Automotive Cushioning
Through The Ages

- A Review -

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Issued By:

The Molded Polyurethane Foam Industry Panel

September 2008

www.MoldedFoam-IP.org
Forward

It is with great pleasure I present the foreword to this paper “Automotive Cushioning Through the Ages.” I feel this paper is a fitting tribute to all the hard work and accomplishments the Polyurethane Molded Foam Industry Panel has achieved since its inception in 2004. In addition, this paper will be the cornerstone of our new industry panel web site. This historical document will take the reader back in time when our first automobiles utilized materials from household furnishings and bedding to fill seat cushions; a vast contrast to our almost exclusive flexible polyurethane foams used today. This paper represents a history of cushioning from 1885 to the present. Being a member of this industry panel has been the highlight of my forty year automotive career. The members have dedicated and achieved the creation of automotive foam specifications that are practical, provide a basic commonality within the automotive industry and establishes best practices. This vision and mission has placed this panel at the forefront of ingenuity and harmony. Our members represent the polyurethane foam industry from the chemical suppliers to the Original Equipment Manufactures (OEM”s). It’s been an honor to work with Ron Blair and Mark Weierstall in support and creation of this important document.

John Reynolds
Material Specialist, Chrysler LLC
Automotive Cushioning Through the Ages

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Automotive Cushioning Through the Ages

1. Introduction

The earliest reference to an automotive seating type was recently described in Old Autos, a Canadian magazine for antique and collectible cars. In an article on “The Benz patent motor car, No 1”, the world's first petroleum-based fuel vehicle (1885), the bench seat on this “horseless carriage” is described; “The padded, leather bench seat sat on springs mounted directly to the frame”.

![Figure 1: Karl Benz Car](image)

Since that time the construction of the automotive seat and the cushioning material employed to provide the occupant a comfortable place to sit while operating a motor vehicle have continued to evolve. These changes have been predicated on cost, ease of manufacture, durability, safety legislation, and the consumer demand for increased comfort. Some materials have stood the test of time and others have been replaced by newer technologies, as illustrated in timeline in Figure 2. This article will try to provide some insight into the why those changes occurred and a historical perspective of cushioning materials.
1.1 Seat Trimming in the 1920s

We will only concern ourselves with seat interiors but in a book entitled “Essentials of Upholstery and Trim for Vintage and Classic”\(^{(2)}\) all aspects of auto upholstery in the 1920s are considered and the book contains many fine photos of luxurious auto interiors. It is interesting to note that “neatness, comfort and durability” are essentials of all “trimming and upholstery work”. Most early autos had large, padded seats essentially similar to furniture seating. Rear seats were exceptionally palatial and comfortable for the gentry who could afford such splendid vehicles.

Some of the materials employed in the 1920s in auto upholstery are: springs, hair and its substitutes, cloth, duck, sheeting, cambric, muslin, buckram, webbing, cotton wadding and battings, down, feathers, top materials, slip cover materials, coated ducks, cords and bindings, etc.*
1.2 Seat and Cushion Springs

Springs are used as shock absorbers and as an aid in the comfort of vehicle occupants. Seat upholstery built of springs and hair, cotton or other resilient materials, is an important component that absorbs shocks from the highway. Thus a well-constructed seat depends on the springs in the cushion and back to ensure it is comfortable, serviceable and durable.

What kinds of springs are used? Manufactured woven, coil springs, interlaced and bound with metal are the best choice. This construction consists of spiral springs linked together with metal clips to ensure they remain in place during use. The springs themselves are considered very important and various manufacturers have patented special types and constructions. Spring
size, capacity and the known cushion/back height limitation are important; as is gauge of wire used to form the springs and the number of spirals per spring. All these 'spring essentials' must be known to ensure the occupant does not bottom-out when the vehicle hits irregularities in the road surface, while maintaining a level of comfort. To some extent, seat comfort can be modified by the use of heavy toppings on the cushions (on top of the springs).

Figure 4: Bench Seat with Heavy Toppings

1.3 Cushion Filling Materials
Curled hair is considered to be the superior type of filling. The most important feature is its ability to spring back to its original shape when unloaded. Other materials can be used as replacement for hair. Such substitutes are fibre, moss, excelsior and various forms of cotton. Exceptionally down and feathers may be used in cushions.

Cushion construction may consist of the spring construction covered by sheeting, burlap or other similar material that is tacked in place. On top of the sheeting, layers of hair are positioned and covered with muslin or another covering material, which is tacked in place. Finally the dress cover is applied and “finished” to complete the seat.
Even the construction of springs within a cushion is important, so that from the front-to-rear of a cushion a difference in height of 75mm (3 inches) is achieved.

Figure 5: Progressive Spring Heights

Spring assemblies are stapled to a wood frame and must be firmly attached. The entire spring is covered with a piece of duck material and tacked to the wooden frame around the outer edges. The cushion is then built-up with hair or other material and a layer of sheeting placed over the hair is stretched smoothly and tightly. After any other treatments, e.g., quilting, the sheeting is tacked to the wood frame.

Figure 6: Springs Attached to Wood Frame
Seat trimmers are reminded that cushion ventilation is important to prevent the seat from having a pneumatic feel and impart discomfort to the occupant. The use of good hair filling is recommended to give the best ventilation results.

It is concluded that seat trimming as described above is a viable occupation and its future is assured using the traditional construction materials outlined above. Little did the seat trimmers of the 1920s realize that incredible changes in materials, seat construction specifications, and safety features would change their task out of all recognition!

1.4 Rubberized Hair/Latex

If we now forward to 1908, the incredible Ford Model T which sold over 15 million models used seats stuffed with hair. Presumably so did other vehicles manufactured both in Europe and North America.

![Figure 7: Ford Model T / Exploded Seat View](image)

In order to ensure the hair fibres did not disintegrate or loosen from the seats, latex-bonded seating interiors were developed. Initially, animal fibres were used such as those from horses, cattle and pigs. The last named were favoured as they have the highest degree of curl and hence the best interlocking capabilities. A light impregnation with natural or synthetic rubber
latex bonds the fibres together where they touch. More recently, coconut fibres have been used alone or blended with animal hair.\(^{(3)}\)

![Figure 8: Rubberized Hair - Roll and Sheet Form](image)

Rubberized hair pads have been described by Pole in 1959.\(^{(4)}\) Apparently, a British patent was issued in 1931\(^{(5)}\) which describe the use of rubber latex as a binder for fibres. This is the same year that latex foam was produced for the first time on a commercial basis (see 1.5 Latex).

How is rubberized fibre seating manufactured? First, the curled fibres are opened and treated with a latex rubber solution, shaped in a perforated metal Mold before being dried and vulcanized. The fibres themselves should be resilient (animal hair), however coil and sisal fibres can also be used, but presumably they give inferior products. The rubber latex is applied to the fibre mats by traversing spray guns on both sides of the fibre pad or batting. The latex is then dried with hot air at 140°C and applied at 2,000 feet/min (approximately 600m/min). A 25mm thick pad with a finished weight of 4oz/ft. (1220g/m²) will contain equal parts of fibre and latex (binder of 55% solids).
How are latex / rubberized hair cushions tested? A pad of 50kg/m³ density is tested before and after flexing to 60% of its original height at 2 cycles/second for 125,000 cycles. Then it is aged for seven days in an air-circulating oven at 70°C. The 50% compression modulus of the original pad is 0.05-0.06 kg/cm². After flexing, the drop in modulus will be 35-38% and then after the successive aging treatment, 38-43%.

Natural latex bonding agent is used to improve the seating load capacity, improve resiliency and gives seating with excellent compression set (rapid recovery to original shape) according to Pole(6). Natural rubber latex can be compounded with combustion modifying materials such as ammonium salts, borates, metallic oxides and chlorinated hydrocarbons to improve flame retardant properties.

The standards used to test rubberized hair for the automotive industry are SAE J18 (April 2002) and for all latex foams, including non-automotive products, ASTM D1055-44.

An important claim made for rubberized hair seating is its excellent breathability due to the open structure and this feature is often cited against lower permeability PU foam. Some recent additional claims(6) have touted rubberized hair seatings good durability and that the fibres “can be picked apart and reused”.(7) The separated fibres are then blended with new materials to
make new cushions. Thus, rubberized hair manufacturers can (and do) claim that their seating is based upon all-natural, renewable materials and that are recyclable.

Seats manufactured in Germany for Chevrolet Caprice police vehicles were tested in a Woodbridge Fleet trial. Unfortunately, due to their extremely-rated discomfort by the police drivers, these seats had to be removed from their vehicles after only a few weeks of use. Thus, they were not tested long enough in the cruisers to ascertain their durability performance. It must be added that the police officers in this study were used to riding on PU-filled seats and the abrupt change to very hard Gummikokos (coconut fibre) seating immediately conveyed an uncomfortable feel.

These “Gummikokos” cushions were evaluated against the GM foam standard, GM6293M, although another specification or standard may be used for these fibrous products. It was found that these cushions had low tensile strengths, low elongation (both properties failed the GM6293M spec limits), marginal tear strength, very high compression sets (normal and after humid aging) and low resiliency as measured by ASTM ball rebound. Also these cushions with density of 44 kg/m³ did not meet the requirements of FMVSS302 where a maximum burn rate of 101.6 mm/minute or less is required. (8)

However, fibre/latex seating has been used by Mercedes for many years since it apparently gives their seats the desired performance of breathability and good lateral support cornering especially at high speeds. Rubberized coconut fibre seating was used by VW in Brazil up until 1994 and small volumes of rubberized hair / latex seat backs are still produced in Europe.

