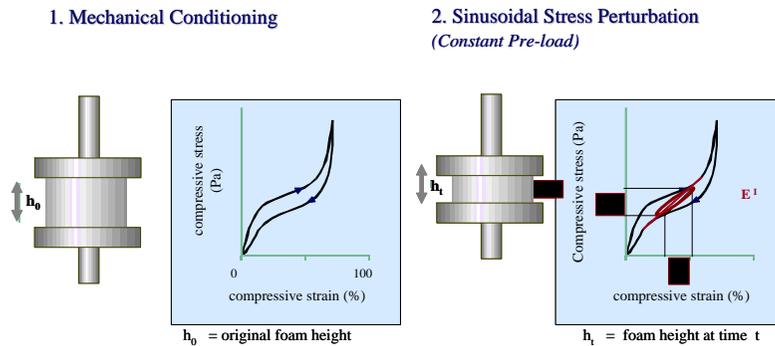
Over this time it has become generally accepted that comfort is described as a combination of both static and dynamic properties that characterise different stages of an automotive journey.⁷ The static elements of comfort or “show room feel” rely upon high resilience combined with surface “softness” whilst dynamic comfort plays a crucial role in delivering superior “ride” comfort.

A significant amount of technical effort has been expended on developing test methodologies that enable Huntsman to characterise the performance of a PUR seating foam in terms of delivering “comfort” to the end user. A critical element within this framework is the consideration that seating foam has to be evaluated in the context of someone “sitting” on the foam, i.e. the foam is actually under precompression during any test. Once at this compression, the foam is also then subjected to a range of vibration input frequencies usually expressed in terms of a power spectral density function.^{8,9,10} It is important to consider that this vibrational input is of low amplitude and can be seen as a vibrational perturbation superimposed on top of the quiescent strain.¹¹ Under typical driving conditions the combined effects of the foam compression and vibrational perturbation result in a change in the foams compression properties which can, with time, result in a change in the ride comfort.¹²

To enable the investigation of these critical parameters we at Huntsman have developed a test method to allow the fundamental characterisation of these properties over the typical ride period of 30 minutes – 2.5 hours. The basic principle of the test method is shown within *figure 1* indicating that the foam under investigation is compressed to a predetermined level and then a low amplitude sinusoidal perturbation of stress is applied where the instantaneous stress at any moment in time is given by the following formula.

$$\delta(t) = \delta_0 \exp(i\omega t)$$

Figure 1: Schematic of developed test method to characterise dynamic performance of PUR seating foam



The corresponding sinusoidal strain output defined by is recorded, where $\epsilon(t)$ is:

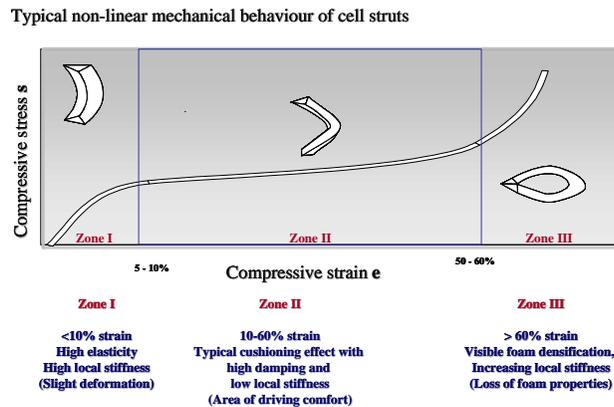
$$\epsilon(t) = \epsilon_0 \exp[i(\omega t + \delta)]$$

Throughout the test period the period load is held constant. This sinusoidal perturbation is superimposed onto an applied initial precompression which is time dependant. $\epsilon_0(t)$ can be viewed as a measure of the

foam’s dynamic creep performance. As figure 1 illustrates the resultant stress strain figure is that of a Lissajou ellipse. As a result the following parameters can therefore be measured as a function of time:

