5
Quality assurance and testing

5.1 Quality assurance

Quality Assurance (QA), is a broader term than quality control in that it embraces all factors which have a relevance to quality and customer satisfaction. QA begins with involvement at the earliest stages of design, communication with customers, through product development, purchasing and monitoring of raw materials, the manufacturing processes, testing and inspection of the finished product and right through to liasing with the customer after delivery to ensure satisfaction. Every member of the workforce and staff is trained to regard quality as their duty, not just the actual quality department. This approach to quality management was set down in BS 5750 and CEN 2900 and later further developed into ISO 9000. These QA systems require detailed and comprehensive specification and documentation of the product being made, materials used, all manufacturing processes and the machinery used, operative training, test methods including standards required and tolerances together with clear records of results and regular review and auditing of all procedures. Only products with test figures within tolerances specified can proceed directly to the next stage of manufacture. Those with results falling below the standard are only sent after agreement with the customer. The objective of this monitoring system is to get things right first time by allowing corrective action to be taken before unsatisfactory products are made – prevention before, rather than detection and correction after. Waste is minimized and efficiency maximized. In mid-1994 a series of QA systems known as QS 9000 was specifically drawn up for the automotive industry by the 'big three' American OEMs, General Motors, Ford and Chrysler, with the support of the American truck (HGV) manufacturers and others. The Third Edition of QS 9000 issued in March 1998 included input from the European OEMs and a growing number of OEMs world-wide now require their suppliers to be accredited with this system or an equivalent which can only be awarded by licensed inspectors. In a similar way to ISO 9000, when a company is QS

9000 registered, it is subject to periodic random checks to ensure that it continues to comply with the system requirements.

5.1.1 Product testing

Production must be monitored for two main reasons, firstly to determine suitability for further processing so that the next process will be right first time every time and secondly, to simulate actual conditions of wear during the life of the automobile. Simulating actual conditions of use over a period of years with accelerated laboratory tests, is not easy nor straightforward, and each OEM has its own methods of doing this. In addition climatic conditions around the world, vary very significantly, and test methods must take all this into consideration. Test methods applied will also depend on the physical conditions of the next process, which the article being tested will have to withstand, and also where in the car it will be situated. Car seat covers have the highest abrasion requirements, whereas parcel shelves and dashboards have the highest lightfastness and UV degradation resistance requirements.

The shade of dyed fabrics must be carefully examined because two pieces of fabric used together in the same car may have been dyed in different dye lots or even different dye works, and the shades may appear slightly different. In addition if the fabric is used in conjunction with a coloured plastic foil or dyed leather the colours may again not be exactly the same. Care must be taken to avoid the occurrence of metamerism.

Fabric volumes are high, schedules tight and it is neither physically nor economically possible to test every single roll or piece of material. The frequency of testing depends on the nature of the process and is decided after consultation with the customer. Results are generally plotted on a statistical process control chart with maximum and minimum control limits. Thus the past history of a process, and any trends in results can be seen at a glance. Customers are informed of the results, especially if they are not precisely within the specification, so allowance can be made in the next process if necessary.

It is important that any poor quality or defects are seen and identified as soon as possible in the production sequence, because value is being added all the time. Some properties such as weight and thickness can be monitored automatically by microprocessors. However the final fabric examination, generally carried out manually is a slow and hence relatively costly process but customers now call for 'zero' defects in goods received, i.e. the exact standard agreed in the sales contract. Present zero defects allows for one marked fault in typically 10m of fabric. Existing automatic examination systems are not sophisticated enough to cope with the whole multitude of factors which result in second-quality material. The technology is probably available, in theory at least, but the cost is prohibitive.

5.1.2 Test standards

Test standards are gradually being raised as the customer demands better value for money and competition amongst OEMs becomes even more intense. Cars being produced now are expected to last longer than before and to maintain high resale values of used cars, the interior must be in as good a condition as possible after years of use.[1] Abrasion resistance and light and UV degradation resistance are especially critical. Anti-soiling properties and effective cleanability are also becoming more important. There are many published articles on standards required and tests methods used.[2–10] In addition a number of textbooks on test methods are available, some of which are listed in Further Reading; the books by Merkel, and Saville are especially useful.

Manufacturing methods are changing and new tests are being introduced to allow rapid and consistent operation of the new techniques. Because of this, the seat makers themselves, the Tier-1 suppliers, are beginning to set their own test methods and standards. Examples of this can be found not only in seat making but also in connection with the new moulding techniques now being developed for door casings, car pillars and rear parcel shelves.

New specialist vehicles such as 'sports utility vehicles (SUV)', 'recreational vehicles' (RV), 'multi-purpose vehicles' (MPV), and in the USA pick-up trucks and mobile homes, are creating new requirements associated with the intended use of the vehicle – or the image it creates. An example is the pick-up truck, the 'cowboys' Cadillac' which conjures up a robust utility vehicle, (Ford advertises their product as 'built Ford Tough'), and it is likely to be treated as such! In the USA car leasing has become more widespread and so the 'private life' of the car does not start until it is say 2 years old. It must not only be in almost showroom condition after this time but it is also going to have a longer life. The American OEMs are expected to push up the specifications of light and UV degradation resistance and also that of abrasion. In addition the move towards 3-year warranties on new cars by European and American OEMs (to match the Japanese and Koreans) is also likely to lift standards all round.

5.1.3 The diversity of test methods

Test methods and standards required by individual OEMs or Tier-1s are generally confidential between themselves and their suppliers. They are however, usually based on national, international or institutional standards e.g. BS, DIN, ASTM or SAE. Table 5.1 summarizes the main test methods in use for interior trim. However, performance standards as well as test methods can vary quite significantly and what is acceptable for one OEM may not be acceptable to another. Some attempts have been made to harmonize test methods both in the USA and Europe, which can only be good for the industry as a whole.[11,12] Test laboratories must be equipped with two, three or even more different types of apparatus to measure the same property, for example for abrasion there are the Martindale, Schopper and Taber apparatuses. All the time, effort and expense incurred by the multitude of different methods could be directed towards more constructive purpose to take the whole industry forward faster. There is some pressure from the United Nations, governments and professional bodies, including the International Organisation of Motor Vehicle Manufactures (OICA), to harmonize test methods and standards in general, not just in the textile and automotive industries.[13]

5.1.4 Processability quality checks

The main properties required for downstream processing include: consistent dimensions of width and thickness; porosity; stretch and set; dimensional stability; elongation; ability to lie flat (curl); cold water stability; peel bond (lamination adhesion); and heat/humidity ageing.

Panel cutting, usually on a cutting table precedes all making up procedures. Many layers of fabric are cut at the same time and the laminate must lie flat for accurate cutting. There must not be any inherent instability to cause the laminate to distort or alter its shape in any way. If the seat cover laminate has been laminated with any one of the components under tension, it may alter slightly in dimension when unrolled or cut. Large cut panels may stretch under their own weight, especially knitted fabric laminates. This is inevitable, but they must all stretch by a consistent amount within close limitations. Mass production methods and getting the process right first time, every time, requires starting materials with consistent properties. Pour in foam methods require consistent porosity, so foam does not strike through to the fabric face and in addition laminate thickness must be within certain limits for some moulding techniques.

Consistency of properties is vital if production is to proceed without continual stops to adjust settings on machines or equipment. With just-in-time production techniques now in widespread use, everybody's production schedules are linked closely together, and a hold-up in one area is likely to cause a hold-up everywhere downstream. The ultimate hold-up is the OEM assembly line where all parts come together at just the right moment. Certain OEMs impose substantial financial penalties if their production line ('the track') is delayed.

Table 5.1 Summary of test methods applied to automotive seating and interior trim fabrics

	British Standard Test Methods	Selected Related Test Methods
Fabric weight measurement	BS2471	SAE J860 DIN 53353
Fabric thickness measurement	BS2544	SAE J882 DIN 53352
Visual evaluation of interior/exterior trim	—	SAE J361
Colour fastness	BS1006: 1990 (1996) Methods of determining colour fastness to about 70 different agencies BS1006: Grey Scales for assessing changes in colour AO2 BS1006: Grey Scales for assessing staining AO3 BS1006: BO1 Blue wool standards	ATCC Test Method 16 ASTM methods DIN 54022 (fastness to hot pressing) DIN 54020 (rub fastness)
Crocking (wet and dry)	BS1006: 1990 (1996)	SAE J861 Jan 94 AATCC Method 8 DIN 54021
Lightfastness	BS1006: 1990 (1996)	SAE J1885 Mar 92 water-cooled xenon-arc SAE J2212 Nov 93 air-cooled xenon-arc SAE J2229 Feb 93 outdoor under glass variable angle SAE J2230 Feb 93 outdoor under glass sun tracking DIN 75202 FAKRA 7/91

Abrasion	BS5690: 1991 (Martindale) NB: sometimes tested after UV exposure	SAE J365 Aug 1994 Scuff Resistance (Taber) SAE J2509D ASTM D3884-92 (Taber rotating platform) ASTM D3885 Flexing Abrasion (Stoll) ASTM D3886 (Inflated diaphragm) DIN 53 863 3/4 Martindale) DIN 53 863/2 (Schopper) DIN 53 528 (Frank Hauser, loss in mass for coated fabrics) DIN 53 754 (Taber)
Pilling	BS5811: 1996 pill box	ASTM D3511-82 (Brush) ASTM D3512-82 (Tumble) ASTM D3514-81 (Elastomeric pad) DIN 53863/3 (modified Martindale) DIN 53865 (modified Martindale)
Frosting		AATCC Method 119 (screen wire) AATCC Method 120 (emery)
Snagging		SAE J948 Aug 94 (also abrasion of vinyl/leather) ASTM D5362-93 (bean bag) ASTM D3939-93 (mace test)
Tear strength	BS4303: 1968 (1995) wing tear BS3242 pt5: 1982 (for coated fabrics) BS4443 pt6 Method 15 (for foam laminates)	ASTM D2261: 96 (tongue tear – single rip CRE) ASTM D1117/95 (trapezoidal tear) DIN 1424-96 Elmdorf tear apparatus DIN 53 356 (tear progagation)
Tensile strength/ breaking and elongation	BS1932 for yarns and threads BS3424: 1982 Method 6 (coated fabrics) BS2576: 1986 (woven fabric/strip method) BS4443 pt6 Method 15 cellular foam (laminates)	ASTM D-751 (Test for coated fabrics) ASTM D1578-93 yarns by Skein method ASTM D1682 (Grab method) not for knitted fabrics ASTM D2261-96 for woven fabrics – single rip (CRE) ASTM D5034-95 (Grab method) DIN 53857 (non wovens) DIN 53571 (tensile and elongation)
Stretch and set	BS3424 pt21: 1987 (for coated fabrics) but BS3424 pt24 1973 still in use	SAE J855 Jan 94 DIN 53853 DIN 53857

Table 5.1 (cont.)