1.5 Latex Foam
Latex foam seating (without any reinforcing fibres) has been used for decades. Initially a patent was issued to E.A. Murphy of Dunlopillo in July 1929 and mattresses were produced using his technology in 1930. Initially latex foam cushions were installed in London bus seats in 1932. Later that decade latex seating for automotives started and continued in use until the 1960s.
Two manufacturing processes have been used – the Dunlopillo, where a latex froth is made using a very intense Oakes shear mixer and a sodium silicate catalyst. The other process developed by B.F. Goodrich produces foam blocks from which fabricated auto seats are manufactured. This Talalay process requires a vacuum to be pulled on the latex blend followed by injection of a blast of carbon dioxide. The latex blocks are produced in a Mold with pins from each side (top and bottom) to help freeze the latex foam during manufacture.\(^{(9)}\)

Both processes need the addition of sulphur and accelerators and the foam has to be cured (vulcanized) using a considerable quantity of energy. Apart from this drawback, the demold times for cure are quite long (15-20 minutes) and with a 2 to 3 hour post cure requirement. Initially natural rubber was used but during WW2, synthetic latexes were developed but were regarded as inferior to natural latex types.

Latex foam densities are in the 80-130 kg/m\(^3\) range and some production continues around the world including Europe and North America, but not for automotive use. Production was quite widespread with the early introduction of latex cushioning in the BMC Morris 1100 in 1963. BMC (British Motor Corp.) production was quite advanced for its time since it was a pour-in-place process with frames embedded in the parts and molded into vinyl covers! Figure 10 shows a prototype part with embedded coil springs.

\[\text{Figure 10: Polycoil Seat Unit (1950s)}\]
Latex foam was considered a much superior, comfortable product to previous types of seating, e.g., horsehair, wadding, springs. Interestingly, the hardness measurement mode differed from that later used for polyurethane products. When IFDs (initially called RMA – Rubber Manufactured Association, then ILD where L=load) were performed, the instantaneous hardness reading is recorded rather than holding at deflection (25%, 50% or 65%) for 60 seconds before the reading is recorded as the cushion’s hardness value.

Other mechanical properties used to classify latex foams are; density (SAE standard only), 25% deflection IFD, aged IFD change after oven treatment for 22 hours at 100°C or 168 hours at 70°C or 22 hours at 70°C depending on the application. Compression sets are also measured after 22 hours at 70°C, or 22 hours at 100°C and low temperature flexing tests are performed after cooling to -40°C, -55°C or -75°C, depending on potential foam usage. Flexing is performed for 250K cycles at 1Hz and foam deflection measured before and after flexing, but the extent of test deflection depends on initial foam hardness, e.g., 25% deflection for >300N IFD foam but 50% deflection for less than 300N IFD foams. Other tests not applicable to seating may also be performed such as water or oil absorption and aging in chambers in the presence of oxygen.

Latex foams were considered the comfort yardstick. They were replaced by polyurethane foam types that for many years did not equal latex foam in comfort. Why was this acceptable? There can be considered to be two major reasons. First, the urethane process, which will be described shortly, whilst, requiring careful formulating and accurate processing is a less difficult process to master and run in production to obtain consistent product, easily trimmed into car seats. Second, the cost of producing urethane cushioning was lower than the more complicated latex processes. Figure 11 illustrates some aspects of the laborious and time consuming process used to manufacture latex foam. It should also be noted that lack of personnel with latex formulating/processing and tooling experience was always a problem. Using latex foam it was difficult to obtain parts with good dimensional quality and consistency to allow precise and engineered trim manufacturing. Also, in the 1950s, there were drastic fluctuations in latex pricing.
All of the seat assembly processes described to date were labor intensive, see Figure 12.

1.7 Polyurethane Foam

In about 1957, the standard used for cushioning was latex foam rubber. Many considered it to have the best stress-strain relationship to produce comfortable automotive cushioning and replacing with another foam material with the same approximate stress-strain curve may not be
the only feature to allow other materials to replace latex foam. Figure 13 compares the stress-strain (i.e. force-deflection) relationship for high density latex foam (88 kg/m$^3$) with pinhole coring and a much lower density hot foam (48 kg/m$^3$). DuPont was able to make an over-all successful foam using their “Teracol” (polybutylene ether) products. It had the extra resiliency required without the bad creep of the current polyester-based flexible PU foams. Its major drawback was that it was too expensive so other new materials had to be found. These can be generally classified as polyether polyols such as:

i) polypropylene glycols (UCC, Dow)

ii) polypropylene-polyethylene glycols (UCC – UCONS)

iii) Pluronics – Wyandotte (now BASF)

Figure 13: Hysteresis Loss Curves for Cored Latex Rubber and Hot Molded Polyurethane Foams

These materials exhibited great potential for cushioning and allowed the elimination of coring and expensive molds. Predictions in 1957 were that foams based on polyether polyols would capture a large share of the cushioning market, and history has proven these predictions to be well-founded.
The first disclosure of flexible foam being made was by Hochlen in 1952. Hydroxyl-terminated polyesters were reacted with diisocyanates in the presence of water to produce a blown product due to the production of carbon dioxide gas generated when water reacts with isocyanate. Around 1955, there was a widespread manufacture of polyester-based flexible foams. These foams found many applications but under hydrolytic conditions it was not possible to forecast how long polyester foam would retain its physical properties. It was established that if a polyester polyol has a high acid number (~10) its aging properties were poor. At this time, experimenters at DuPont ran hydrolytic tests at 90°C and 100% RH to evaluate the stability of polyester foams. It was established that the rate of foam modulus retention was dependent on the temperature at which reaction occurs, i.e., the higher the temperature the more rapidly the foam modulus would fall. Another drawback to polyesters was that those based on adipic acid had bad creep properties.

So with these problems, it appeared that polyether foams with their improved hydrolytic resistance would prevail and this proved to be the case. In addition, these polyether foams were less expensive and offered greater comfort than even the traditional spring and flock padding constructions. Thus their success in upholstered furniture and automotive applications were ensured.

One of the major advantages of PU foams over latex foam is their resistance to bottoming-out when stressed. This superior performance is achieved if the foam exhibits fairly rapid force/deflection beyond 50% deflection and rapidly at 70-80% deflection.

Latex foam has inferior UV resistance compared with PU foam and latex may show the early formation of a heavy crust whereas PU foam may exhibit some surface crumbling and/or friability after long UV exposure. Interestingly, after an “oxygen bomb” test, latex foam will lose considerable tensile strength whereas PU foam does not due to its superior resistance to oxidation.(16) Some latex foams may support combustion in flammability testing.
2. Evolution of Polyurethane Foam Seating

1950 Flexible polyester urethane foams became available and were commercialized. Interest in these new products was limited due to raw material costs and foam shortcomings in comparison with foam rubber made with latex.

1954 Commercial production of flexible polyester PUF commenced in the UK.\(^{(11)}\)

1955 Flexible slabstock PU foam was introduced into the USA but without much success.\(^{(12)}\)

1956 Polyether polyols were used to produce flexible urethane foams commercially. Initially a prepolymer process was used. This involved reacting a polyol with an isocyanate to give a prepolymer with some NCO groups from the isocyanate still available for subsequent reaction. This prepolymer was then metered and mixed with the other ingredients (water, catalysts, silicones) to produce a foam. This process is difficult to control since the prepolymer created has a high viscosity that required it to be heated to make it more fluid for pumping and metering. Also, the ratio of prepolymer to the “activator” was about 95 to 5 respectively making mixing difficult and quite critical. However, as early as January 1957, DuPont (a manufacturer of various urethane chemicals especially TDIs), introduced an on-off mixer that could be used to successfully mix ingredients to produce Molded PU foams.

1957 Union Carbide Corporation (now Bayer Material Science) commenced the manufacture of a polyether polyol exclusively for the new “one shot” process (NiaxLG-56, a 2900 molecular weight polyol).

Hot molded flexible foam for use in Chrysler rear seats introduced by Reynolds Chemical Products, Ann Arbor, MI
1958 A great simplification in PU foam manufacture came about. The single stage or “one shot” process was commercialized. This was achieved by the introduction of new catalysts such as TEDA (triethylene diamine by Air Products & Chemicals, formerly Houdry Process Corporation). Foam processing was much easier since no prepolymer needed to be made and the metering/mixing was much easier due to the reduced viscosity of the chemicals and the incorporation of new stabilizing surfactants. Surprisingly the first complete seats made by pouring the foam reaction mix between the preformed cover and the wooden base were announced. Deep seating was first proved by Austin-Morris in England in 1960. Their production line, run by Austin engineers, used a “hold-up” type mixer with the chemical components being metered into and stirred in a mixer barrel before being ejected as a complete homogeneous reaction mixture into the mold.

In 1958, GM started using PU foam topper pads in the seats of some of its vehicles. Polyether foams proved to be highly satisfactory and they were resilient, strong, light in weight, inexpensive to manufacture and easy to assemble. All of these advantages ensured the demise of latex foam cushioning for automobiles.

1960 As far as Molded foam parts are concerned, once it was recognized that there was a need for a high heat flux early on in the foaming stage, particularly in the Molding of seat topper pads, molded parts became practical. Shorter cycle times, lower foam density and easier demolding improved the process and foam physical properties steadily improved.

Molded foam became much more accepted since its load/deflection curve exhibits a greater load-bearing ability at high deflections, i.e., at greater than 50% compression. This is due to the load distribution contribution by the molded skin and to some extent by the random cell orientation and distribution as well.

1961 During 1961, the first flexible molded production line came on stream, using cast aluminum molds and heating by a hot air oven. Figure 14 shows a seat cushion construction with a foam topper pad on sinusoidal springs.
The one shot urethane process was the preferred mixing route to manufacture polyether foams. These foams were used by the automotive industry in increasing amounts to replace cotton batting, latex foam rubber, textile cushioning and filling and even steel springs.