Dynamic modulus ($E'(t)$)– This is defined by the major axis of the ellipse and corresponds to the instantaneous hardness of the foam experienced by the occupant. It has been proposed that excessive changes to this value will be detectable as a change in comfort. Since, in most practical cases this value will increase an excessive change will be felt as a hardness increase or will be experienced as a “bottoming out” effect when the foam takes on a hard and dead feel. Hilyard and Cunningham showed that the dynamic properties of flexible foam are also strongly dependant of the zone in which compression occurs and as a result within the Huntsman Polyurethanes test method all measurements are conducted in Zone II (see figure 2).¹³ This has been found to more closely mimic the vast majority of automotive ride conditions which operate in the maximum compressive range of 15-50% empirically to be the most comfortable foam compression zone under static conditions.¹⁴

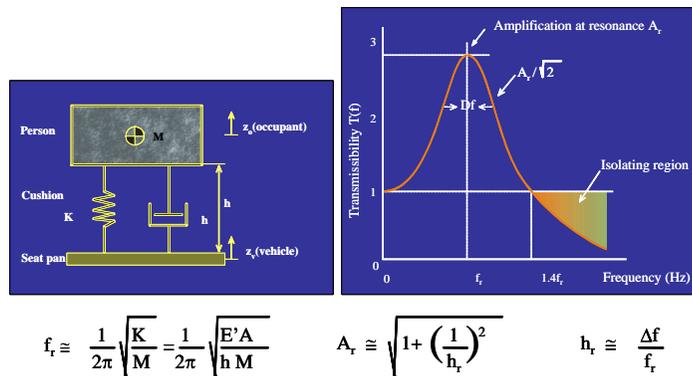
Figure 2: Key zones in compressive stress-strain curve of flexible polyurethane foam



Quiescent strain – This strain fixes the initial H point for the occupant. Excessive changes will be felt as an unacceptable H point loss.

Loss factor – The loss factor of the foam determined by the test is the real factor under the given precompression. It is the loss factor and coupled dynamic modulus that primarily controls the shape and magnitude of the seat vibrational transmissibility.

Figure 3: Representation of a one degree of freedom model of a person seated on a full depth cushion defining the factors controlling the resonance frequency of such a cushion



Resonance frequency (R_f) – The test also allows the generation of the frequency at which the maximum transfer of energy occurs within the seating construction. Using a simple one degree of freedom model represented a seating cushion as in *figure 3* the frequency can be defined as being driven by the mass of the cushion, the height of the cushion and the dynamic modulus of the cushion itself based on simple Hookian-type formula shown in *figure 3*.¹⁵ Resonance frequency is an important factor in comfort as from a vibration input it has been shown that the range of 4-8Hz is the most critical for human beings and seating systems that have their resonance frequency in this range coupled with high levels of amplification can result in serious ride discomfort.^{16,17}

Amplification – can be defined as multiple increase of energy transfer in the seating system at the point of resonance frequency. In comfort terms, the lower the amplification values the better as it will result in dampening within the seating system.

Additional, we find that the additional test crucial to an understanding of comfort is hysteresis loss.¹⁸

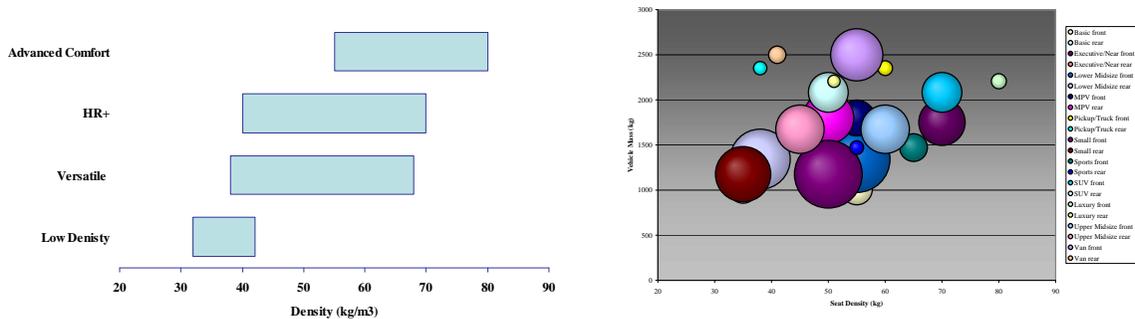
Hardness/Hysteresis loss (%) – The load bearing properties of flexible foam is measured by compression or by indentation. During the fourth (or fifth) compression cycle to 70 per cent (or 75%) the complete strain curve is recorded. The values at 25, 50, 40 and 65% are divided by the compression area and expressed as compression force in kPa to obtain the CLD for the case of a small foam sample, the ILD is directly the values expressed in N (mainly for complete seat pad). The ratio of the areas under the loading and unloading curves is then used to measure the energy absorbed during compression. This ratio is called hysteresis and provides a simple measure of the foam elasticity / resilience.