	British Standard Test Methods	Selected Related Test Methods
Stretch and recovery	BS4952: 1992 (for elastic fabrics – replaces BS4294: 1968)	ASTM D3107-75 (lower stretch wovens) ASTM D1775-94 (elasticated fabrics – CRL) ASTM D2594-87 (low power knits)
Bursting strength	BS4768: 1972 (1997) Bursting strength and destinsion	DIN 53861 ASTM D3786-87 (Mullen or hydraulic test for knits/non-wovens ASTM D3787-89 ball method for knits – CRT
Dimensional stability	BS4736: 1996 (cold water)	SAE J883 Jan 94 Cold Water SAE J315A DIN 53894
Stiffness	BS3356: 1990 bending length and flexural rigidity	ASTM D1338-96
Drape	BS5058 1973 (1997)	DIN 53350 (bendability)
Crease recovery	BS EN 22313: 1992	AATCC Method 88C
Seam strength yarn slippage	BS3320: 1988 woven fabrics seam method BS2543 woven and knitted upholstery	ASTM D4034-92 woven ASTM D1683-90a for woven fabrics SAE J1531D ASTM D4159 (simulated seam)
Peel bond	BS3424 pt7 1982 Method 9 (coating adhesion)	ASTM D751 ASTM D902 DIN 53357
Compression (for foam/laminates)	BS4443 pt1 Method 5A stress strain characteristics BS4443 pt1 Method 6A compression set	ASTM D2406-73 Method B DIN 53 572 Compression set DIN 53 577 Stress strain characteristics
Odours		SAE J351 hot odour test (for insulation materials)

Air permeability	BS5636: 1978 for fabrics now BS EN ISO 9237: 1995 BS4442 pt6 1980 Method 16 (for foam laminates)	ASTM D737
	BS6538 pt3 1987 (Gurley Method)	DIN 53887
Surface resistivity (antistatic)	BS6524: 1984 (surface resistivity)	DIN 54345 DIN 53282 (surface resistivity) ASTM F365-73 Charge Decay Federal Method 101C – 4046 (Charge Decay) BTTG Body Voltage Chair Test
Cleanability		AATCC Method 118 – 1992 (oil repellency) 3M Methods
Stain repellency	BS4948: 1994 soiling by body contact	
Fogging	BS AU 168: 1978	SAE J1756: 1994 ASTM D5393 DIN 75201
Flammability resistance	BS AU 170 1979: 1987	FMVSS302 DIN 75200 SAE J369
Water wicking		SAE J913
Acoustic/thermal		SAE J1324 Oct 89 Recommended Practices
Acclerated ageing methods	BS3424: 1996 pt 12 for coated fabrics BS4443 pt 4 Method 11 for cellular materials (foam) humidity and elevated temperatures BS4443 pt6 Method 12 (heat ageing)	ASTM D2406-73 DIN 53378 'Environmental cycles' of individual manufacturers as pretreatments for further testing, e.g., peel bond dimensional stability, effect on appearance and shade change. Sometimes includes cooling to as low as –40°C and heating to as high as 120°C
Resistance to micro-organisms		AATCC Method 30 resistance to mildew and rot AATCC Method 100 resistance to bacteria AATCC Method 174 bacteria resistance for carpets Federal Test Method standard 191 Method 5750 Mildew Resistance, Mixed Culture method

5.1.5 Customer satisfaction quality checks

The more familiar tests associated with fabric include the following: uniformity of shade; regularity of pattern; abrasion resistance; lightfastness; wet perspiration dye fastness; dye-crocking fastness; tear strength; bursting strength; laminate peel bond; crease recovery; cleanability/soil resistance; 'environmental' tests; and flame resistance.

Test specifications may seem unrealistically high to the layman, but it is easy to misjudge the wear and tear over several years of daily use and the combined effects of high temperature, varying humidity and UV radiation. Cars produced in say the UK must generally be capable of withstanding climatic conditions in any part of the world. In recent years the following factors have grown in importance or become more critical: fogging; odour-free; cleanability; and antistatic properties.

5.2 Test method details

This section provides some details and comments on the more common tests applied to automotive fabrics. The test laboratory should be controlled to the standard textile laboratory conditioned atmosphere of 20–22 °C (68–72 °F) and 60–70% relative humidity. Test apparatus should be calibrated at least annually and a certificate issued by the certifying body.

5.2.1 General checks and appearance

General items such as the correct fabric width, weight, thickness, and construction (ends/picks in woven fabrics; courses/wales in knits), must be checked regularly to ensure that they are as specified by the customer. There are standard procedures for these relatively simple tasks. They can in fact, sometimes give clues to other properties, for example, thicker than normal laminates could indicate less burn off or lower pressure during lamination and perhaps lower peel bonds. Fabrics with raised surfaces need to be examined for pile in the correct direction, pile distortion and correct pile height. The fabric design must be examined for regularity, especially warp and weft lines ('bow and skew') to ensure that they are within agreed tolerances.

5.2.2 Colour shade approval

Dyebatch to dyebatch shade variation is inevitable and virtually impossible to eliminate completely even within the same dyehouse, let alone different dyehouses, possibly in different countries. It is therefore important that the customer and his dyer must agree on what is acceptable and what is not. Nowadays this is usually assessed objectively on a 'pass or reject' basis using quantitative colour information obtained with colour measurement instruments. This procedure removes human error and subjective assessment variations, which used to present so many problems in the past.

As stated in Chapter 4, two types of instrument are in use, the spectrophotometer and the tristimulus colorimeter both producing data from which quantities known as the chromaticity co-ordinates can be calculated. This information is measured from an agreed standard master shade and also from the submitted test pattern. A colour computer then processes the data from both sets of measurements and calculates the differences between them. These differences can be mathematically processed and represented by a single figure. The size of this figure relates to the magnitude of the colour difference between the submitted pattern and the standard master shade. If the submitted shade is acceptable it should be inside an agreed tolerance. There is, however, more than one method of processing this information for pass/fail decisions.

A widely used system involved the so called, CIE 1976 L^* a^* b^* co-ordinates which were recommended by the International Commission on Illumination, (Commission International de l'Eclairage) to specify a particular shade of colour. The co-ordinates comprise three numerical values to specify the colour in three-dimensional colour space on the axes; L^* representing lightness (i.e. $0 = \text{black}$, $100 = \text{white}$), a^* where positive values are red and negative values are green, b^* where positive values are yellow and negative values are blue. The computer then calculates the difference between the two test patterns for each of these co-ordinates. The differences are represented by delta L^*, delta a^* and delta b^*. The difference between the two patterns in colour space gives the total colour difference represented by delta E (calculated using Pythagoras' Theorem for triangles).

This equation, CIELAB 1976 did not always give consistent results with textiles across a broad range of different shades. Further work was then carried out to improve this situation by various researchers including colour instrument makers and major purchasers.[14] Eventually, development work under the auspices of the Society of Dyers and Colourists resulted in the publication of the CMC(2:1) equation which has proved to be a significant improvement on CIELAB 1976 for acceptability decisions. This equation has now been adopted by both ISO and CEN and is published as the International Standard for Colour-difference Measurement as BS EN ISO 105-J03:1997.

It is possible to calculate a value for delta E, which represents the actual difference perceptible by the human eye. However this quality is complicated by the fact that the human eye is more sensitive to certain colours and all the other human limitations, including fatigue. The situation is not completely resolved – not all dyehouses use CMC(2:1) for their pass/fail systems. However, the ultimate decisions are made on *visual* assessment under specified lighting conditions and dialogue between the dyer and the customer.

5.2.3 Colour fastness and crocking

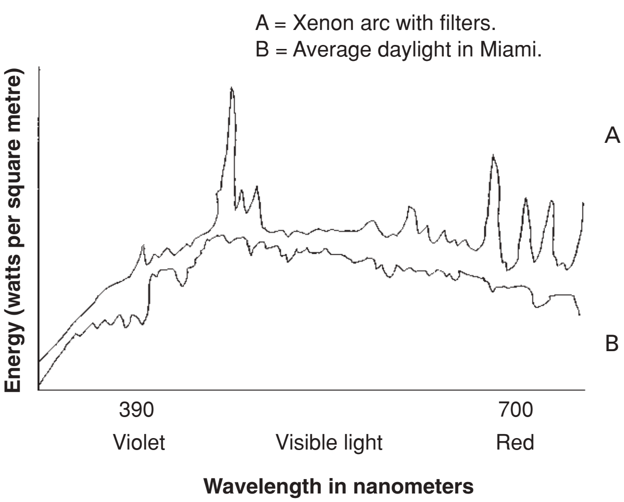
The car seat cover is fixed to the seat and washing fastness is not an issue, however perspiration dye fastness, cold-water leaching and rubbing fastness (tested by crocking) must be checked. Simulated human perspiration liquor is made up, and a test sample of the fabric is wetted out with it and sandwiched between two white undyed pieces of fabric, one is cotton, the other sometimes wool or made from several different fibres (so called multifibre test material). The 'sandwich' is placed between glass plates and put into an oven for 4h at 37°C to simulate body heat. Any staining off of loose dye is assessed using Grey Scales, of which there are two types. One type is used to assess change of shade (COS) of the dyed fabric, the other type is used to assess the mark off or bleed off of loose dye on to the white undyed pieces of fabric used in the test. Grey scales standards were prepared in accordance with the International Standards Organisation and are specified in BS 1006, (ISO 105-A02). Rating 5 indicates no change of shade with the COS grey scale and no staining off with the staining grey scale. Rating 4 indicates slight and generally acceptable levels of change of shade and staining off.