Some problems still existed to perfect the PU Molding process such as foam/part reproducibility/part release problems from Molds/foam densification and some poor foam physicals. Improvements continued and some typical foam properties were.\(^{(13)}\)

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Density (kg/m(^3))</th>
<th>Tensile Strength (kPa)</th>
<th>Elongation (%)</th>
<th>Tear Resistance (N/m)</th>
<th>50% def. IFD N/m</th>
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<td>200</td>
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<td>76</td>
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</table>

As early as December 1961, Chrysler issued a foam specification for urethane topper pads. Compression sets were included, both regular and after humid aging at 105°C.
(200°F). Similarly foam load loss (more correctly termed force loss) was measured after the same humid aging treatment. The dynamic fatigue property of foam (a measure of foam durability) was measured using a flexing test by repeatedly compressing a foam cylinder (100 mm diameter by 100 mm thick) for 100,000 cycles. Both thickness and hardness (CFD) losses were specified; i.e., 4, 25 and 15% losses for height, 25 and 65% deflection CFDs (max) respectively.

1961-3 By 1962, other Molding lines were being installed. Some used sheet metal Molds instead of cast aluminum and infra-red heating. Economics quickly improved and lower capital and tool costs improved plant efficiency and lower labour costs all contributed to reduced production costs. Cure time of 10 minutes for a 1.6 kg Molding and 12 minutes for a 2.3 kg part was achieved. In 1962 GM installed full depth foam cushions, which sat on zigzag springs.

Figure 15: Full Foam Cushion an Zigzag Springs

There was a very rapid growth in the flexible PU foam industry due to the displacement of traditional upholstery materials in furniture and in the automotive seating industry. By 1963 molded foam was in production in Europe and North America but slabstock foam still predominated. Nearly all of the European OEMs had, or were planning to setup their
own Molding lines for production of their seating requirements. They were even considering full depth seating Molded directly over the seat springs and some even contemplated direct foaming over a steel frame as they considered this to be feasible.\(^{14}\)

Late 1960s The first cold cure Molding systems were announced. These were based on newly-developed, high reactivity polyether polyols with molecular weights of 4,000-5,000. The isocyanates used had to have a functionality greater than 2 and this was obtained by blending TDI with polymeric MDI (Mobay, Dunlop) or Trimerization or allophanate modification of part of the TDI. For instance, Bayer/Mobay introduced Moltopren T, a cold-curing, two component system for Molding, in 1967. It was based on polymeric MDI (3 parts) plus 2 parts of 65:35 TDI used with a high molecular weight triol and the necessary catalysts, surfactants and cross-linkers. By the early 1970s alternative formulations using MDI/TDI blends and various grades of modified and ‘crude’ TDI, including TDI compositions containing TDI trimer and allophonates derived from low molecular weight diols were promoted. The problem with these systems was that they were too variable in reactivity and they could not compete successfully in cost against polymer polyol-type formulations (see below). Thus, they exited the marketplace.

1967 General Tire and Rubber Co. started-up a new, economical and rapid molding line to pour up to 8,000 full car cushions and 16,000 bucket seats/day respectively.

1968 The first commercially polymer polyols were introduced by Union Carbide Corporation (now Bayer Material Science) in a technical bulletin entitled “Cold Cure Flexible Foam Molding”. [Polymer polyols are also termed graft polyols (BASF) or copolymer polyols (Dow)].

1974 A noticeable trend was found, especially in North America where high resiliency (HR) or cold cure foam rapidly replaced hot foam since it offered attractive heat energy savings and more comfortable, saleable automobiles. In production, HR foams offered improved working conditions and foam with faster demold times.
1974  About 90% of auto seating in the USA was now HR foam.

1976-78  HR Molded foam cushioning had penetrated the German automotive market but some rubberized hair was still being produced as shown in Figure 16.

The first in-house HR Molded foam was made by the Inland Division of General Motors followed in Europe by GM/Opel division and VW. Patten et al.,\textsuperscript{(15)} at Union Carbide Corporation invented and developed polymer polyol high resiliency Molded foam. General Motors (N.A.) had seen and sampled the new high resiliency (HR) foams being introduced in Europe in the early 1970s. They wanted their seating to have the luxurious feel offered by HR Molded foam and formerly achieved by latex foams. On specific instructions from GM, Patten et al. abandoned their co-development work on HR foams incorporating LD813, a blend containing 40% MOCA which was suspected as a carcinogen. They concentrated their efforts on a system containing substantial proportions of their polymer polyols, Niax 31-28 and 34-28. The latter became the material of choice.

2.1 Hot Foam

What kind of properties did hot foam achieve and what types of chemicals were used? Initially hot foam chemistry included the use of a 3,000 molecular weight polyol (75 parts), blended with polypropylene glycol of 2,000 molecular weight (25 parts). Freon-11 blowing agent up to 10 parts was incorporated into formulations, especially at lower densities/softer foams for seat backs. Straight TDI (80:20 isomers) was used and usually a low pressure metering/mixing
machine was the norm. Rather than tightly-sealed Molds that are now used for high resiliency Molded foam, the hot foam molds had floating lids with many bleed holes for venting. Hence, a considerable amount of foam extruded from the vents and was either discarded or very occasionally incinerated to recover some heat (in Europe).

Some hot foam parts, such as thin topper pads, were crushed to obtain good dimensionals but not as severely as the later HR foam parts. Sometimes parts were post cured for a few hours at say 120°C to ensure that they did not set during processing/transportation.

The testing methods used for these hot parts was approved by the Cellular Plastics Division of the SPI (Society of the Plastics Industry). Most of the properties are well-known to Molders as they have been handed down through the decades. Density, tensile strength/elongation, tear resistance, load indentation (RMA) and CFD were called for and two compression sets at 50 and 90% deflection. The latter set deflection was demanded by some OEMs. Even as early as the mid 1950s, foam hydrolysis resistance was considered critical (e.g., heat foam in a closed container with water for seven days at 87.5-90.5°C and measure compression set and CFD loss). This hydrolytic test was due to the problems OEMs encountered with the early polyester polyurethane foams that had poor humid stability. An example of typical hot foam properties for non-post cured foam was:
<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>24</td>
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<td>Tensile Strength</td>
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<tr>
<td>Elongation</td>
<td>%</td>
<td>240</td>
</tr>
<tr>
<td>Tear Resistance</td>
<td>N/m</td>
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<tr>
<td>50% Comp. Set</td>
<td>%</td>
<td>10-20</td>
</tr>
<tr>
<td>90% Comp. Set</td>
<td>%</td>
<td>5-7</td>
</tr>
<tr>
<td>50% HA Comp. Set</td>
<td>%</td>
<td>5-7</td>
</tr>
<tr>
<td>50% CFD loss</td>
<td>%</td>
<td>10</td>
</tr>
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</table>

What were considered the advantages of molded PU foam over earlier forms of seating? Several attributes have been stated:

a) foam had good resiliency giving comfortable cushioning
b) foam has no undesirable “bounce-back”
c) foam resists matting, stiffening or crumbling after prolonged use or aging
d) foam is non-allergenic, odorless and is unaffected by dampness
e) foam can be welted, stitched, pulled, stretched, sewn, nailed and cut with conventional tools if necessary

These attributes must have been more than acceptable to the OEMs who compared the older seating technologies such as cotton wadding and even latex foam with PU foams superior performance and lower costs. The use of PU foam would allow the construction of highly desirable bucket seats, easily and relatively inexpensively.

By the latter half of the 1960s foam specifications with property limits were being issued. For instance, in 1967 a “Proposed Commercial Standard for Flexible Slab Urethane for Bedding and Seat Cushioning”, was released. It is worth noting some of the limits suggested as these values “limped-along” without much alteration for the next few decades:
### Molded Polyurethane Foam Industry Panel

#### Humid Aged Foam Grades

<table>
<thead>
<tr>
<th>Foam Grade #</th>
<th>IFD@ 25% def. lbs</th>
<th>S.R. Min.</th>
<th>C.S @ 90% def. %</th>
<th>Comp Set, %</th>
<th>CFD change, %</th>
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<td>(44+/-.6)</td>
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<td>15</td>
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<td>USU 27</td>
<td>(27+/-.3)</td>
<td>1.9</td>
<td>15</td>
<td>20</td>
<td>+/-20</td>
</tr>
<tr>
<td>USU 21</td>
<td>(21+/-.3)</td>
<td>1.9</td>
<td>15</td>
<td>20</td>
<td>+/-20</td>
</tr>
<tr>
<td>USU 15</td>
<td>(15+/-.3)</td>
<td>1.8</td>
<td>20</td>
<td>25</td>
<td>+/-20</td>
</tr>
<tr>
<td>USU 9</td>
<td>(9+/-.3)</td>
<td>1.8</td>
<td>25</td>
<td>30</td>
<td>+/-20</td>
</tr>
</tbody>
</table>

Where:
- IFD = Indentation Force Deflection (formerly ILD where L=load)
- S.R. = Support Ratio (formerly Sag Ratio)
- C.S. = Compression Set
- CFD = Compression Force Deflection (formerly CLD where L=load)

In addition, these foam grades were to meet a fatigue test requirement of about 30% loss maximum in 25% def. IFD and 5% thickness loss max. Resiliency requirements were quite low since these foams were not HR-types. So percentage ball rebounds (a measure of foam resiliency) required were 45 or 40% depending on grade. All of these property requirements were to be performed according to a new ASTM standard for slab foam testing issued in 1958 and revised in 1964, i.e., D1564-64T* - the T stands for tentative but the actual values appearing above lasted for many years!\(^{(17)}\) A year later a similar ASTM Standard was released with molded foam test methods, ASTM D2406-65T

*ASTM Std Title “Tentative Methods of Test for Flexible Urethane Foam”.
Technically Molded foam could be produced, but was it more attractive than pouring large slabstock blocks and fabricating seating by cutting and gluing pieces together? What exactly were the advantages of molded parts for automotive cushioning in the 1960s? The main points were outlined by Buist and Woods in a RAPRA paper.\(^{(11)}\)

1. Substantial reduction in labour costs (much lower than the fabricating of complex shapes)
2. Reduction in foam wastage (from the cutting operation)
3. Greater ease by which pieces of complex curvature can be made.