4. Characterisation of performance within a range of model systems

4.1. Description of seating systems

Currently Huntsman Polyurethanes offers a significant range of seating technology based solely on MDI isocyanates to cover many different customer requirements which often correspond directly to the model classes within the industry (*see figure 3*).

Figure 3: Schematic of the seating system technologies provide by Huntsman Polyurethanes and map of the average seating densities by segment in the European Automotive market



These can be described in three broad categories where the isocyanate chemistry has been tuned to provide performance features relevant to the corresponding customer base. For the purposes of this discussion we not include the low density systems for seating as comfort performance is less of a feature in the market segments in which it is positioned.

Versatile: These are MDI based systems formulated to provide good performance features coupled with ease of processing. Typically, the MDI system is designed to work with standard polyol technology giving the customer the freedom to source many types of polyol.

HR⁺: These are MDI based systems designed to provide high comfort performance features than the Versatile range of products. Typically, the MDI system is designed to work with standard polyol technology giving the customer the freedom to source many types of polyol.

Advanced ComfortTM: These are specialty MDI systems designed to provide the ultimate in comfort performance coupled with exceptional durability. These are supplied as fully formulated systems and are based on proprietary technology of Huntsman Polyurethanes.¹⁹

To enable a relative ranking of the performance of some components of this offer a range of model systems were prepared and then tested according to the previously described methodologies. The evaluation was made at a range of foam densities to enable the isolation of the effect of foam density on the reported results.

4.2. Preparation of model systems

A range of formulations were developed for this study to enable the direct comparison of the systems. Factors such as *M_w* of the polyols used were constant (where possible) and foams were produced under as near identical conditions in terms of index and other factors as possible. Molded blocks were produced using a Krauss Maffei high pressure machine and a square block heated aluminum mold. For each block the mold temperature was about 55-65 deg C and the demolding time was approx 3 to 4 minutes. After molding the blocks were crushed immediately after de-molding and allowed to post cure for at least one week at room temperature. Prior to testing the foam blocks were conditioned for 48hrs at 25 deg C and 50% relative humidity.

4.3. Testing conditions for model systems

For the comparison of the different seating system, the hardness was measured following the method ISO 3386. The hardness values are similar for all samples and correspond to 7.5 kPa+/-0.5kPa.

4.3.1. Hysteresis testing

Measured with the method ISO 3386 on a sample of 10*10*5cm core on the fourth cycle.

4.3.2 Dynamic Creep Testing

Each of the prepared samples were characterised under the following test conditions:

Temperature	40 deg C
Humidity	25% & 80% constant & cycled
Pre-compression level	45%
Strain amplitude	1%
Frequency	1 Hz
Test duration	16 hrs

Test configuration

- Foam with skin (10*10*5)
- Uniaxial compression
- Constant pre-load (CLD 45%)

4.3.3 Resonance Frequency & Amplification results

Each of the prepared samples were characterised under the following test conditions:

Temperature 25 deg C
 Humidity 50% constant
 Test method (Jaso method) : 50 kg Tekken type
 Sample size: 400*400*100 mm

Figure 5: Current construction of the dynamic testing equipment with Huntsman Polyurethanes