Rub fastness, both wet and dry is assessed using a Crockmeter, a machine with a wooden peg around which is fastened a white piece of cotton fabric. The machine action is to rub the fabric sample ten times with the cotton fabric covered peg, after which any staining off of dye is assessed using Grey Scales. It is especially important to check dyed polyester by these fastness tests to ensure that the reduction clearing treatment after dyeing has been effectively carried out.

5.2.4 Lightfastness and UV degradation resistance

This is probably the single most important test and also the most difficult to reproduce and consequently much research has been carried out.[14–21] One of the reasons of course is simply because sunlight conditions vary not only according to location in the world, especially latitude, but they also vary at a given place according to the position of the sun in the sky and therefore the time of day. The weather and cloud cover are also relevant factors in addition to variations in actual solar UV radiation. The large amounts of glass in modern cars allow the entry of substantial amounts of sunlight, which heat up the confined space of the car raising the temperature to as high as 130 °C in extreme conditions in the Arizona Desert. On normal summer days in the UK, temperatures of car interior surfaces exceed 70 °C with ambient exterior temperatures of only 23 °C. As the sun sets, the temperature will fall and this will significantly affect the relative humidity and cause dampness. Some test procedures attempt to reproduce all of these conditions. The daily cycle of heating and cooling could be influencing rate of colour fade and fabric degradation. Some tests such as the American standard SAE J1885 includes a period with the light switched off to simulate this. If the procedure involves the sample becoming wet, the test is best described as a weathering test rather than a light-fading test.

Sunlight is a mixture of all the colours of the rainbow plus infra-red, ultra violet and other radiation, see Fig. 5.1. The UV rays are the shortest in wavelength and, having the most energy, are by far the most damaging to fabrics. Although much of this radiation is filtered out by car window glass some of the longer UV rays still penetrate. The thickness of the car window glass will have an effect – the thicker the glass, the fewer UV rays enter the car.



5.1 Spectral Energy Distribution of Daylight compared to that obtained with artificial Xenon arc light with filters. Diagram produced from information supplied by Atlas Material Testing Technology BV. A Nanometer (nm) is one millionth of a millimetre. Visible light, made up by the colours, violet, blue, green, yellow, orange and red is in the region of 390 nm to 700 nm, with violet (390 to 430 nm) and red (610 to 700 nm) at each end. Beyond the range of visible light is ultraviolet (30 to 390 nm) and infrared (700 to 3000 nm). The shortest wavelengths have the most energy and the ultraviolet is the most damaging radiation to textiles, but windscreen glass filters out some parts of it.

Tinted glass also reduces the amount of radiation including visible light but there are safety limitations on the degree of tint permissible.

Following investigations over a number of decades, researchers agree that, among other factors and combination of factors, the three most important single factors causing degradation by sunlight are, UV radiation, heat and dampness. To obtain test results, which will give accurate information on likely performance over several years in actual use in the car, the test machines use these three factors at extreme, but realistic levels, mainly running all altogether at the same time. It is important that these extreme conditions are comparable to what is observed in actual daylight because misleading information could result. For example using substantially higher levels of radiation could cause other types of degradation, which would never actually occur under natural conditions. However, it is important that the test is completed in the shortest possible time so that fabric can be released for use as soon as possible after manufacture.

Clear information on the type of test machine and the light source is vital because the spectral distribution of the light source and the filters used vary from machine to machine. In addition both lamp and filters have a finite life and deteriorate during use, making it necessary to monitor their performance and to replace them regularly. In some machines the gradual deterioration in lamp efficiency is compensated by an automatic increase in wattage.

Development of a suitable artificial source of light, which accurately reproduces natural sunlight, was one of the first tasks faced by research workers. The first lamp developed was the enclosed carbon arc (Atlas in 1920s) which was used in the Fade-Ometer. The spectral distribution of this lamp was very different to sunlight because in particular, UV rays, which are responsible for much of the damage caused by sunlight, were absent. This situation improved shortly after with the appearance of the sunshine carbon arc, which was used in the Weather-Ometer. This lamp had a better resemblance to sunlight and did produce accelerated fading, allowing some useful results. However it contained certain bands of UV radiation which do not occur in natural sunlight, and therefore it was judged to be too severe. Furthermore some visible light was absent from its spectrum. Maintenance was expensive because the electrodes of the carbon arc lamps had to be changed daily and test machines using fluorescent lamps appeared as cheaper alternatives. Although fluorescent lamps do give accelerated fading and may be of some use, they are now considered unrealistic because, although their spectrum is rich in UV radiation, other wavelengths are absent.[15]

The latest developments involve the xenon arc lamp, which is at present the best reproduction of natural sunlight commercially available, see Fig. 5.2. The first machine of this type, which was introduced during the 1950s

5.2 Ci4000 Weather-Ometer (Atlas Material Testing). The test samples and lamp are located in the centre of the illustration. The apparatus accurately controls the uniformity of light, temperature and humidity of the test samples. Photograph supplied by Atlas Material Testing Technology BV and reproduced with kind permission.

by Heraeus, was an air-cooled model. A water-cooled model produced by Atlas followed shortly after, and both types now are in widespread use. However, it is important to specify the method of cooling and which filters are to be used, because the spectral distributions of the two types are not the same. Results of fading tests will be different because of the following reasons. The Atlas model has two glass tubes around the xenon lamp, which act both as filters and also as part of the cooling apparatus. The spectral distribution of the light is therefore the same in all directions. The air-cooled Heraeus model on the other hand uses a combination of filters to produce an overall spectral distribution. The carbon arc lamp is still used but this is declining in favour of the xenon models. There is now some evidence available, supporting the view that the whole spectrum of sunlight needs to be reproduced to obtain accelerated test results, which accurately reproduces damage by natural sunlight.

For the above reasons the OEMs specify the test method they require, including the type of machine, and a typical test requirement includes the following information: test machine model and lamp; filter system; humidity; test chamber temperature, (ambient inside the apparatus); black panel temperature, (temperature of the actual test sample); exposure time.

The test standard can be specified by the amount of fading or discoloration acceptable, as assessed by Grey Scales or the wool Blue Scale after exposure for a certain length of time under the specified conditions. The Grey Scales are prepared according to The International Standards Organisation and BS 1006 in the UK. The wool Blue Scales were developed by the Society of Dyers and Colourists in conjunction with other relevant organizations, and are based on eight dyes, one for each level of lightfastness rating. Note that the Blue Scale used in the USA is not the same – it is based on mixtures of two dyes to give the eight levels. With both wool Blue Scales, each level requires approximately double the amount of energy as the level immediately beneath it to produce the same level of fading. Alternatively the fading or discoloration is assessed after exposure to a measured amount of energy in kilojoules per square metre (kJ/m^2). The American wool Blue Scale 7 is approximately equivalent to 680 kJ/m^2 at 420 nm wavelength of light.

In addition to all the factors discussed above, obtaining reproducible and inter-laboratory test results, which agree with each other may prove difficult for a number of reasons. The test substrate itself may not be completely uniform and may have varying amounts of chemical finishes, UV absorbers or other substances on it. In addition fabric samples could have been produced under varying processing conditions of scouring, stentering or lamination etc. One factor, which is especially difficult to reproduce in the laboratory, is the effect of several years' exposure to air pollution and traffic fumes, the composition of which will vary widely with location. These factors may also be playing a part in conjunction with the combined effect of all the other variables, not to mention the surface abrasion and other factors associated with the car occupants sitting on the fabric.

Fibre lustre, or the titanium dioxide delustrant added to the yarn during manufacture, has a very significant effect on UV resistance as can be seen from Table 1.3. Matt yarns, which contain the most delustrant, break down significantly faster than bright yarns. This is thought to be due to the titanium dioxide photosensitizing degradation, or because of light being scattered more internally within the fibre filament in the case of delustred yarns. UV degradation is also influenced by the thickness of the filament; the thicker, the better. This is because less radiation will penetrate into the centre of the filament and the lower specific surface area of the thicker filament reduces the rate of photo-oxidative attack.

When fabric is tested for lightfastness and UV degradation, it is important to test it either in the laminated form or with polyurethane foam underneath it. The foam is believed to act as a heat sink and hence more accurately reproduces the conditions actually prevailing inside the car.

Different OEMs specify different test conditions but there are steps to standardize procedures to reduce the number of test methods especially in the USA and Europe. In Germany there has been some successful harmonization with the FAKKRA test procedure, DIN 75202 being widely used, and, in the USA, the SAE J 1885 test is widely used. Harmonization should result in some savings because fabric producers supplying several OEMs must possess every machine necessary and these machines are expensive to buy and expensive to run.