---

Figure 18: ASTM D2406-65

Figure 19: Slab Stock Blocks / Molded Foam Pad
How did the molding process take shape and become so widely accepted in most industrialized countries, primarily for automotive seat production but for furniture seating as well?

2.2 Hot Foam Molding Processes

In 1962-1963 microwave heating using radar frequency radiation (12.5cm wavelength, 2450 Mc/s) was developed and grew rapidly over the following two years to become fully-commercialized. This type of equipment was developed by ICI Chemicals. Molds made of glass-reinforced epoxy resin with an inner skin of resin loaded with iron powder gave rapid heating of this inner surface and good foam cure and release. Foam cure times were three-and-a-half to four minutes (1962). Soon these molds were replaced with asbestos-reinforced phenolic ones and multi-unit magnetron cavities further reduced cure times to 1-2 minutes. These phenolic molds were backed with rigid foam to insulate and reinforce. Fortunately rigid foam did not absorb the wavelength of radiation being used. Initially a “hold-up” type mixing head was used to blend all the chemicals before dispensing into a mold. Low mold temperatures were used, 35 +/- 1°C and a part was made every 45 seconds.

Productivity from this type of molding operation was very good and it was reported in 1965 that these multi-unit lines could produce two to fifty thousand seat cushions per week and the product had satisfactory physical properties. Even at this early stage in molded PU development, it was advocated that improved cure (or was it reduced cost?) could be achieved by the addition of barium sulphate powder (BaSO₄). Since it is a dense compound, this BaSO₄ also increased part weights and may have promoted the concept that “more mass equals better quality”. Let us consider the foam physicals obtained via microwave heating:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>with BaSO₄</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, kg/m³</td>
<td>34-36</td>
<td>BaSO₄ 70</td>
<td></td>
</tr>
<tr>
<td>50% IFD, N</td>
<td>245-285</td>
<td>320</td>
<td></td>
</tr>
<tr>
<td>Tensile strength, kPa</td>
<td>88-118</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>Elongation, %</td>
<td>140-170</td>
<td>133</td>
<td></td>
</tr>
<tr>
<td>50% Comp. Set, %</td>
<td>-</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>75% Comp. Set, %</td>
<td>7</td>
<td>4.4</td>
<td></td>
</tr>
</tbody>
</table>
These physicals were tested against the relatively new British Standard BS 3667 part 2 issued in 1963.

Some negative aspects of microwave curing were the high maintenance of the microwave units, mold size limitations and mold life and it was difficult to obtain uniform energy fields.

At about this time molding trials with tipped or capped polyols, i.e., with ethylene oxide added at the end of the polyol chain-building process to obtain highly-reactive polyols with primary hydroxyl end-groups that react much faster than secondary hydroxyls (from polypropylene oxide additions) with isocyanates. These “tipped or capped” polyols gave improved foam cure, higher foam densities, increased part hardness and also increased some physical properties (tensile strength, elongation) but had no adverse affects on compression sets especially the so-called, critical/important humid aged compression set (steam exposure at 5psi [± 35kPa] for 2, 4 or 7 days).

So during the 60s there was a substantial increase in flexible Molding not least because of the excellent rates of productivity achieved with reject/scrap rate of less than 5%. As indicated earlier, labour costs decreased dramatically to about 10% of the cost of making an equivalent fabricated part from slabstock foam.

In the late 1960s, a typical seat construction using a thin urethane part would have consisted of:

1. Frame + S-shaped springs
2. Wire, cotton batting and burlap support pad
3. 38-50mm (1½-2 inches) molded urethane cushion
4. Fibre foam pleating insert
5. Fabric or fabric-backed vinyl cover

This type of seat construction was still in use for some seats until 1970.

In May 1965, Chrysler issued their new foam spec. MS-AY322. This contained requirements for the usual physical foam properties but included a flexing test on a 100mm (4 inch) diameter
specimen. These cylinders were compressed at 50mm/minute by 85% of their original 100mm height for 100,000 cycles. Both height and CFD losses at 25 and 65% were recorded. The maximum allowed changes were 4%, 25% and 15% for height, 25 and 65% deflection CFDs respectively. Chrysler also called for a functional life test of 80K kms or 50K miles seat performance on their proving ground or 100,000 cycles on their Bouncing Betty Seat tester. The same height and hardness (IFD) criteria were specified. At the issue of this spec., the humid aging treatment specified was five hours at 121°C (250°F) followed by the normal drying and ASTM D1564 compression set test. In addition, Chrysler called for a 90% regular compression set.

In 1970 mid-year, General Motors took the molded urethane cushioning concept still further. They introduced substantially thicker PU seat pads which they claimed were more comfortable, more luxurious and from their viewpoint, easier to handle and less seat parts were now involved. Gone was the burlap-cotton batting/padding and many of the small support wires and springs. Pads up to 127mm (5 inches) were molded using new high temperature ovens and demold times of 18-20 minutes or less.\(^{(10)}\) These thicker pads were introduced into Chevrolet Camaro and Pontiac Firebird models (1970½) and the foam had to meet the recently issued (1969 Sept 10) foam spec FBMS 7-1. This specification included a fatigue deterioration criteria which is a roller shear test illustrated in Figure 20 (GMs TM 46-8) that called for a foam to have a maximum loss number of 25% but this had to be increased to 35% as foams would not meet the 25% maximum requirement. Maximum loss number is the combined loss in sample height + 25% IFD loss + 65% IFD loss. FB (Fisher Body) distinguished between cushions and backs in that the former were tested with a 222N (50 lb\(_f\)) load whereas the less demanding backs were only loaded with 111N (25 lb\(_f\)).
Figure 20: Roller Shear Tester

Other FBMS 7-1 criteria were:

- Core density, kg/m$^3$: 28-32
- Tensile strength, kPa: 82 min
- Elongation, %: 175 min
- Tear Resistance, N/m: 306 min
- Comp. Set, %: 20 max
- CFD change after humid aging, %: 20 max

2.3 High Resiliency Foam

In the late 1960, early 1970s a new type of urethane foam was introduced and promoted by several of the major chemical companies. Since this foam had a much higher resiliency (measured via ball rebound, Figure 21), it was termed High Resiliency foam. However, since it was possible to mold at much lower or even ambient mold temperatures, it was also called “cold cure” molded foam. In this survey we will call it high resiliency (HR) molded foam.
Apart from improvements in resiliency, what else did HR foam offer? First of all, HR foam had a latex rubber-like feel, higher support ratio (65% IFD/25% IFD), improved inherent flammability resistance when tested to the FMVSS302 test protocol. A typical flammability chamber is pictured in Figure 22. In addition, HR cushions had lower hysteresis loss (energy input – energy recovered/energy input x 100%) and most importantly good flex fatigue properties. As mentioned earlier, lower processing temperatures are used and as an added bonus cure cycle times are much lower. Of course as with all processes, there were some negatives. Some of the foam physicals were considerably lower than those found for hot foams, i.e., lower elongations, tear resistance and high part densities. Poor compression sets were a concern especially after humid aging. Due to the nature of the chemicals used to make HR foam, the demolded products had a large content of closed cells and these caused foam shrinkage during pad cure. This could be prevented by crushing the pads soon after demold to burst-open the cells by rupturing the very thin cell walls (membranes) between cells. The open structure was then dimensionally stable. In many processing plants an additional processing stage was considered necessary to ensure parts were cured enough for subsequent handling, transportation and assembly into seats. Thus a post curing treatment at elevated temperature, e.g., 120°C for half-an-hour or longer was used.
How was this HR foam made? The whole idea was to try and obtain properties as good as or better than latex foam. The problem with hot foam was that it required a high force (load) to obtain say a 65% deflection (i.e., compression). Latex foam, in contrast has a much lower IFD hardness at the same deflection.

Therefore since latex foam came before hot foam, its deflection/force curve was considered the standard in obtaining comfortable foam in compression. To try and achieve the “latex feel” the polyurethane chemistprocessors tried a variety of chemistries. They all involved much higher molecular weight polyols (4500-6000 MW) in comparison with the 3,000 MW triols used to make hot foam. These new polyols were capped or tipped with ethylene oxide to give the more highly reactive primary hydroxyl groups at the ends of their chains. 78-80% primary hydroxyls are typical of the polyols used in HR Molded foam. In addition, other reactive chemicals were used such as diethanolamine, triethanolamine, aromatic diols and liquid aromatic diamines. Whereas hot foam was made with regular 80:20 isomer TDI, HR foam systems were developed using “crude” MDI, “crude” TDI, blends of “crude” MDI/pure TDI. Here “crude” means that the isocyanate was not refined or distilled to obtain a pure product. Today, the word “crude” is not used, having been replaced with “polymeric” in the case of MDI.
Another approach to obtain HR foam with acceptable molded processing and foam properties was to use, what can be termed generically, dispersion-modified polyols. These were initially released by Union Carbide Corporation (now Bayer Materials Science) and labeled as Polymer polyols. They contain in-situ modified polymer particles that are stable in the base polyol but are opaque rather than clear due to the particle dispersion. Other names for these dispersion-modified polyols are Graft polyols (BASF), Copolymer polyols (Dow), PhD polyols (Bayer) and PIPA polyols. These last dispersion-modified suspensions are a “kind-of-home made material” in that the foam manufacturer was able to make the suspension in-house. The patented technology was owned by Innochem and various foamers and chemical companies (e.g., ICI, Shell) were licensed to make the suspension. For molded foam, the most successful foamer was Woodbridge Foam Corporation who ran production using PIPA in North America and Europe for some years. The polymer/graft/copolymer polyols contain a suspension of ACN (acrylonitrile) or SAN (styrene acrylonitrile), PhD polyols a suspension of urea particles and PIPA a suspension of polyurethane particles. In all products the particles are stable in the carrier or base polyol.