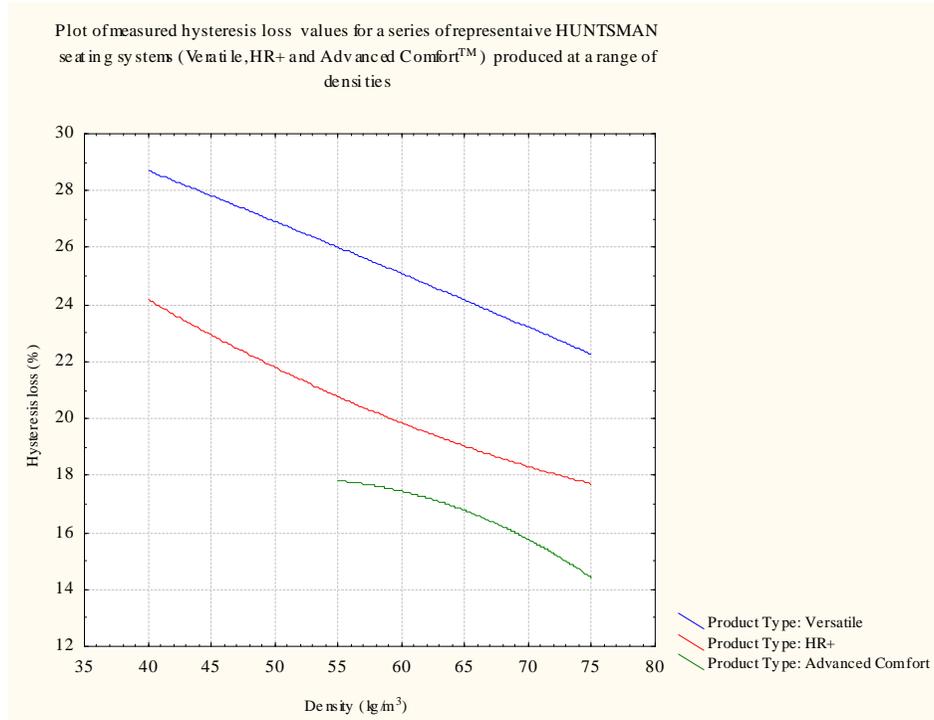


4.4. Comparative test results

4.4.1. Hysteresis loss

Analysis of the results for hysteresis loss show that as expected hysteresis decreases with increasing density of the PUR foam samples (see figure 5). Data show that the versatile and HR⁺ system appear to have the same relationship between performance & density. The Advanced ComfortTM foams clearly obey a separate relationship as expected based on the fundamentally different system technology. Literature suggests that the increase in water levels required to achieve the low densities result in an increase in disubstituted ureas in the polymer which, although enhancing the rubbery modulus, actually lead to a proportionate decrease in hysteresis performance due to the impact on durability.

Figure 5: Plot of measured hysteresis loss values for the range of Huntsman foam systems



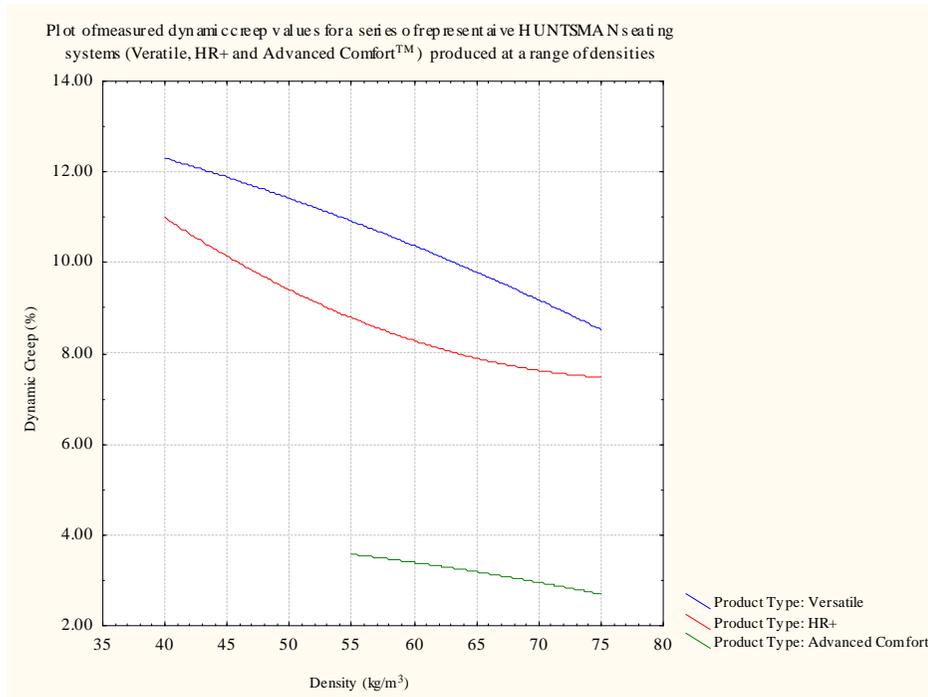
Additionally, it is important to consider the nature of the hysteresis test when considering these results in that it is effectively performed at one frequency and is therefore static in nature.