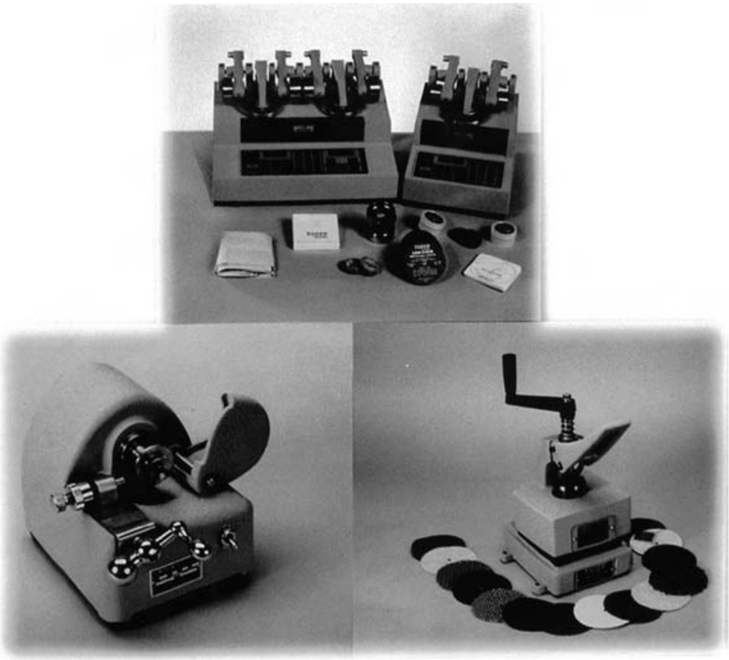
5.2.5 Abrasion resistance and associated factors

Fabric is normally tested for abrasion in the form in which it will be used in the car, i.e. when laminated to polyurethane foam and back coated if specified. Abrasion results are usually slightly better when the fabric has been laminated to polyurethane foam, compared to abrasion results carried out on the base fabric alone. This is because the foam helps to lock the fibres together in the fabric. When it is necessary to test non-laminated (singles) fabric, for example during fabric development, a small piece of polyurethane foam is placed underneath the fabric being tested in the test holder. Sometimes the foam is attached to the fabric sample with double-sided adhesive tape to simulate lamination. Some test procedures require exposure to light and UV radiation before testing, which significantly reduces the abrasion performance in most cases. Where in the car the fabric is situated determines the standard of abrasion required. The seat usually requires the highest standard of abrasion; some OEMs specify different standards for the centre seat panels, the bolster (the side and front edges of the seat), and the back of the seat – the bolster requirements usually being the most demanding. Door casing fabric specifications are sometimes lower than those for the seat and those of the headliner are significantly lower.

There are three main test methods for abrasion resistance in use, Martindale (using 12 kPa, 28 oz weight), Schopper and Taber which *very generally* agree with each other – but certainly not always, see Figs. 5.3–5.5. The three test methods actually represent different types of abrading motion as well as using different abrading materials. The Schopper machine operates with a reversing circular motion, whereas the Taber motion is a little more

5.3 Martindale Fabric Abrasion Tester. Photograph supplied by SDL International Ltd and reproduced with kind permission.

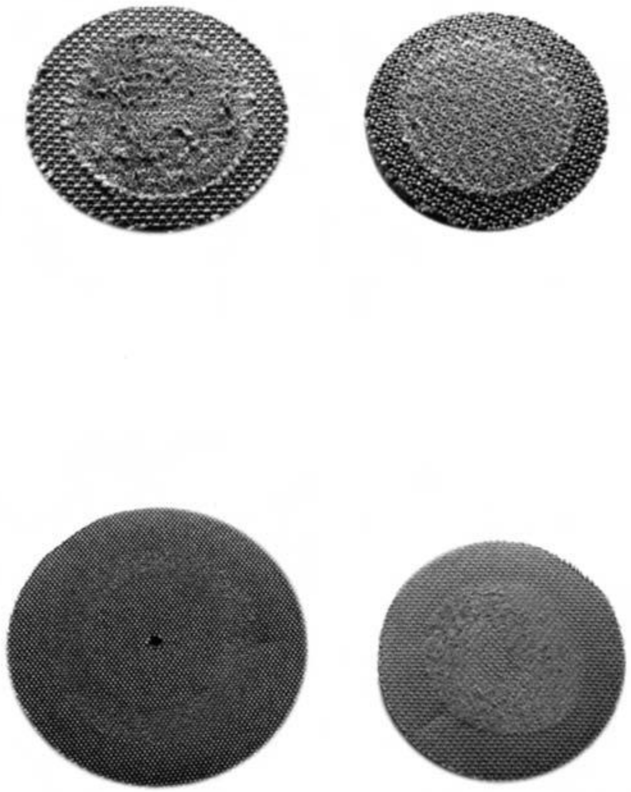
5.4 Karl Schroder Schopper Abrasion Testing Machine. Photograph supplied by SDL International and reproduced with kind permission.



5.5 Taber Industries Abrasion Testing Machine. Photograph supplied by SDL International and reproduced with kind permission.

complicated with two circular wheels rotating in opposite directions. Martindale operates in a multi-directional manner, the abrading heads moving in a Lissajous pattern. The Taber uses an abrading wheel made from rubber/aluminium oxide abrasive particles (Calibrase), the Schopper uses fine emery paper, whereas the Martindale uses a standard grade of woven wool. Many researchers regard the Martindale's multi-direction action and use of wool as the abrading material as the most realistic of the three tests, but it does take substantially more time than the other two. To reproduce significant wear in actual use, a minimum of 50000 Martindale rubs are necessary taking about 16h to complete. In comparison a comparable Taber test only takes 15–30min and a typical Schopper test requires 1–2h. Abraded samples appear in Fig. 5.6.

Abrasion is influenced by the fabric construction, yarns used, finishes applied and amount of coating. Yarns of higher dtex/filament generally have better abrasion than yarns made from finer filaments. Highly textured yarns usually have slightly lower abrasion than yarns with a lower degree of texture. Excessive wet processing, prolonged dyeing or rigorous reduction clearing can all reduce abrasion resistance, and in some cases spun-dyed yarns may have better abrasion resistance than yarns of the same shade, which have been aqueous dyed. Fabric construction can have a substantial



5.6 Abrasion testing of automotive seat cover fabric. The top two were abraded on the Martindale apparatus. The top left sample shows broken threads and some pilling. The right hand sample shows some wear and 'frosting'. The bottom left sample has been abraded using the Taber apparatus and is satisfactory, while the bottom right, abraded on the Schopper apparatus is showing signs of wear. Note; The photographs are not to scale, the Martindale samples are about 4 cm across, the Taber samples about 13 cm and the Schopper samples are about 11 cm.

effect on surface abrasion. Those constructions with long 'floats' or which otherwise provide points for frictional stress, have the poorest abrasion. Fabric finishes can significantly improve abrasion, by acting as a lubricant in the abrading action, or as a barrier between the fabric and the abrading material. However they are rarely used on automotive fabrics because of the risk of fogging and also because they could lead to the development of unsightly or sticky deposits on fabric surfaces over a period of time, probably caused by degradation of the chemical by heat, humidity and light radiation. In addition drops of water could lead to the appearance of 'tide' marks or discoloration. Certain waxes and silicones in particular must be avoided because they can affect adhesion of foam during lamination. The most common method of improving abrasion resistance of woven fabrics is by coating the back of the fabric with an acrylic or polyurethane resin. Anti-abrasion finishes are also available which can be applied either by padding or directly to the surface of fabric by foam coating. After testing by the prescribed method, the abraded samples are inspected for wear or broken threads. A certain amount of wear is usually acceptable but most OEMs will not accept a broken thread.

5.2.5.1 Frosting

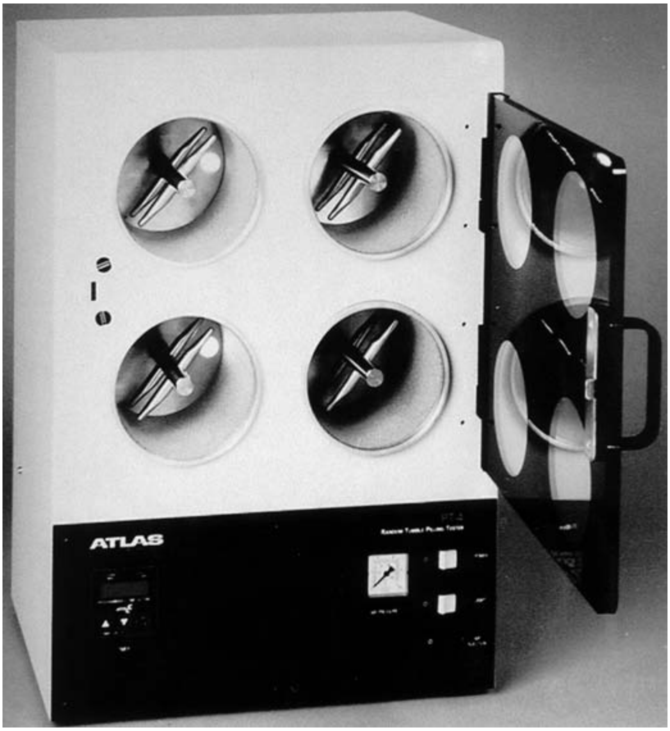
In some instances the material may not have any significant wear or any broken threads after abrasion testing, but may be whiter in appearance. This condition is referred to as 'frosting' or 'ghosting' and is sometimes associated with fibrillation of the yarns and sometimes with poor dye penetration. In other cases, especially if a finish has been applied to the face side of the material, the abraded pattern may be glazed and appear shiny. These defects may or may not be acceptable to the seat maker or OEM.

5.2.5.2 Pilling

Also associated with abrasion resistance is pilling, which is the formation of little circular clusters of fibre on the surface of the fabric, produced as a result of the fabric being rubbed against itself or against some other material. It is believed that fibre ends become tangled and twisted together sometimes with the fibre ends and broken threads of the material it is being rubbed against. A number of papers are available on pilling phenomena.[22–25] Unsightly pilling can occur where the seat occupants' clothing is perhaps more to blame than the seat fabric itself. This is sometimes referred to as 'foreign' pilling.[22] Fabrics constructed from spun yarns are significantly more prone to pill than continuous filament, and the problem is probably more pronounced with polyester than wool. Wool is an inherently weaker fibre and pills can break off from the fabric surface before the end of the test cycle. This does not always happen with polyester because of its higher strength and the pills grow larger, become more conspicuous and unsightly, and unlike wool are present at the end of testing and are assessed. Thus misleading results, which do not reflect actual wear may be obtained.