Dispersion-modified (DMP) polyols have been the most successful route to HR molded foam production and all earlier or concurrent technologies have been abandoned. This is mainly due to the superior processing using DMP polyols including foam cure, easy or no foam crushing and good physical properties. In addition, DMPs have the added advantage of rapid hardness build-up and better humid aged properties and strength than HR foam made via other routes. As an example DuPont\(^{(18)}\) promoted the use of HR foam based on an aromatic diamine LD813, a special isocyanate, LD3020-3. Basically, the main ingredients in the formulation were:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000 MW polyol</td>
<td>1,000</td>
</tr>
<tr>
<td>LD813</td>
<td>3.5</td>
</tr>
<tr>
<td>Water</td>
<td>27</td>
</tr>
<tr>
<td>LD3020-3 ISO</td>
<td>100 Index</td>
</tr>
</tbody>
</table>

This formulation was developed to be used in the 1973 model year vehicles which had to meet the newly-introduced flammability standard FMVSS-302 (1972 issue). The isocyanate LD3020-3 was an undistilled version of TDI. The aim of this HR foam work was to produce deep molded
foam cushioning with improved comfort, fatigue, flame resistance, and low smoke generation. What properties did foam made using this technology obtain?

<table>
<thead>
<tr>
<th>Property</th>
<th>LD813</th>
<th>LD813</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, kg/m³</td>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>Tensile strength, kPa</td>
<td>145</td>
<td>138</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>210</td>
<td>205</td>
</tr>
<tr>
<td>Tear resistance, N/m</td>
<td>385</td>
<td>350</td>
</tr>
<tr>
<td>50% Comp. Set, %</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>75% Comp. Set, %</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>50% HA Comp. Set, %</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>IFD 25%, N</td>
<td>116</td>
<td>75</td>
</tr>
<tr>
<td>IFD 35%, N</td>
<td>347</td>
<td>213</td>
</tr>
<tr>
<td>Support Ratio</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>FMVSS-302</td>
<td>non-burning</td>
<td>non-burning</td>
</tr>
</tbody>
</table>

(Tested using ASTMD 1564-71 standard test methods)

Other chemical companies also favoured the use of 'crosslinkers' mainly because they did not have access to the dispersion modified polyols. Allied Chemical published information in 1971 on the use of LD813 with their Nacconate 5050 (a special isocyanate\(^{20}\)). Recall that at this time the use of Freon 11 was in wide use and some of Allied’s formulations were co-blown with F-11. Foam at 47 kg/m³ produced using this technology had good tensile strength/elongation/tear resistance. Its major drawback was that although the foam would pass the FMVSS-302 standard limits, it had a burn rate of 60-90 mm/minute.

An interesting technical service pamphlet by Dow chemical in 1970 makes some interesting statements:

- “LD813 produced by E.I. DuPont will affect load bearing strength and compression set in a desirable manner”.
- “Crude TDI (undistilled) gives good tear resistance but requires special surfactants and techniques to overcome poor compression sets and moldability.”

Even more interesting is Dow’s “Comparison of Foam Properties imparted by Isocyanates to HR Foam”: 
Molded Polyurethane Foam Industry Panel

<table>
<thead>
<tr>
<th>Property</th>
<th>MDI</th>
<th>Crude TDI</th>
<th>TDI</th>
<th>MT-40 (Mobay)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFD</td>
<td>H</td>
<td>Medium H</td>
<td>L</td>
<td>Med</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>P</td>
<td>Ex</td>
<td>Ex</td>
<td>G</td>
</tr>
<tr>
<td>Modulus</td>
<td>G</td>
<td>Ex</td>
<td>P</td>
<td>G</td>
</tr>
<tr>
<td>Comp. Set</td>
<td>Ex</td>
<td>P</td>
<td>P</td>
<td>G</td>
</tr>
<tr>
<td>Cure</td>
<td>G</td>
<td>G</td>
<td>P</td>
<td>G</td>
</tr>
<tr>
<td>Moldability</td>
<td>Ex</td>
<td>P</td>
<td>P</td>
<td>G</td>
</tr>
<tr>
<td>Feel</td>
<td>Boardy</td>
<td>Latex-like</td>
<td>Soft</td>
<td>G</td>
</tr>
</tbody>
</table>

Where:  
H = high  
L = low  
P = poor  
G = good  
Ex = Excellent  
Med = Medium

From this table it looks like MT-40 isocyanate produces the best performing foam and TDI the worst! MDI also looks good.

In contrast, Patten et al., at Union Carbide Corporation\(^{(19)}\) published the use of polymer polyols to make HR Molded foam. They had to use a new class of surfactants that allowed control of foam cell size and eliminated localized cell collapse at foam surfaces, so-called basal cells. Some other chemical changes had to be made to overcome/provide adequate foam firmness for auto-seating applications. They knew that by using short chain alkanol and aromatic amines to increase polymer chain stiffness via higher concentrations of urethane and urea structures was not the way to go. The reason? Poor foam processibility and the resultant properties using these chemicals resulted in poor foam properties, unacceptable to the OEMs. Thus, the incorporation of polymer polyols over a range of composition resulted in the required IFDs and support factors. This led to the acceptance of polymer polyol technology in HR Molded foam, especially at General Motors who held about 50% of the auto production in North America at that time. GM operated in-house Molding lines and these switched over to HR foam production in 1973.

Automotive Cushioning Through the Ages  
September 2008
Why was HR foam based on polymer polyol (PP) accepted? Polymer polyol HR foam offered several advantages:

- Increased PP levels increases tensile strength
- Decreases elongation but still acceptable
- Has negligible effect on compression set
- Increase humid aged load loss but acceptable
- Negligible effect on humid aged comp. set (?)
- Support ratio and resiliency are unaffected

By the end of 1973, over 68K metric tonnes of foam was being poured using polymer polyol technology. It also was reported that polymer polyol-type of HR foams had superior quality than latex foam and had better resistance to oxidation than latex.
Later work by BASF with their version of DMP, (their graft polyol) proved similar in processing and in resultant foam properties using TDI or blends of TDI and MDI, that it could be used interchangeably with UCC DMP polyol.

This success with HR Molding was encouraging and it was projected that one-piece bucket seats (presumably cushion and back) would be feasible. All sorts of components could be molded in place and frames were targeted for incorporation (Figure 24). Experiments with molding in skins (probably vinyls) were reported and even integral skinned seating was suggested but the problem was the lack of skin breathability.

Figure 24: Trim Attachments, Cloth Reinforcement, Border Wire, and Wire Frame

Although GM marched successfully down the HR foam route, others were not as aggressive/advanced. American Motors Corp. (AMC) did produce some HR backrests in-house but Ford (25-30% of N.A. production) still had a springs and topper pad approach to seating and in 1974 did not have much interest in HR foam Molded products.
So in the mid-1970s, HR Molding was well-established at the in-house OEM plants and by custom Molders. The major consumers of flexible polyols for Molding in the USA at that time (both hot and HR types) were:

- Inland Division, GM: 18-23K metric tonnes
- Fisher Body Division, GM: 18-23K
- Goodyear Tire & Rubber: 14K
- Hoover Chemicals Product, Dev: 14K
- The Davidson Rubber Co.: 9K
- Allen Industries: 9K

At that time Hoover (now JCI) claimed to be the largest custom molder in the USA making hot foam molded products. Hoover had evaluated several HR systems based on modified isocyanates and mixed isocyanates but they rejected these technologies due to low tear resistance values (less than 175 N/m). Another foamer, Burkhardt Division of Textron Industries Inc., still poured hot foam on two production lines but had a single HR foam line in Cairo, Illinois.

When HR Molded foam was accepted in North America and Europe, some changes had to be made in the OEM specifications to allow this foam to be acceptable. For example, since HR foam could not match hot foam elongations or pass the compression set requirements after humid aging at 120°C and a pressure of 35kPa (5 psi), these requirements were lowered, e.g., elongation reduced to 150% min. (and much later to 120%) and humid aging was performed at 105°C for three hours instead of five hours at 120°C. This latter temperature was shown to actually degrade the foam during treatment\(^{(21)}\), a phenomenon that would never occur in vehicle use. Reducing the elongation requirement to even 120% min. proved to be quite sufficient as foam cushioning is used in compression in vehicles and the tensile properties do not reflect seat performance.
However, in Japan it was recognized in the late 70s\textsuperscript{(22)} that any humid aging treatment (in steam autoclaves) before testing did not reflect the functionality of seats in tropical conditions. Thus for Asian OEMs the switch from hot to HR foam was slow and in 1977 there was no Asian foam flammability requirement. Japanese Molders considered HR foam more difficult to mold and they worried about the use of this kind of foam during the high humidity Japanese summer.