4.4.2. Dynamic test results

4.4.2.1. Dynamic creep results

The results from the dynamic creep testing of the three seating foams demonstrate the significant impact that the Advanced Comfort™ technology has on the reported values (see figure 6). This graph effectively shows the change in foam height during the test. A large change in strain is disadvantageous as it implies that the foam is less stable during these typical conditions resulting in a reduction of comfort to the user felt as H-point loss. A significant change can also lead to a vibrationally-induced feeling of discomfort.²⁰ The data show that all the MDI systems demonstrate features that will afford long term seating comfort. The progression of systems versatile – HR+ - Advanced Comfort™ enable changes in the overall level of creep performance with the Advanced Comfort system demonstrating exceptional performance which is also significantly less affected by any cyclical humidity applied to the foam pad.

Figure 6: Plot of measured dynamic creep values for the range of Huntsman foam systems

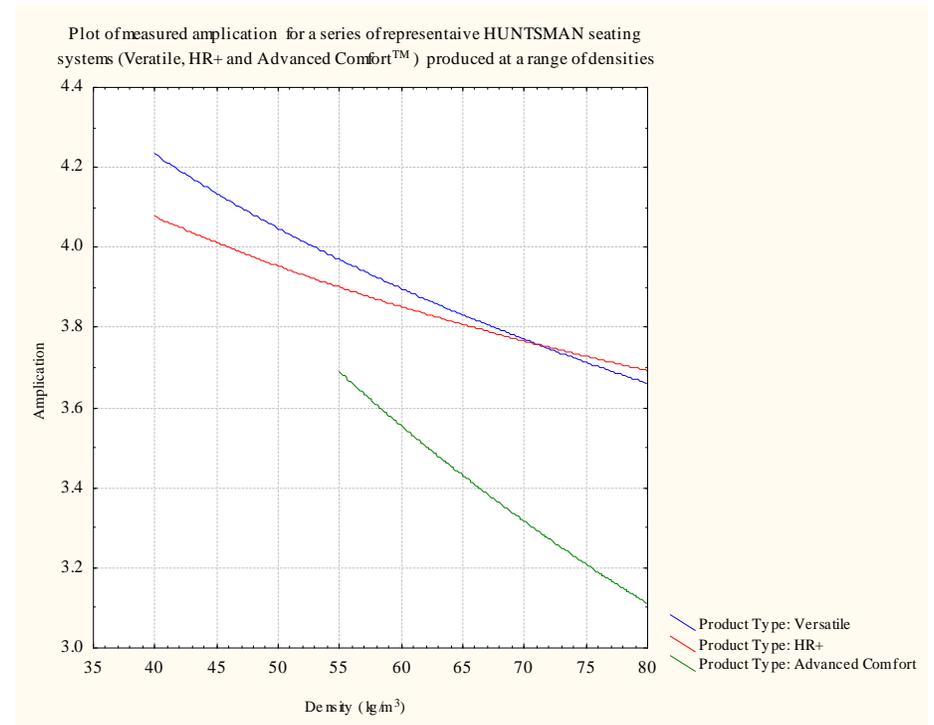
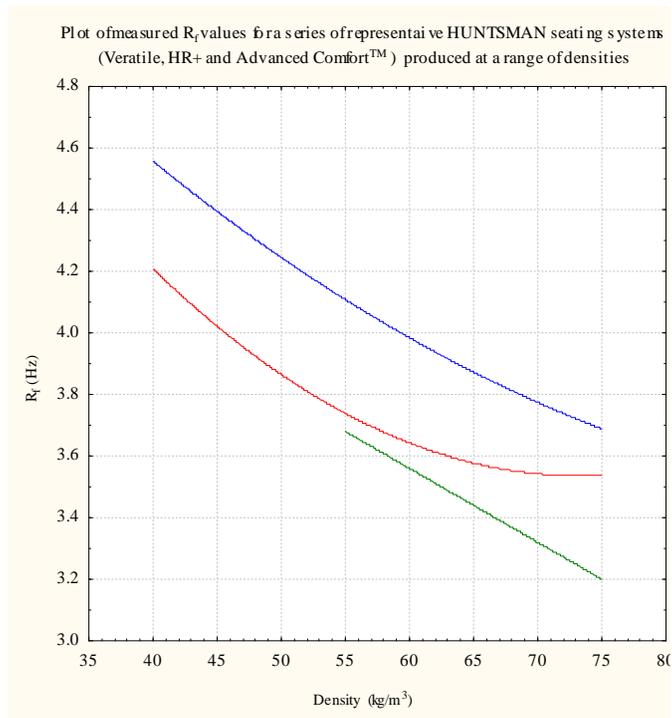