Pilling can be minimized by chemical finishes, increasing the yarn filament thickness, use of higher twist yarns and by brushing and cropping of the fabric. However any one of these factors may change the handle and other qualities of the material.

Fabric is sometimes tested for pilling using a pill box of the type designed by ICI. This consists of twin wooden cubic boxes, each with sides about



5.7 Atlas Random Tumble Pilling Tester. Photograph supplied by SDL International and reproduced with kind permission.

25 cm long, the inside walls of which are lined with cork. Fabric samples are wrapped around rubber formers and placed inside the boxes, which are then rotated around a common axis for a measured length of time. The samples are assessed against masters and the degree of pilling assessed on a scale of 1 to 5, the higher the rating the less the pilling. In an alternative test method, the so-called Random Tumble Pilling Tester Method (ASTM D 3512), cotton fibres can, if required, be added as a source of foreign fibres, see Fig. 5.7. The Martindale tester is also used to assess pilling by subjecting the test fabric to cycles of say 1000 or more rubs and the number of pills counted.

5.2.5.3 Snagging

Snagging occurs when a sharp point or rough surface catches a thread in a knitted or woven fabric. Constructions incorporating long floats are especially prone to this problem. The thread is pulled out of the fabric forming a small loop on the surface, and the thread still in the fabric, is stretched and appears as a shiny line – a tight end. The phenomenon of snagging is tested using a Mace snag tester which comprises an array of spiked metal balls. These are abraded against the fabric for a set time and the degree of snagging assessed on a 1 to 5 scale.

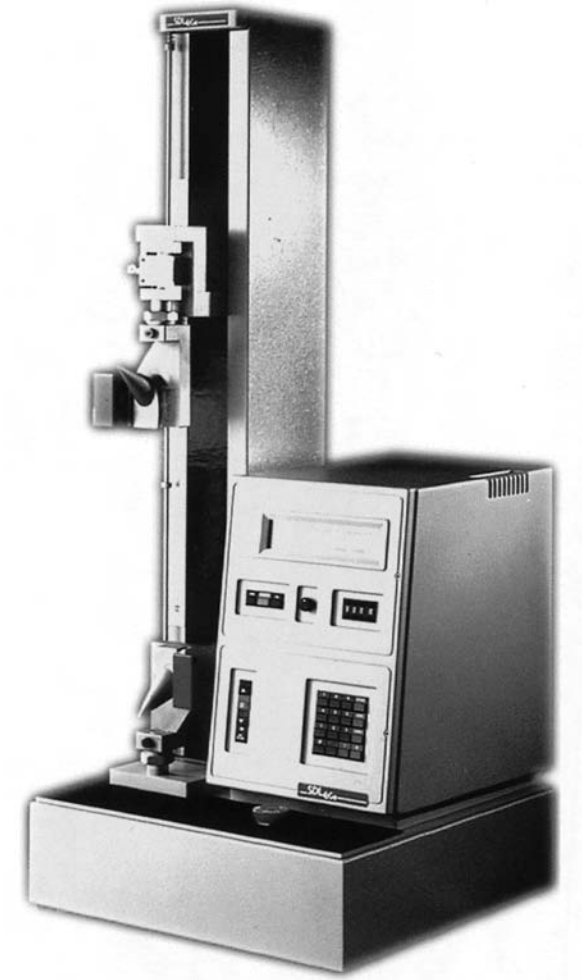
5.2.6 Peel bond tests

Peel bond tests on the cover laminate, face fabric to foam and foam to scrim are important to ensure delamination does not occur in the car during use or during downstream processing. Samples are taken and tested both in the warp (lengthways) and weft (width) direction. To simulate possible conditions which may be encountered during the life of the car and during subsequent processing, the peel bond test is carried out as received, and also after heat ageing, while wet, and sometimes after treatment with solvents. Peel bond tests are usually carried out on a universal strength testing machine controlled by computer software, the rate of separation being specified, see Fig. 5.8. Again the actual test procedures vary according to the method specified by the OEM and the standard required (expressed in Newtons per centimetre width of sample) is also specific to the particular OEM. The direct joining of seat cover to the foam squab and cushion may necessitate higher peel bonds because there are fewer sew lines to help hold the laminate components in place. The negative influence of fabric finishes, especially silicones on peel bond, has already been mentioned.

5.2.7 Fogging

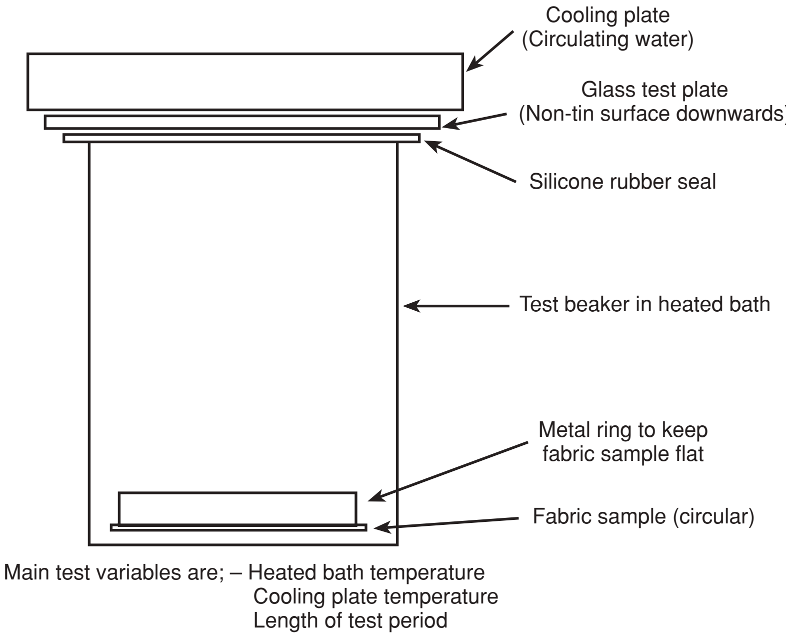
Fogging is the mist-like deposit that forms on car windscreens reducing visibility and sometimes is difficult to remove, even with soap and water. Fogging, is caused by volatile materials vaporizing out of *all* interior trim components, such as plastic foils, polyurethane foam and not just the fabric. Modern polypropylene foils hardly fog at all, but PVC, if not formulated with suitable plasticizers, can fog quite badly. Fabrics if not stentered well or scoured can fog very markedly due to the multiplicity of lubricants applied during dyeing, yarn doubling, warping, weaving, knitting and finishing. Velvets or other pile fabrics can fog very significantly because of the much larger surface area of yarn on the face of these fabrics. Chemical analysis of the fogging deposits have been attempted and published along with other findings.[26–32]

The fog test is carried out by putting a specified amount of fabric into a beaker, which is covered and sealed by a glass plate. The light reflectance of the glass plate is measured beforehand. Because the 'non-tin' side of the glass plate must face downwards towards the material being tested, which side is which, must be labelled by the supplier. This glass plate is cooled by



5.8 Universal Strength Tester. This machine is used for determining tensile strength, tear strength, peel bond, stretch and set and other physical tests. Different clamps and jaws are needed for different materials and the rate of separation of the jaws are generally computer controlled.

a metal cooling plate which rests on it, and cooling water is pumped through it at a specified temperature, usually room temperature, see Fig. 5.9. The beaker is heated at 90 to 110°C for 3 to 6h; the actual conditions being specified by the OEM. After this time, the light reflectance of the glass plate is re-measured to determine the reduction in reflectance, which has been caused by condensation of the volatile materials from the test sample. This is usually expressed as a percentage of the original reflectance and a good



5.9 Automotive fabric fogging testing.

result is generally anything over 90%, although some OEMs may specify considerably less than this value. The three main test parameters, i.e. temperature of sample heating, time and cooling water temperature are specified by the OEM. Before any actual determinations are carried out, the whole apparatus is checked by measuring the fogging obtained with DIDP (di-isodecyl phthalate), a plasticizer used in PVC, which should be in the region of 76–9%. Depending on the information supplied by the manufacturer, e.g. Merck, this check should be carried out periodically about once a month but some test houses include a DIDP standard with every test batch.

Problems have been experienced in obtaining inter-laboratory reproducibility and much discussion has taken place to standardize procedure aimed at improving this. Cleaning of the glass plates is generally believed to be critical. Some researchers however believe that a gravimetric method, which weighs the volatile deposits, is more satisfactory, but this method relies on a balance capable of weighing to five places of decimals. More recent work has focused on the formation of crystals on the glass plate, which may still reduce visibility but give a high reflectance reading. Two test rigs are widely used, those made by Haake and Hart, but the test specifications are written in such detail that self-assembly is possible. Operative procedure is believed to substantially influence the accuracy of the test and the methods to be used are detailed in the test specifications. A video has been produced by the Industrial Fabrics Association International to assist with training to carry out SAE J1756.

Fogging has assumed more importance recently and is related to the problem of mal-odours in new cars, being caused by volatile materials. The whole subject of air quality inside cars is now under examination – see the section below on odours and the section on cabin air filters in Chapter 7.

5.2.8 Antistatic properties

The problem of static shocks when getting out of cars has been known for some time, and a small number of OEMs have for some time required antistatic finishes on their car seat covers.[33–36] Static electricity, is generated by the person's clothes rubbing over the polyester car seat cover, especially when he or she stands up to get out of the car. Some individuals seem to be especially prone to static shocks, which are also influenced by the clothes and shoes worn and also the ambient air conditions inside the car. The polyester seat cover is hydrophobic, i.e. containing very little moisture to conduct away or help dissipate the static electricity. However, many OEMs at the present time do not specify any particular finish. Antistatic properties are easily conferred on the fabric by application of an antistatic finish by padding, or by foam coating, but these finishes are not permanent and eventually wear off. Their efficiency is measured by surface conductivity methods and they work simply by their hydrophilic nature, which ensures that a small amount of moisture is always present on the car seat surface.