They expected HR foam to undergo severe fatigue failure even at temperatures less than 100°C.

To overcome these fears an alternative hydrolytic test was presented. They decided to use compression set under tropical conditions as a means of evaluating and predicting long term HR foam performance. They selected 50°C, 95% RH conditions and all Asian OEMs called for wet compression sets under these conditions. Typical wet compression set apparatus and chamber are shown in Figure 26. Later, it will be noted that wet compression set is indeed a good predictor of foam durability and the humidity treatment of choice.
It is interesting to note that GM Fisher Body personnel have indicated that the swing to HR foam was partially fortuitous. They had decided to switch to full depth seating late in 1969 but were going to scale-up production using hot foam technology. The advent of the new HR foam chemistry based on polymer polyols and its improved processing and desirable physical properties convinced them to go with HR foam. They were able to improve productivity, efficiently utilize labour, produce at low scrap rates, achieve efficient material usage, obtain outstanding formulation flexibility and produce parts with excellent physical property control especially foam modulus.\(^{(23)}\)

Advances in chemistry and process allow parts to be molded with a thermoplastic or cloth cover in place, hence the name foam-in-place seating. Although this trim / molding process provides a finished seat cushion, it has its limitations when it comes to part complexity and craftsmanship. Another drawback is the cost penalty that is incurred if reject parts are produced. However, the foam-in-place process can be advantageously applied to the production of complex small parts, such as head rests.

Today HR molded foam is the predominant material used in automotive seating. Progressive improvements in the chemistry and processing have insured that reproducible parts can be manufactured day in and day out. Improvements in foam testing and seat evaluation have been
made to insure that current HR molded foam performs well and reproducibly in today’s wide range of vehicles.

There are a plethora of components that are either molded into or attached foam seat parts, which provide comfort, address safety, and provide ease of assembly. Today’s advanced polyurethane foam chemistry allows very complicated parts to be successfully molded, such as multiple hardness or density zones in the same cushion. For instance, within the same pad the bolsters can be made firmer than the foam in the seating area. Optimization of chemistry and processing also allows for the production of complex shapes, e.g. hooded seat backs, whereas previously two separate parts were molded and glued together to form the finished part.

Figure 27: Foam Pads with Various Components

3. Accelerated Laboratory Durability Testing

No matter how an automotive seat is constructed it must be fully-functional throughout its service life with no or minimal change. This can be simulated in the laboratory by performing accelerated durability tests on foam samples or on fully-trimmed seats using, for instance, a jounce and squirm fatigue tester (Figure28). This machine applies cyclic loads and shearing motion to seats and any change in appearance or properties recorded. For instance, a seat may be subjected to a buttocks being applied to its top surface 100k cycles at ambient
conditions. In these trials not only is the foam tested but all seat components, frame, wires, suspension and cover.

Figure 28: Jounce and Squirm Tester

Seat durability is one critical property that must be met. The other one is seat comfort — a much more difficult property/concept to ascertain. This is especially true when “so-called comfort experts” are consulted. The best definition they can come up with for comfort is the absence of discomfort”.

Let us consider what may be termed a comfortable seat. It is considered important for the occupant to reach his/her final position in the seat quickly and hence rear view mirror adjustments are minimized or unnecessary. Once the final seating position is attained, the seat should still have some degree of resiliency remaining (some bounciness left). To achieve the initial seat position, it is important for the air within the seat, primarily in the foam cells, to be expelled rapidly so that the occupant does not encounter a feeling of pneumaticity.

Foam resiliency is always measured on an uncompressed foam sample but can the compressed foam in a seat be measured for resiliency? Pseudo-resiliency measurements can be made which indicate that the foam retains its resiliency at least to a compression of say, 60% deflection. Even at this degree of compression the foam is still cellular although the cells will be considerably compressed vertically. Thus seat comfort should be maintained. Some compressive creep of the foam will occur during seat occupancy but studies have shown that if
good quality foam is installed in a seat, the extent of creep is small and not noticeable. If extensive creep (compaction of the foam) occurs, constant seat and/or rear or side-view mirror adjustment will be necessary. Only in the case of poor quality foam (made deliberately) or substituting fibrous material for foam in a cushion will creep be serious enough to cause visual/buttocks discomfort\(^\text{(26)}\).

4. Synthetic Fibrous Fillings

Earlier we discussed the use of natural fibres in vehicle cushioning such as animal and vegetable fibres, e.g., pig hair, coconut fibre and cotton. Over the last thirty years or so, various attempts have been made to use synthetic fibres in seating, either to replace polyurethane foam, or to be used in conjunction with foam. We will consider a few of these materials, their type, properties and the reasons for their demise.

Figure 29: Polyester Material and Pad

In 1973, DuPont introduced polyester fibres using the ‘Pneumacel’ name.\(^\text{(27)}\) This consisted of an intermingled mass of polyester fibres held together with a thermoplastic binder, PVA. These fibres were produced in sheets of 13mm (1/2 inch) in thickness and could be formed into cushions/backs using perforated, sheet-metal Molds. Hot air at 138-150°C was blown into the Molds to heat the fibres and expand the sheets to fill the Mold. After demold/cooling the shaped cushion was placed directly over a spring suspension in the seat and then trimmed. It was claimed that these seats were very comfortable and did not “bottom-out” in use. However, to ensure the necessary amount of ‘sink-in’ when the occupant sat on the seat, a 38mm (3/4 inch)
layer of PU foam had to be laid on top of the Pneumacel. Also claimed that the material was easy to work, lighter than PU foam and satisfied the FMVSS-302 flammability requirements. The claimed cost savings over foam was 25%.

Pneumacel fibres contained minute cells pressurized by Freon gas (which has been withdrawn/banned in most countries) and fibre expansion occurred when the Freon expanded on heating.

Very few seats were made from Pneumacel. Avanti vehicles with very limited production volume were made, but other uses/users are unknown. Some furniture use may have occurred.

In 1998, JCI introduced PET fibre pads made from crimped fibres manufactured from post-consumer, recycled bottle resin\(^{(21)}\). These PET fibres were thermoformed with bicomponent PET fibres to obtain the required shapes. It was claimed that these materials produced seats that met all OEM comfort and durability requirements (North American and European OEMs).

The claimed advantages for these “Slimline” seats were:

- no adhesives used and no hazardous emissions
- seat pads are 10-20% lighter than PU foam seats
- they are up to ten times more breathable
- they can be Molded to multiple densities
- they provide equivalent load support with 10-20% weight reduction over PU foam seats
- PET cushions have a lower maximum peek at resonance than PU cushioning and thus should be more “comfortable” in use (vibrational resonance testing)

These “Slimline” seats were available for the 1999 model year vehicles but it is not known if they were actually used for production-series vehicles.

Some other fibrous materials, almost exclusively polyester (PET) based have been reported in the literature.
Araco Toyota introduced ‘Elfwool’ fibrous cushioning which had been developed by Teijin Limited in Japan. Once again the claim was made that seats were approximately 20% lighter, had better breathability than PU foam and they had excellent cushioning performance. They could be finished to a fine, soft texture (so probably they did not need a PU foam topper layer) and they were less affected by changes in atmospheric humidity.

In December 1999, it was announced that these PET fibre seats were being used in kindergarten hybrid bus seats.

The Teijin web site introduced another material “Elk”, again an interlocking polyester fibre which it claimed emitted less toxic gases when burnt and offered more seating comfort to users.

Yet another Japanese supplier also promoted the use of PET fibres; Takagi Chemicals, Inc. This material called “Curllock” was mentioned in the literature in 1989 but there is no record of this fibrous type being used in any automotive application.

In December 1996, Modern Plastics had an announcement by DuPont concerning their “Dacron”-based seating. Dacron fibres were hollow in cross-section with either single or multiple holes. These fibres were formed into “fibre clusters” which it is claimed contributed to superior loft and shape retention. In addition, these clusters were hypo-allergenic, non-absorbent and mildew resistant, i.e., superior to natural fibres. The fibre balls, marketed as “Ecofil” were:

- 100% polyester (no Freon) and could be molded to replace PU foam seating
- molded seats were five times more breathable than PU foam seating
- the cushions will retain 85-90% of their thickness after years of use
- 30-40% lighter than PU foam
- good showroom appeal (presumably the seats “felt” good)
- recyclable

The fibres themselves consisted of 80% regular PET fibres and 20% of lower melting point fibres which were used to bind all of the fibres together.
Seats were made using perforated, low cost, stamped metal tools. The fibre clusters were loaded into the mold, and hot air blown through the mold to soften the binder fibres and to bond the structure together. Air was then used to cool the mold before the cushion was removed. This process could produce thinner seating with at least a 30% weight saving and the cost was “competitive with PU foam seating.”

DuPont was reported to be working with the Oakwood Group, Dearborn, Michigan to commercialize this technology. Formerly, JCI was also a partner but left to develop its own technology. Polyester cushions have different load-bearing traits from PU foam cushions and they feel firmer.

Woodbridge Foam Corporation contracted with DuPont to manufacture some cushions for the 1993 Chevrolet Caprice Classic vehicle that was extensively used by police departments in North America. Seats were inserted in vehicles, a comfort survey was performed and the vehicles were returned to use. In about three to four weeks, the seats had to be removed due to comfort complaints from the police officers. They were seen to be “flattened” and the resulting properties (tested against the GM6293M foam spec) were poor. No further trials were done and the seats were classified as failures.