Previous work has shown that the result from the dynamic creep test correlate well with full scale tests originally developed by Griffin providing a S.E.A.T (Seat Effective Amplitude Transmissibility percent number) and thus provide an effective guide to the performance of a seating technology to deliver comfort performance to the end customer.²¹

4.4.2.2 Resonance Frequency & Amplification results

Characterisation of the combined resonance frequency and magnitude of amplification at this frequency are described below (see figure 7). Data from the analysis confirmed that the non-linear modulus behaviour and dynamic creep of the foams affect their vibrational performance. In addition, the data demonstrate that the versatile systems have relatively clear relationship to density. The resonance frequency relationship exhibited by the HR+ system shows the clear improvement in a critical comfort element. Interestingly, at higher densities the magnitude of the amplification exhibited by the two systems appears to converge. Again, the Advanced Comfort™ system demonstrates a step change in performance especially in the magnitude of amplification at resonance offered by the Advanced Comfort™ technology.

Figure 7: Plot of measured R_f and amplification values for the range of Huntsman foam systems



5. Conclusions

- Using a combination of test methods Huntsman Polyurethanes has developed a good predictive approach to the performance of flexible foams in automotive seating under a range of conditions.
- Under a constant compression load automotive flexible foams experience a change in dynamic modulus and height when subjected to low amplitude sinusoidal stress and the majority of the change will occur within the first 30 mins of any test. These changes can be correlated with an increase in discomfort and should be reduced as much as possible.
- Within the context of automotive seating Huntsman Polyurethanes offers a number of technological platforms that can meet a broad range of customer requirements driven by the density of seating system the customer wishes to install.
- The HR⁺ platform offers clearly superior comfort performance when compared to the standard versatile (HR) technology at equivalent density or will offer equivalent comfort performance at significantly lower density.
- The Advanced ComfortTM foam system from Huntsman provides changes in dynamic modulus that are significant different from standard PUR foam technologies (HR & HR⁺) at a broad range of densities.
- The Advanced ComfortTM foam system from Huntsman provides significantly improved dynamic comfort characterised by lower hysteresis, lower transmissibility and enhanced vibrational damping whilst providing excellent durability with little change in height during ride.