It is especially important that fabric samples are conditioned in the laboratory before testing and that the laboratory temperature and relative humidity conditions are correct. The conductivity meter actually measures surface resistivity in units of ohms. A resistivity of about 1×10^{10} ohms is considered a reasonable level of antistatic behaviour, but the lower the better. Padding a fabric with a good antistatic agent can easily give a figure of 1×10^{7}. The surface conductivity method has its limitations and some researchers question its suitability for car seats. Some OEMs and research institutions such as the British Textile Technology Group (BTTG) and John Chubb Instrumentation have developed whole chair tests which are carried out by human subjects wearing specified clothing.

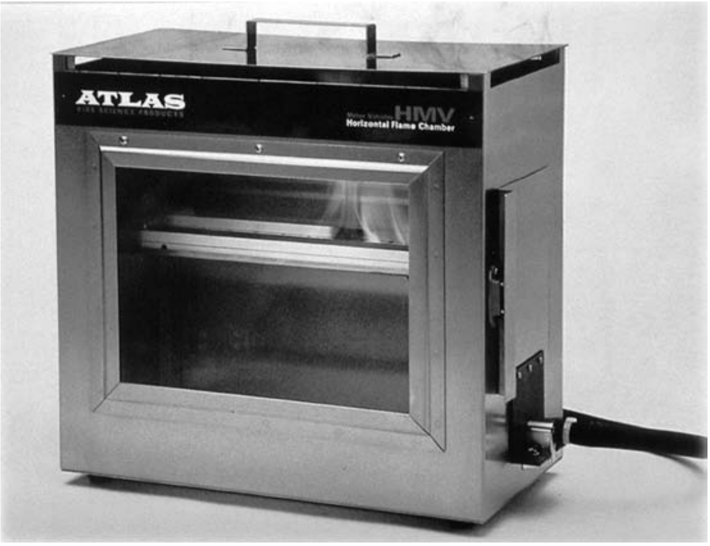
Very recently, concern has been expressed about the possibility of static electricity interfering with electronic equipment controls in the car and even the possibility, in extreme cases, of igniting petrol vapours.[35] There has been renewed interest in development work using conductive yarns such as Negastat (DuPont) and R. Stat. which can confer permanent antistatic properties to the car seat fabric. These specialist yarns are very expensive but only small amounts are required in a fabric to confer some measure of durable antistatic behaviour.

5.2.9 Flammability

The test used by most OEMs is the USA standard FMVSS 302, a horizontal burn method, but the test performance standard required varies according to the OEM. Generally this test, see Fig. 5.10, is not especially difficult to pass, but sometimes a flame-retardant coating is needed on the fabric or a flame-retardant foam is necessary. Sometimes both are required to satisfy the test standard. Flame-retardant chemicals both in the foam and the coating add to the cost and for commercial reasons the concentration levels in both foam and coating are kept to a minimum. A fabric coating can cause stiffening as well as adding to the overall weight and cost.

The antimony trioxide/bromine synergy combination is still widely used in coating formulations although the organic bromine compounds have come under scrutiny as environmentally unfriendly and possible health hazards. Alternative compounds are available, but they are believed to require higher concentrations and therefore higher add-ons of coating, with all the disadvantages, for the same performance.

Flammability is assessed by the burn rate, which is the distance in centimetres burnt in 1 min. The burn rate regarded as acceptable varies accord-



5.10 Apparatus for automotive fabric testing. Most car interior trim fabrics are tested using methods similar to the US FMVSS302 horizontal burn test.

ing to the OEM. Door panel fabric is usually assessed on the actual door panel itself. Variations in flammability test results are sometimes caused by uneven up-take of fabric finishes or variations in scour or stentering. Stentering may influence the flammability of stretchy knitted fabrics because it could affect the manner in which the fabrics shrink away from the flame. Some OEMs require that pile fabrics be brushed in a particular way before testing.

Flammability is an especially important test for public passenger vehicles, aircraft and boats and ships and a fuller account of this subject is in Chapter 9. The tests and performance standards are much more severe than the requirements for private cars and much use is made of flame-retardant varieties of polyester and more specialist fibres. The cost of these specialist fibres would be prohibitive for general use in private cars at present.

5.2.10 Dimensional stability

Fabric laminates are examined visually for curl and other dimension stability tests involve measuring the percentage shrinkage after soaking in cold water and heating in an oven for several days at various temperatures. Efficient heat setting during fabric finishing significantly reduces thermal shrinkage. Figure 4.7 shows the general relationship between heat shrinkage and heat setting temperature with polyester fabric.

As previously mentioned some of these tests have assumed more importance recently with the newer methods of manufacture and high production rates, which do not allow for continual machine adjustments. Lamination must be carried out under conditions of no tension if the products are to pass these tests consistently. In especially poor cases, the fabric laminates curl, usually because the foam or scrim has been stretched during lamination, and accurate cutting is impossible. Stretch and set tests, see below, are also carried out to screen material for these potential problems.

5.2.11 Stretch and set

These properties are important in fabrication of the interior component. After panel cutting the material may elongate under its own weight and may then be longer than another piece cut to the same size to which it is being sewn. An oblong shape may need to be folded around into a cylinder shape, say for a headrest and one edge may be slightly longer than the other. Another fabric panel may require pulling around a seat cushion or squab and it may not be possible to do this without the use of undue force. Conversely it could be too loose or too stretchy and this would cause bagging and creasing during use. These pieces would be rejected because they could not be used – there is no time to trim them to the correct size. Stretch and set are determined by testing strips of fabric of specified dimensions at specified rates of extension on a computer-controlled universal strength tester.

5.2.12 Soiling and cleanability

These factors are assessed by the application of materials likely to be accidentally spilt on to the surface of car seat fabric. They are applied to test pieces of fabric in the laboratory and then cleaned off using a specified procedure. The degree of soiling left behind is assessed under a standard light source such as CIE D65 (chosen as closely resembling natural daylight), and either compared to standard patterns or assessed using Grey Scales. Rating 5 of the Grey Scale records no noticeable staining, 4 records slight staining, descending down to rating 1, which records very significant staining. The soiling agents include materials such as chocolate, coffee, tea, ice cream, hair-dressing fluid and engine oil. A brand name or chemical type of soiling agent is usually specified for the tests to be reproducible. Antisoiling seems to be an increasing concern and there have been recent reports on the subject.[37,38]

Water repellency is tested by pouring a measured amount of water on to the fabric held at an angle of 45 degrees from a funnel and assessing the drops adhering to the fabric using standards.

The problem of 'linting' or appearance of white specks of fibrous material on the car seat is well known and is quite difficult to overcome. These 'lints' are not easy to remove by brushing and tests have been carried out to minimize the problem using certain soil-release agents. Associated with linting is 'minking', the removal of hairs from fur coats by abrasive action of the car seat fabric. Some OEMs require the tendency of these problems to occur to be assessed by specified test procedures.

5.2.13 Environmental and ageing

These tests try to reproduce several years' ageing in the space of one or two weeks in the laboratory. They are important for picking out poor adhesive bonds, which may allow fabric to lift or 'bridge' in mouldings with sharp angles or corners. Shade change, dimensional stability and peel bonds are also examined after ageing. Typical tests involve exposing the sample to heat for about two weeks at over 100 °C and to relative humidity at 100%. Environmental tests are generally carried out on the component as a whole e.g. an entire completed door casing. The tests frequently involve a complete cycle of extreme conditions e.g. exposing the test piece to say, 24 hours at –40 °C, then to say, 24 hours at 100 °C and 100% relative humidity.

5.2.14 Fabric handle, drape and stiffness

Fabric stiffness is assessed by a bending length tester of the type designed by the Shirley Institute (now BTTG). Fabric stiffening, especially as a result of back coating is usually accompanied by a reduction in tear strength. This should be remembered especially when dealing with lighter-weight fabrics.

Some efforts have been made to quantify surface touch using the Kawabata system, which has been used with some success in the clothing industry.[39–43] For automotive fabric the quantities relating to drape and flexing are not relevant but the tactile surface touch properties are important. However, this work was done by a research institute and does not appear to have been followed up by an OEM or seat maker. Research on fabric handle of apparel and household textiles has revealed national preferences for touch properties and softness. For automotive textiles where the fabric is fixed to a seat, door casing or headliner, the only relevant mechanical properties out of the five specified by Kawabata are probably compression and surface properties.

5.2.15 Fabric strength – tear and tensile

Good tear strength and resistance to tear propagation are important for car seat fabric, which is expected to last the life of the vehicle. Torn seat fabric would deter prospective purchasers and significantly reduce the resale value of used cars. The tearing strength is influenced by the smoothness of the yarns and the construction as well as by the thickness of the yarns. If the construction is rigid and inflexible, the applied force breaks the threads one at a time and low tear strength is obtained. A fabric coating which penetrates the fabric structure and holds the threads in place, will generally cause stiffening in addition to a lowering of tear strength. If the threads move under the tearing force, and bunch together, several threads will be broken together, producing a higher tearing strength. Some fabric lubricants will allow this to happen, and it is more likely if yarns have a smooth surface. Care must be exercised however because lubricants and finishes can reduce peel bonds if the fabric is to be laminated. In fact, silicone finishes can significantly improve tears strength – but these are *not recommended* on automotive fabrics because of their effect on adhesion and because they can contaminate surfaces to be painted. Certain constructions such as twill weaves allow threads to group together more easily and thus tend to have better tear resistance than plain weaves. The yarn and fibre type also determines fabric strength; polyester is stronger than wool and continuous filament yarns will be stronger than those made from spun staple fibre. Tear-strength testing is also sometimes required after exposure to UV light. Polyester fabric tear strength is generally satisfactory after exposure, but that of wool fabrics may be significantly lower. As has been noted, yarn lustre has a significant effect, see Table 1.3.