In Japan (1996), Toyota used fibre seating in their new Lexus models. This choice was made to obtain Mercedes-Benz-like seating which still used rubberized-coconut fibre seating. Toyota did not believe they could use coconut fibre seating. To simulate/replicate the Mercedes-Benz seating performance, NHK made seats marketed as “Neo-curl” PET fibre seating for Toyota. Neo-curl seating was made with polyester fibres soaked in a urethane adhesive and then Molded to shape in a hot tool. Subsequently there were durability and comfort failures with this seating and they had to replace them with PU foam cushions. Once again, these Neo-curl seats were promoted to take advantage of their greater porosity and openness for heated seats, but this was found to be a fallacy. The high cost of these Neo-curl seats and their poor durability lead to their abandonment.
Fibrous-type cushioning suffers in accelerated laboratory tests such as constant force pounding or in a dynamic fatigue test. In these tests, after pounding/cycling, the cushions exhibit severe marking/deformation where the circular indenter meets the pad. Recovery, even after twenty-four hours, only takes place marginally and leaves a distinct hollow. “Ecofil” cushions, developed by DuPont for the 1993 Ford Escort, were subjected to a dynamic fatigue test. The cushions had an initial harness of about 208 N but a final hardness of only 152 N, i.e., a loss of about 27%. Cushion height loss of almost 8% was recorded and a creep of about 7%. Factoring these losses into a standard equation for dynamic fatigue (developed by Dr. V.S. Murty at GM) resulted in a dynamic fatigue number (DF No.) of 106. This is not an acceptable loss number as it exceeds 100 which is regarded as the maximum loss number for durable seating. For instance, a typical, comfortable and durable PU foam seat will have a DF No. of 90 or less (the lower the number, the better the durability).

It is also claimed that fibrous seating can be reused. Natural fibres can be recovered by “picking them apart”, whereas, synthetic fibres can be remelted or dissolved and a new one produced. This may be possible but mixed-grade fibres (normal + low melting point fibres) may prove difficult to reuse in the same process as developed for virgin fibres.

5. Other Support Materials

In 1995, Milliken & Co. claimed that a new fabric called Gemstone can be used to eliminate or reduce “costly, bulky foam and springs.” “Gemstone” consisted of a three-fabric formation technology that used ‘Elas-ter’ from Hoechst Celanese. This material was claimed to be a fatigue resistant polyester monofilament which provided seating comfort and support via the fabric instead of via foam and springs. It also claimed to reduce part weight and size (thickness?) of a seat and the material was recyclable. Any seating firmness requirement can be achieved by engineering the Elas-ter monofilament stretch.
This Milliken construction proposed suggested that using Gemstone fabric and a thin PU foam topper pad resulting in the cushion having a 50mm thickness and a weight of about five kg. As far as this survey has determined, no commercial automotive seating has been manufactured using the Elas-ter (elastic-thermoplastic) monofilament or Gemstone fabric.

A few years later (1999) Lear Corporation indicated an interest in elastomeric seats using multifunctional fabrics. They were considering a suspension fabric with a thin layer of PU foam on top. The main components used to provide suspension are monofilaments made from thermoplastic elastomers and these filaments are the dominant load bearing yarns in these elastomeric fabrics.

The claimed advantages for this material are:

- reduced weight
- space saved
- quick response to cabin environmental temperature change
- easy heating/cooling of seats
- potential cost savings
- less bulk to recycle or dispose when seats are removed from expired vehicles

No comfort or durability data was published and no known production series usage is known.
6. **Seating Comfort/Durability**

Up until the early 1980s, seating comfort had been of little importance as a selling feature in an automobile. Let us consider what a driver/passenger requires from a comfortable seat:

- optimum distribution of seating pressure
- safe support in all driving conditions, especially lateral support while turning/swerving
- protect the occupants from minor vibrations, oscillations and shocks transmitted from the road via the vehicle construction and seat mounting.
- feeling of comfort in the vehicle under all climatic conditions

![Pressure Distribution and Ventilated Seat](image1)

*Figure 31: Pressure Distribution and Ventilated Seat*

![Vibration Transmissibility](image2)

*Figure 32: Vibration Transmissibility*
In North America and many countries in Europe, full foam cushioning is used to obtain comfortable seating. Some vehicles have cushion supports of sinusoidal (zig-zag) springs whereas other OEMs use deadpan or shell supports.

High resiliency, molded foam for seat cushions is now used almost exclusively for comfortable seating and some OEMs specify a minimum foam density requirement to ensure good vibration absorption and long term durability. Full foam seats dampen vibrations by air friction flowing through the open cells of the foam. HR foams offer improved (reduced) seating pressure points even during long distance travel. If a seat is constructed of a deep foam cushion sitting on a perforated shell or flexing support (springs/wires), it will have a lower vibration peak amplitude than can be achieved, by say, a foam topper pad and spring construction. Some seat designers consider a foam thickness of 120-150mm to be the optimum to achieve superior comfort. However, it must be noted that seat contours and the trim cover play an important role in vibration dampening.

Another aspect of seating comfort is the removal of the heat generated by the human buttocks sitting on the seat. One important route for the removal of this heat is by transmission of the warm, humid air horizontally through the seat surface. This can be enhanced via optimum seat surface contouring.

Seat durability is another important property that must be addressed during the design stage and when prototypes become available. Some experimenters consider the long term seat capability can be assessed using accelerated laboratory tests such as a pounding or so-called dynamic fatigue test, either at ambient conditions, or even at tropical climate conditions, e.g., 40°C, 80% RH. It has been recognized that a pounding test, as illustrated in Figure 33, can be used to screen between good, mediocre and unsatisfactory foam seating. Usually the accelerated tests will indicate satisfactory cushioning if a height (thickness) loss of less than 10mm is found. Larger changes in seat hardness are often experienced but firmness recovery is quite rapid, say in less than 24 hours and if the seat is not pounded again for some time, further recovery is experienced. A few percent loss in hardness may never be recovered due to
some foam damage that occurs during the 80 or 100K cycles of pounding. A good correlation between actual in-vehicle usage and accelerated laboratory pounding has been established.\(^{(26)}\)

![Figure 33: Constant Force Pounding Tester](image)

It has been mentioned that PU foam seating hardness can be altered by changes in climatic conditions (both temperature and humidity). Increasing temperature and/or humidity will result in softer cushioning but any change is recoverable if the seat is returned to standard conditions (23 +/- 2°C, 50 +/- 5% RH). Similarly, if cushions experience very cold conditions, they will exhibit increases in hardness, but once again they will recover to their original values when reconditioned.\(^{(13)}\) Similarly, if a seat is say, wetted by a liquid (water, coffee, tea, etc.), it will change its hardness but when the liquid is removed, complete recovery is usually achieved.\(^{(34)}\) However, it should be noted that if foam is subjected to unrealistic conditions such as treatment in an autoclave at elevated temperature (105 or 120°C) for several hours, it may experience considerable hardness and other property changes. It is recognized that some of these unrealistic treatments, which do not bear any resemblance to real-world conditions, actually change the foam structure (this will not take place in vehicle usage) and sometimes large property changes result.\(^{(21,35,36)}\) However, on many occasions even these changes are at least partially recoverable leaving only a small amount of permanent change.
The Molded Foam Industry Panel (made up of chemical suppliers, foam Molders, seat assemblers and three OEMs\textsuperscript{(37)}) have established that seat foam for long term service usage can be successfully evaluated in the laboratory using two stringent tests. These tests are the aforementioned Constant Force Pounding test (repeated compression of foam coupons using a 750 N mass for 80K cycles) and a hydrolytic test called Wet Compression Set. This latter test consists of compressing foam specimens to 50\% of their original height and then conditioning the compressed specimens for 22 hours in an environmental chamber held at 50 \pm 2^\circ C, 95 \pm 5\% RH. Specimens after removal and reconditioning in a standard laboratory for only 30 minutes are re-measured and any height loss calculated. All foams exhibit height (thickness) losses when measured but height recovery takes place quite rapidly on further conditioning and only a few percent permanent loss is found for good quality PU foams.

The combination of dynamic flexing in the Constant Force Pounding Test and the response to compression under tropical conditions, are considered encompassing – enough to predict the potential performance of molded foam cushioning. Foams that perform well in these two accelerated aging tests are predicted to perform well during in-vehicle usage. In contrast, materials which have poor pounding and/or wet compression set properties have unacceptable in-vehicle performance.

7. The Future of Auto Cushioning

Will PUF still hold the dominant position that it now occupies? What must be done or happen to see PUF displaced? To answer these questions we have to consider the unique material under consideration. Polyurethane is the most versatile of the common polymers and can be formulated to satisfy many applications from a dense elastomer to a low density foam both flexible or rigid, and other types such as varnishes and sealants. As far as auto-cushioning is concerned, the urethane polymer is flexible and can be flexed almost infinitely without rupturing. The specific gravity (s.g.) of this polymer is about 1.15 i.e., heavier than water and many other polymers such as PE or PP. Yet although it has a relatively high s.g., it has been used for over 50 years for cushioning in spite of “attacks” by other materials, such as polyester fibres of various types. It must also be noted that urethane is a cross-linked structure, which although
susceptible to humidity/temperature changes, it can be used even at relatively low and high temperatures. Even the changes that take place due to humidity fluctuations are reversible and the material regains its original properties. Other polymers are less “forgiving”.

As far as auto-cushioning is concerned, the polyurethane polymer that has been used has changed considerably since the introduction of PUF seating. This was achieved by advances in PU chemistry and the advent of new raw materials of various types. For example, new polyols, new catalysts, and surfactants and of course new and modified isocyanates, both TDI and MDI types. Similarly great changes have been made in PU processing, each change resulting in improved metering, mixing and foam distribution and structure. For instance, PUF cushioning can be made with multi-property areas (hardness, density or modulus) with excellent continuity between the area types. The range of properties within these areas (phases) can be extremely wide to satisfy specific seating performance. Very low or high densities can easily be achieved with a wide range of physical performances.