6. Glossary

- Amine:** A class of compounds used as catalysts in polyurethane foam reactions. Amines are characterized by having N, NH or NH₂ groups in the molecule.
- Bottoming:** The characteristic of some flexible materials, especially polyesters, to support an initial load with a small amount of deflection but virtually collapse under any additional load. After this severe compression, any additional load will cause little further deflection.
- Catalyst:** A substance that changes the rate of a chemical reaction.
- Cell Opener:** A compound added to a foam formulation for the specific purpose of increasing the population of open cell-windows. Successful cell opening is evidenced by higher airflow and decreased foam shrinkage.
- Chain extender:** Short-chain reactive molecules joining diisocyanates in a linear fashion to form crystalline hard segments that modify the properties of a polyurethane.
- Creep:** The degree of compression or height loss that occurs when a flexible foam cushioning material is subjected to a static load over a defined time period.
- Crushing:** Usually a mechanical or vacuum-assisted procedure to open the closed cells of a cold-cure or high-resilience foam after demolding
- Demold time:** The time between the discharge of the foam ingredients from the mixing head and the time at which a molded object may be removed readily from the mold without tearing or altering its shape and without post-expansion.
- Density** Density is the weight per unit volume of the foam normally expressed in kilograms per cubic meter (kg/m³). The general range of polyether flexible polyurethane foams is 16 to 64 kg/m³. This density is not a measure of firmness as it is with latex rubber foams. Density is an important factor, however, in that for a given load-bearing requirement, a higher density foam generally gives better quality and performance.
- Dual hardness:** Seating cushions containing areas of quite distinct hardness variation for example on the main pad versus the bolster.
- System:** A chemical system for producing foam which consists of only two materials. One part is referred to as the isocyanate side and is usually the 'pure' isocyanate with no additives. The second part is often called the resin side and usually consists of blended polyol(s), catalysts, surfactants and other desired additives.
- Full foam seat:** Seat constructed from large PU cushion positioned on a metal shell (alternative is PU foam positioned on a spring base).
- High resilience:** High-resilience (HR) molded polyurethane foams are based on the reaction of higher-molecular-weight polyols (4,500-7,000), either with polymeric isocyanates, with blends of distilled and polymeric isocyanates. The term "high resilience" results from the improved resilience of these foams compared to that of more conventional hot-molded or slabstock foams.
- Hysteresis:** This is a measure of the energy lost or absorbed by a foam when subjected to deflection and is typically given by the ratio of the areas under the loading and unloading curves. The results give a percentage of the energy absorbed during compression. This ratio is called hysteresis and provides a simple measure of foam elasticity/resilience.

In another sense, hysteresis is a measure of the ability of a foam to dampen vibrations.

- ILDⁱⁱ: An indication of the load-bearing ability of foam. The standard test is to depress a square indenter plate into the foam and measure the mass required to achieve a desired deflection.
- MDI: The basic monomer of a di-functional isocyanate
- OEM: Original Equipment Manufacturer. A term used to describe automotive producers such as BMW, Ford, Renault.
- Polyol: Generally, any organic molecule containing a plurality of hydroxyl groups. For polyurethane foams, polyols are usually polyethers (or formerly polyesters) with hydroxyl reaction sites.
- Silicones: Chemicals formed from a combination of silicon and organic molecules that exhibit surface-active properties. These compounds are used to add stability to the liquid foaming mixture so that drainage is retarded and flowability of the mass is improved.
- Suprasec: Registered trade name for isocyanate systems marketed by Huntsman Polyurethanes

ⁱⁱ *Indentation load deflection*

Biographies

Chris Skinner

Chris Skinner holds a Ph.D. in organofluorine chemistry and an M.B.A. He joined ICI (Huntsman) in 1995 and has worked in a number of technology areas including fluorinated refrigerants, specialty titanium catalysts, composite wood products, Thermoplastic polyurethanes and more recently Automotive. He has held a number of positions in technical and marketing areas and is currently the Automotive Platform manager based in Brussels. Chris Skinner has published numerous articles and currently holds 14 patents.

Christophe Ponce

Christophe Ponce holds a masters degree of science and technology with a specialty of physico-chimie of formulation from the University of Science (Montpellier). He joined ICI (Huntsman) in 1996 and has worked in a number of technology areas including surfactants / performance products and more recently polyurethanes. He has held a number of positions in technical and marketing areas within Polyurethanes and is currently the Product Manager for Automotive Seating for EAME based in Brussels.