There are a number of tear tests in use, single rip, wing tear and Elmdorf tear. The wing tear avoids transfer of tear, whereas the Elmdorf method measures energy loss during the tear process. Care must be exercised in clamping the specimen in the jaws of the test machine because any slippage could be mistaken for a tear or a failure of the test specimen. Jaws and clamps of different designs are available for different types of materials to be tested. Straight load or tensile strength tests on strips of fabric are useful for investigating the effect of a material or process change on fabric properties. Certain knitted fabrics may distort or unravel and bursting strength tests are likely to be more reliable.

5.2.16 Fabric strength – bursting

This test is more relevant to a knitted fabric or a non-woven where the test load is multidirectional. The fabric is clamped in the machine over a rubber diaphragm and pressure is applied via water or some other fluid, which during the test stretches the rubber and thus applies a force to the fabric. The exact procedure and diameter of the test specimen vary with customer requirements.

5.2.17 Fabric strength – seams

This can be assessed by preparing a test seam, and attempting to separate the two sewn pieces using a universal strength tester. Special machines have been developed by some OEMs, which simulate continual forces of separation. Actual seam strength is generally satisfactory if a quality sewing thread is used, but opening of sew holes referred to as 'seam fatigue' must be checked with some constructions. The scrim on the back of the seat fabric laminate can be selected to contribute to the overall seam strength of the laminate and may even be critical with certain lighter weight and open construction woven fabrics.

5.2.18 Air porosity and permeability

For automotive fabric laminates this is usually measured as the volume of air in litres per second required to maintain a specified constant pressure differential across a test specimen of a certain dimension. Test conditions specified by OEMs are generally similar to those in BS 4443: Part 6: 1980 Method 16. High material porosity makes panel cutting of several layers more trouble-free and accurate especially when a vacuum is used to hold material flat down on the cutting table. Porosity also influences seat comfort, see below. Porosity has become more important recently as a measure of laminate suitability for 'foam-in-place' manufacturing methods. When the materials are of much lower air porosity, the Gurley Method, which is used widely for packaging materials is specified.

5.2.19 Comfort – breathability

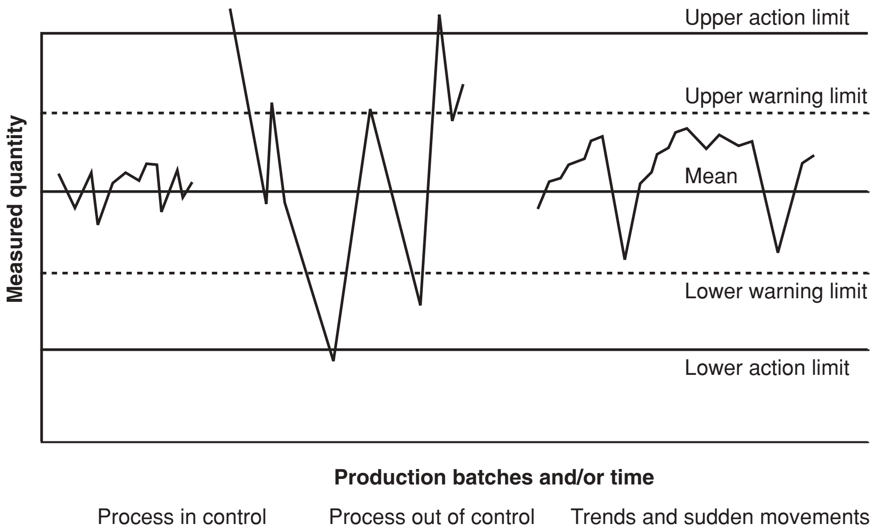
This quality is a measure of the permeability of a material to human perspiration and can thus provide some indication of the possible effect on thermal comfort of the car seat which incorporates the material. At present there are no breathability test requirements for the fabric producer, but they may be relevant for the seat manufacturer to carry out on the seat as a whole, especially when a direct joining technique has been used. The ultimate test is the sweating hot plate test developed by the Hohenstein Institute in Germany but some information can be obtained by simpler tests, which are less expensive. These include evaporative tests such as ASTM E-99 B, BS 7421 and the Turl Dish test. Films including adhesive films, barrier films or other materials to be used in novel methods of seat manufacture can be checked for breathability to ascertain whether or not they could give rise to thermal discomfort. However it is important that they are compared with materials known to have acceptable levels of breathability to human perspiration such as, Goretex (WL Gore), or Sympatex (AKZO) membranes. The most meaningful tests are however carried out on whole chair assemblies. Numerous other factors need to be considered and seat comfort is discussed in more detail in Chapter 6 together with some data on breathability of materials.

5.2.20 Odour assessment

Many OEMs simply state that the material must be free of any unpleasant odours but this issue is likely to become more important in the future as concerns with health and safety increase.[44] Within the last 2 years Fords have introduced an 'electronic nose' to detect and measure odours.[44–46]

5.2.21 Recording of results – statistical process control

All results must be recorded and filed for a reasonable length of time so that if any problems occur in down-stream processing, the incident can be investigated. The results of individual tests are plotted on to a statistical process control (SPC) chart and it is possible to see, at a glance, how consistently the product is being produced. Sudden changes in test results, trends and recurring cycles can sometimes give clues as to what is happen-



Warning limits can be mean plus/minus 2× standard deviations.
Action limits can be mean plus/minus 3× standard deviations.

Statistical Process Control provides a method of detecting faults during production, as a way of continuous improvements with the objective of achieving zero defects.

5.11 Statistical Process Control production chart.

ing if there is a problem, see Fig. 5.11. If the results are within acceptable limitations, it is known that the process is in control. If results begin to deviate significantly from the mean, this may be taken as a warning that something may have happened, and corrective action may be needed. If the 'warning' limits are set at the mean value ±2 standard deviations, 'action' limits are usually set at the mean ±3 standard deviations. This technique allows quality to be checked while the component is being made and not after completion when it is usually too late. The philosophy is not to detect faults after production has been completed, but rather the prevention of faults occurring during production, as a means of continuous improvement with the objective of achieving zero defects.

5.2.22 Fabric examination

Every metre of laminated fabric must be examined carefully before it leaves the factory to go on to the next stage of manufacture. Trained examiners carefully inspect the material for: width; shade/pattern regularity; lamination faults, e.g. delamination; oil marks or other soiling; weaving or knitting faults; handle/drape/stiffness; joins in foam or scrim; and any other faults which could cause complaints from customers or problems in downstream processing.

Faults are marked with a coloured tag or label and a length allowance is given to the customer. Usually the faults are colour coded. However even experienced examiners cannot see all faults at practical, commercial examination speeds and ways of improving this situation are always under consideration, for example, better quality examination frames, better illumination, etc. Some OEMs specify the speed at which the material is examined – the slower the speed the better the chance of seeing all faults. The examiners also measure the length of fabric and put it on to rolls of the required size for despatch.

Automatic examination systems can pick out basic construction faults, tears, creasing, etc. but more sophisticated apparatus is necessary to identify every possible fault especially pattern distortions. As previously stated, technology which is capable of doing this, probably does exist, but the actual problem in reality is making it affordable.

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6
Product engineering – interior trim

6.1 Introduction

Modern methods of production are revolutionizing the industry, but they have also brought fresh challenges to the fabric producer. Specifications governing fabric and fabric laminate consistency are becoming more exacting. The more established standards for dimensional stability and for requiring the fabric to lie flat, so layers of material can be cut accurately, have been joined by additional requirements such as porosity, thickness and tighter tolerances all round. This is because moulding techniques usually applied to plastics, are being adapted to produce car interior components on a large scale. Usually heat is applied in a moulding operation or to activate hot-melt adhesives but polyester fabric being thermoplastic is vulnerable to thermal damage during these operations. The fabric is especially at risk because it is invariably textured or surface raised when used for car interiors.

The automotive industry has become so competitive that manufacturers are reluctant to divulge precise details of their process for fear that it could be helpful to their competitors. This is true of almost any industry but probably more so of the automotive industry at the present time. Mass production methods are still being evolved, developed and refined to suit particular circumstances and frequently changing requirements. These factors add to the already intensely competitive nature of the industry. The information contained in this chapter is therefore of a general nature and is what is already in the public domain. Basic scientific principles and material properties however do not change, and it is hoped that knowledge of these will help in future design, and also in problem solving. Details of the materials used and some properties appear in Tables 1.4, 1.5, and 9.1. The effect of heat on the shrinkage of polyester fabric is shown in Fig. 4.7.

The car interior has grown very significantly in importance in recent years; the aesthetics factors have already been made clear. We are spending more time in cars, and comfort in all its forms, is now a major factor that customers take into consideration when purchasing a new car. Textiles are essential for producing surfaces with an attractive appearance and soft touch but they also play an important part in sound and vibration insulation and, as will be seen in the next chapter, an increasing role in road safety.

6.2 Seats

6.2.1 Introduction

The seat is probably the most important item in the car interior. It is the first thing the customer sees when the car door is opened and he or she will probably instinctively touch it; there is only one opportunity to make the most of this first impression. The seat is also the main interface of man and machine and seat comfort is of paramount importance. The factors influencing driving comfort have been researched in detail, especially within the last 10 years or so, by the OEMs, foam manufacturers and university departments, who have studied the ergonomic aspects and sound and vibration factors on human health.[1–2] Seat comfort and safety have also been the subject of European-sponsored research projects involving OEMs, seat makers, fabric producers and universities.[3] Textiles have become by far the most widely used material in seat coverings and are beginning to be used in other areas of the seat in place of polyurethane foam. They are also used in a number of specialist cases in place of metal springs and the actual seat pan and seat back. The move to replace polyurethane foam is mainly driven by recycling, commonization of materials and disposal factors at the end of the car's life. The use of one material; polyester, in the face fabric, polyester non-woven in the cover laminate and polyester non-woven also in the seat squab and cushion, would certainly simplify recycling and disassembly. However there are several factors to consider that are difficult to overcome, as will be seen. New techniques to make seats, which is overall still a fairly labour-intensive process have been developed and some are being put into commercial use. However despite this, some automotive engineers hold the view that seat process development and materials innovation are the slowest moving sectors of the automotive industry.[4] Seating systems are amongst the most costly items in the car interior.