Figure 34: Cushion and Back Multi-Firmness Zones

However, it must be remembered that typical PUF cushioning for autos are all quite low in density. If we assume that current auto-cushioning is manufactured within the density range 25 to 100 kg/m$^3$, how much actual urethane polymer is present? Also remember that almost all of this polymer is concentrated in several areas of a cushion, namely the struts making-up the PU
cells and at the skin surfaces. A very small amount of polymer is found at the cell windows but this can essentially be neglected in this discussion.

If we consider the foam core free of skins, the amount of PU polymer in the struts can be calculated and its volume is surprisingly small. For example, foam with a core density of 30, 50 or 70 kg/m$^3$ have polymer volumes of about 2.8, 4.3 and 6% respectively. Thus the very low volume percentage of polymer to “do the work” in auto-cushioning can be realized. So a change of 5 kg/m$^3$ in a cushions density only involves a change of about 0.4% in polymer content. If significant changes in seating performance are required, such as cushion hardness to achieve the desired seating H-point, it is probably desirable to change the polymer composition via one or more of the chemical possibilities available to foam producers, e.g., change the isocyanate index or polyol solids content if a DMP polyol is being used. If cushion mass is critical, then polymer changes resulting in a cushion with the same “weight” is the best solution.
It is certain that the rigorous evaluation/testing of successive PUF types has demonstrated their performance worth and ensured that long term durability as predicted by accelerated, short term laboratory tests have guaranteed long term successful in-vehicle performance. Both the PUF industry (chemical suppliers, foamers, seat assemblers) and the automotive OEMs have developed a foam performance criteria that ensures long term, functional PUF cushioning.

However, recently it has been recognized that not all of the tests requested/ performed on auto-cushioning are useful in predicting the functionality/performance of cushioning. Many of the tests/properties performed on flexible foam cushioning have been handed down or inherited from earlier seating materials, such as rubber-latex foam. With the introduction and acceptance of successive PUF types, many of these properties were “carried-over”. Only by critically-reviewing each property against foam seating functionality has the inappropriateness of some tests been highlighted. Some of these non-functional properties may surprise a few in the industry.

An extensive industry-wide survey has clearly indicated that some inherited properties do not reflect the functionality to which auto-cushioning must perform. For example, PUF is used almost exclusively in compression, and yet foam tensile properties have remained as “important” physicals for PUF qualification in seating. Likewise other “hand-me-down”
properties do not serve as predictors of cushioning performance, either short or long term. Thus an industry group (The Molded Foam Industry Panel) has recommended a set of foam test properties that, in their consideration and based on several hundreds of years of combined PUF experience/knowledge, will adequately predict the performance of PUF cushioning.

In addition, these foam properties have been thoroughly evaluated and checked for repeatability/reproducibility and it has been demonstrated that these selected properties are well-correlated with actual, long term cushioning performance in test vehicles. These properties are:

i) Tear resistance (using a die C specimen as called for in ASTM D624-00)
ii) Compression Set under tropical conditions (50°C, 95% RH); also called Wet Set
iii) Resistance to thickness and hardness changes after arduous, repeated pounding for 8-K cycles (ASTM D3574-05, test I3, Constant Force Pounding)

The most immediate challenge for the PUF cushioning industry is to ensure that it responds to changing marketplace challenges. Recycled polyols (glycolysates) were offered about ten years ago and if of sufficient purity, could be used in new foams at significant replacement levels without loss in foam performance. “Cruder” recyclates could be incorporated but at lower levels and foam performance suffered. To date, foam containing recyclate is not being manufactured commercially.

Within the last five years, the promotion of polyols from renewable resources (biopolyols) has been actively received by the urethane industry. Such polyols have been used since the inception of the urethane industry and although small amounts of caster oil-based polyols have continued to be used, the preponderance of polyols used commercially have been petroleum-based. Vegetable-based polyols from such sources as soy, palm and others have been developed and offered to the industry. These new polyols can replace petroleum-based polyols but only limited substitution is possible to date. For auto cushioning, a substitution level of 5% by mass is proven and higher levels will likely be possible. It is most probable that the OEMs will allow and/or will promote even higher substitution levels if the resulting foam properties are as good as, or better than, petroleum -based chemistries both in short term laboratory testing
and in vehicle performances. In addition, OEMs expect these foams containing vegetable-oil based polyols to be revenue neutral or even less expensive than current foams!

![Image]

Figure 37: Vegetable-Oil Based Foam Chemistry

8. **Conclusions**

From the above summary, it is obvious that PUF (polyurethane foam) is an extremely versatile material that has been changed many times since its introduction to auto-cushioning. Thus, any replacement material will have to be versatile and have at least the same, or superior properties, to allow seating to remain both comfortable and functional for the lifetime of a vehicle. The “attacks” on PUF by fibrous products have failed since these materials do not satisfy seating criteria. Likewise, products made from lower specific gravity polymers, have not been able to reproduce the performance of PUF, although they are used in other applications. For example, PS bead foam is used in some furniture cushioning and PE foam has found uses in flotation devices and gym mats.

What would help to displace the current types of PU cushioning? A few possibilities/suggestions are:

i) Substantial increase in cushioning density, much above that used or even conceived at present. Density increase may be required if much thinner cushions/backs are designed while performance must be maintained.
ii) Changes in seating performance, most probably reduced properties that may allow the use of materials unable to match PUF properties. These lower grade materials may be just “fillers” and the seating performance desired by OEMs seating engineers, but most especially by auto-customers, achieved by other means.

In conclusion, PUF has proven to be an excellent seating medium with many desirable properties and excellent long term durability in all climates. Foam has been improved considerably over the last 50 years and with minor exceptions, became and has remained the material of choice for quality cushioning in vehicles of all types (from motorcycles, through passenger cars and buses, to heavy trucks and machinery). Many historic and collector vehicles are still dependent on the original PUF seating that was installed during the vehicle build and will continue to perform well for many years to come.

Figure 38: Transportation Seating; Automotive, Bus, Truck, and Motorcycle

It is conceivable that new products will displace some or all PUF cushioning applications but none are on the horizon at present. If the PUF chemists continue to adapt their product to satisfy their customers; e.g., by incorporation of vegetable-oil based polyols and other desired changes, then the future for Polyurethane Foams is bright. Should it become mandatory or desirable to extract PUF from expired vehicles, there are many avenues open to recycle PUF either back into auto components or other applications. PUF can be “recycled” into energy if required but reusing as desirable new products may be the preferred route.
Polyurethane Foam is an extremely versatile product with a myriad of uses to enhance our daily lives and will continue to serve as a functional family of products for many years to come.
## Appendix

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batting</td>
<td>Cotton or wool pressed into thin layers</td>
</tr>
<tr>
<td>Buckram</td>
<td>Coarse linen or cloth stiffened with gum or paste</td>
</tr>
<tr>
<td>Burlap</td>
<td>Coarse canvas of jute for sacking</td>
</tr>
<tr>
<td>Cambric</td>
<td>A fine, thin linen or cotton cloth</td>
</tr>
<tr>
<td>Coil</td>
<td>A twist of hair</td>
</tr>
<tr>
<td>Duck</td>
<td>A strong cotton or linen cloth with a lighter and finer weave than canvas</td>
</tr>
<tr>
<td>Flock</td>
<td>Waste wool or cotton used for stuffing furniture and mattresses; pulverized wool or felt applied to paper, cloth or metal to produce a texture or pattern</td>
</tr>
<tr>
<td>Excelsior</td>
<td>Shavings of soft wood for stuffing (to create lofting)</td>
</tr>
<tr>
<td>Muslin</td>
<td>Fine woven cotton fibres</td>
</tr>
<tr>
<td>Sisal</td>
<td>A strong white fibre used for making rope, twine, etc. From the Sisal plant</td>
</tr>
<tr>
<td>Wadding</td>
<td>A soft material for padding, stuffing, packing – especially carded cotton in sheets</td>
</tr>
<tr>
<td>Webbing</td>
<td>Cloth woven into strong strips, used in upholstery and belts</td>
</tr>
</tbody>
</table>
Acknowledgements

The authors would like to express their sincere thanks to all members of the Molded Polyurethane Foam Industry Panel for their encouragement, discussions and critique of this document. We hope that it will serve as a basis for a more comprehensive cushioning survey which will contain more detailed information and fill any gaps in this survey.

We would be amiss if we did not express our gratitude to our employers Chrysler LLC and The Woodbridge Group for their support. In addition we appreciate the preparation of this document by Kathy Lane of Woodbridge and the assistance of the excellent team at the P3T Lab (www.P3Tlab.com) under the leadership of Julian Milakowski.

Also we would like to express our gratitude to Paul Garant of R M Classic Cars Inc (www.rmcars.com). Paul kindly showed us the R M Classic Cars restoration facility, explained the seat restoration process and supplied us with cushion restoration components for reference purposes.

Additionally we would like to sincerely thank the people, companies, and organizations that contributed pictures and illustrations to this review or provided access to their facilities, so we could photograph selected vehicles and their seats. This includes the GM Heritage Center, the Walter P. Chrysler Museum, The Henry Ford, and the member companies of the Molded Polyurethane Foam Industry Panel.

Finally, we are pleased to acknowledge the support given to us by our wives Stella, Janice and Maureen. Janice kindly edited the early version of the document and offered us considerable help in making it more readable.

We hope this survey will prove to be both useful, interesting and a reference resource for those engaged in or entering the automotive seating industry.

2008 September,

Ron Blair

John Reynolds

Mark Weierstall
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