7. References

- ¹ International Labor organisation, Report on “*Motor vehicle industry trends affecting component suppliers*”, Geneva (2005); European Foundation for the Improvement of Living and Working Conditions, Report on “*Trends and drivers of change in the European automotive industry: Mapping report*”, 2004.
- ² U. Struß, “*Ergonomical seat design*”, CTI Wiesbaden (2005).
- ³ C. Skinner, “*Trends in the Eastern European Automotive market from a PUR suppliers perspective*”, FSK Conference Heidelberg November (2005).
- ⁴ F.J. Villmer, “*Seat trends and requirements of seating engineering*”, CTI Wiesbaden (2005).
- ⁵ V.A. Runkle, “*Benchmarking Seat Comfort*, Proceedings of the SAE International Congress and Exposition; Detroit, Michigan, Feb 28 (1994).
- ⁶ A. Cunningham, E. Huygens, J. W. Leenslag, “*MDI comfort cushioning for automotive applications*”, Paper 5 Utech (1994).
- ⁷ J. W. Leenslag, E. Huygens, A. Tan, “*Recent advances in the development and characterisation of automotive comfort seating foams*”, Polyurethanes World Congress, September 29 (1997).
- ⁸ T.E. Fairley, M. J. Griffin, *SAE Technical Paper Series* 860046 (1986).
- ⁹ J. Ick, H.M. Rothermal, H. G. Hauptmann, *J. Cell. Plastics*, May/June, 177-181 (1976)
- ¹⁰ M. J. Griffin, *Applied Ergonomics* 9.1, 15-21 (1978).
- ¹¹ N.C. Hilyard, W. L. Lee, A. Cunningham, *Cellular Polymers*, Forum Hotel, London UK, 20-22nd March 1991, RAPRA technology Ltd. 187-191, (1991).
- ¹² K. Vorphol, J. Mertes, R. Zschiesche, H-D. Lutter, R. Drumm, SPI-1993, 546-551 (1993).
- ¹³ N N.C. Hilyard, W. L. Lee, A. Cunningham, *Cellular Polymers*, Forum Hotel, London UK, 20-22nd March 1991, RAPRA technology Ltd. 187-191, (1991).
- ¹⁴ P.T. Stone, *Automotive Body Engineering*, January 28 (1965); G. A. Campbell, *J. Appl. Polym. Sci.*, 24, 709-723 (1979); F. Heidinger, B. Kunz, W. Diebschlag, *Plastverarbeiter*, 39, 116-121 (1988); W. Diebschlag, F. Heidinger, *Kunststoffberater*, 3, 43-46 (1988); A. Weichenrieder, H. G. Haldenwanger, *SAE Technical Paper Series* 770247 (1977); T. E. Fairley, M. J. Griffin, *SAE Technical Paper Series* 860046 (1986), H. G. Haldenwanger, *Automobiltechnische Zeitschrift* 84, 9, 437-445 (1982); I. Ick, H. M. Rothermal, H. G. Hauptmann, *J. Cell Plastics*, May/June 177-181 (1976).
- ¹⁵ M. R Kinkelaar, K. D. Cavender, G. Grocco, “*Vibrational characterisation of various polyurethane foams employed in automotive seating applications*”, Proceedings SPI Conference, p.496 (1996)
- ¹⁶ M. J. Brown, 34th Annual Polyurethane Technical / Marketing Conference, October 9 (1994).
- ¹⁷ A. Weichenrieder, H. G. Haldenwanger, *SAE Technical Paper Series* 770247 (1977); M. J. Griffin, *Applied Ergonomics*, 9.1, 15-21 (1978)
- ¹⁸ J. T. McEvoy, “*Advances in Polyurethane Foam Property control*”, SAE 2001 World Congress, Detroit, Michigan, March 5 (2001).
- ¹⁹ M. Belhache, “*High performance foam in automotive seating*”, CTI Wiesbaden (2005).
- ²⁰ J. W. Leenslag, E. Huygens, A. Tan, “*Recent advances in the development and characterisation of automotive comfort seating foams*”, Polyurethanes World Congress, September 29 (1997).
- ²¹ W. J. Pielemeier, J. A. Greenberg, V. Jeyabalan, The Estimation of SEAT Values from transmissibility data, SAE World Congress, Detroit March 5 (2001); J. W. Leenslag, E. Huygens, A. Tan, “*Recent advances in the development and characterisation of automotive comfort seating foams*”, Polyurethanes World Congress, September 29 (1997).