6.2.2 Methods of seat construction

The traditional method of seat making involves cutting and sewing of panels of the seat cover laminate (face fabric/foam/scrim) into a cover, which is then pulled over the squab (seat back) and cushion (seat bottom), and then fixed in place using a variety of clips and fastenings. This process is both time-consuming and cumbersome, and because it includes considerable

6.1 The modern car seat – designed for comfort and styled for attractive up-to-date appearance.

'human element', consistency of quality could be better, which is a cause for concern even with skilled operatives. Furthermore, this problem is becoming even more troublesome with modern highly contoured seats, see Fig. 6.1. Several attempts have been made over the years to find better ways using a variety of techniques.[5] Three-dimensional knitting of the seat cover is an option which so far appears to have had only limited usage.

6.2.2.1 Foam in place

The 'foam in place' technique (also called 'foam in fabric' or 'pour in foam'), was developed in the late 1980s and achieved considerable initial success, especially with the Ford Fiesta.[6–8] The method combined two separate processes into one; foam cushion and squab moulding with the fixing of the seat cover in place over the pre-moulded foam. Panels of the seat cover laminate were cut and sewn into a 'bag' and the liquid foam components were poured in. These liquids reacted together to form the solid foam, but to prevent the liquids seeping through the fabric cover laminate before the reaction was complete, it was necessary to include a polyurethane barrier film into the cover laminate beforehand. It was believed that this polyurethane film reduced seat thermal comfort because the water vapour permeability of the films used was too low to allow the passage of human perspiration. For this and other reasons, this novel method of seat making was generally discontinued for large-volume production. However, the basic method is still used for smaller, less critical items such as headrests and armrests. These smaller items do not need polyurethane films to act as liquid foam barriers, because the actual liquid foam pressure in such small items is not as great as in a seat cushion or squab. Laminate foam of higher density or slightly lower porosity, or a non-woven scrim, is generally sufficient to prevent liquid foam strike through.

6.2.2.2 Direct joining techniques

Several other methods have been developed based on directly joining the cover fabric laminate to the squab and cushion.[9–11] Direct joining is especially suited to seats with curvaceous contours and it also allows a reduction in the thickness of the laminate foam. There are many variations to the basic principle and both hot-melt adhesive films and solvent spray adhesives are used. Vacuum is applied to hold the components together, and the hot-melt adhesive is activated by steam or hot air. This general method is gaining in popularity because it removes some of the human variation factors (the least controllable) and generally produces a more uniform seat appearance. However there are still problems to overcome such as preserving the pile in velvets, and other raised or textured fabrics, and cover laminate thickness has become more important. Certain other quality control tests have become more critical such as cover fabric to laminate foam adhesion, which needs to be generally higher because there are fewer sewings in the new process, to help keep the two materials together. In addition alternatives may have to be found eventually to replace solvent-sprayed adhesives as environmental laws tighten. Changing production to this method requires investment in costly new equipment and specially made tools, and for this reason, the traditional methods are likely to be with us for some considerable time.

6.2.2.3 Hook-and-loop fastenings

Newer, novel ways of joining components together are finding applications in the car. Hook-and-loop type fastenings, sometimes called 'touch-and-close', examples of which are the Velcro-branded products, which have been used in other industries for many years are especially suited to the car where ease of disassembly has become important. These fasteners are much stronger than many believe and can be used for permanent joins –

permanent, that is until the end of the car's life. These materials are generally made from raised, knitted nylon 66 although polyester is sometimes used. They have many applications in the car and a method of seat making has been developed, which has the advantage of producing sharp well-defined deep contours without any of the lifting or bridging problems that are sometimes associated with stretch fabrics. The hook part of the fastener is attached to the seat foam cushion and the loop part sewn to the cover. When brought together, a very strong join is produced.

6.2.2.4 Tunnel tie

Hope Webbing Company of Rhode Island, USA, has introduced yet another new method of securing seat covers over the foam cushion. It features a specially designed sleeve through which a draw cord passes. The sleeve is sewn to the edge of the seat cover, which is then drawn over the foam cushion and the cover is secured by pulling the cord tight. For more complex seat forms the cord is drawn through small apertures in the sleeve and secured to the back of the cushion. Tunnel Tie is economical and simple to use without the need for hooks, 'hog rings' or plastic clips. It is also easier to disassemble, which could facilitate recycling, and seems to be especially suitable for detachable seat covers, which can be changed by the customer.

6.2.2.5 3-D knitting of car seat covers

This highly advanced, computer-controlled knitting technique enables several conventional cut and sew panels to be replaced with just a single 3-D shaped piece.[12–19] The novel development originated in the Research Division of Courtaulds at Spondon, Derby from garment-making research. The objective was to knit garments in one piece, thus eliminating panel cutting and making up together with the associated cutting waste of up to 30%. The potential benefits for car seat covers were soon realized and General Motors became involved.

Initial progress was hampered by the mechanical flat-bed weft knitting machine controls and its jacquard card needle selection mechanisms, but these limitations were soon overcome by the appearance of the computer.[13] Now each needle is individually computer controlled to enable almost infinite colour combinations and design patterns. Car seat covers can be knitted in just one piece, the single item includes all tubes, flaps and tie downs necessary for direct fitting. The labour intensive stages of panel cutting and sewing of up to 17 individual pieces of fabric are reduced to just one or two with no cutting waste.

The 3-D technique allows considerable design flexibility and creativity. Computer-assisted design 'paint box' systems facilitate design themes;

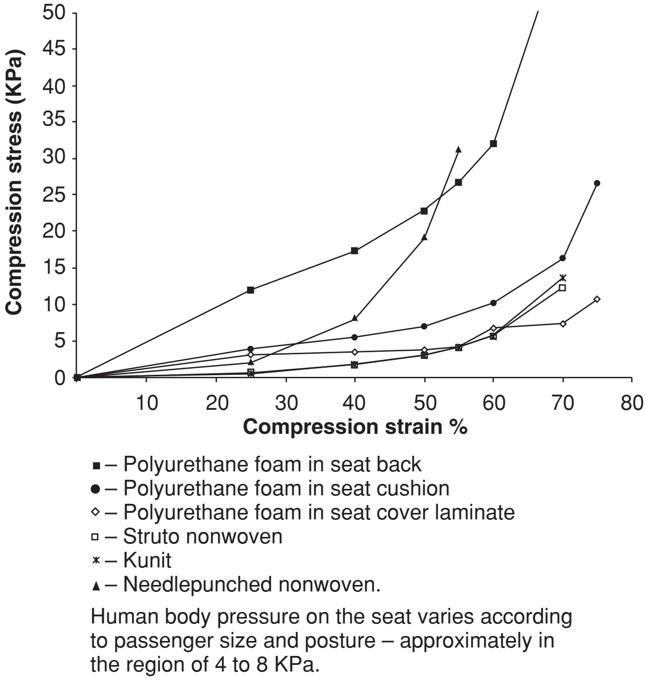
visual appearance can be dramatically modified by changes in fabric construction, yarn type and colour. Logos can be accurately placed and design themes can cover two or more seats and can even include the door panels if so desired. The actual seat cover itself and the patterned fabric are developed simultaneously which reduces development time by months. The design-approval process is both shortened and enhanced by the ability to view the finished seat in 3-D form on the computer screen. Other benefits include rapid set up and dramatically reduced stock holding especially of end of model surplus. A new model cover, can be produced simply by changing the yarns, inserting a new floppy disk, and a new seat cover is available for fitting within minutes.

These 3-D seat covers were first used in Europe in the Vauxhall Rascal van and in the USA in the 1993 Chevrolet Indy Pace car. They are now being used in the General Motors (GM) electric car, EV1 and in the GM car, GEO Prism. Research work continues with a variety of different yarns to further develop the aesthetics and handle. The 25 or so 3-D world-wide patents relevant to automotive application were held by GM but the original inventors are mainly British and until recently continued their work at Spondon, Derby. In late 1998 the Lear Corporation acquired the seat-making facilities of the GM subsidiary company, Delphi.

6.2.3 Materials for seat making

6.2.3.1 Alternatives for seat cover laminate foam

Non-woven polyesters fabrics – especially those made from recycled fibres,[20–24] and novel knitted structure such as spacer fabrics, Kunit, Multiknit[25,26] and Struto[27] have been considered as substitutes for polyurethane foam in the cover laminate. Spacer fabric is essentially a knitting product with threads perpendicular to the plane of the fabric with a knitted layer each side. Multiknit is a continuous process, which makes fabrics from fibrous webs using Malimo knitting techniques (Karl Meyer). Kunit consists of a stitch layer with a pile on the top whereas Multiknit comprises two stitch layers with the pile in between. A novel development from the Czech Republic, Struto non-woven fabric, is produced from layers of fibre vertically lapped, see Fig. 3.36. Non-woven materials made from recycled wool and polyester have also been examined and are used commercially. Tests show that they have generally similar compression/strain characteristics to polyurethane foam, see Fig. 6.2. Materials based on polyester fibre all lose significant thickness when tested by the compression/strain test according to BS 4443 Part 1 Method 6A, even when the test is done at lower temperatures than that specified by the test.[20,28] See Fig. 6.3 and Table 6.1. This would not be noticed in thin layers say under 3 mm thickness in the

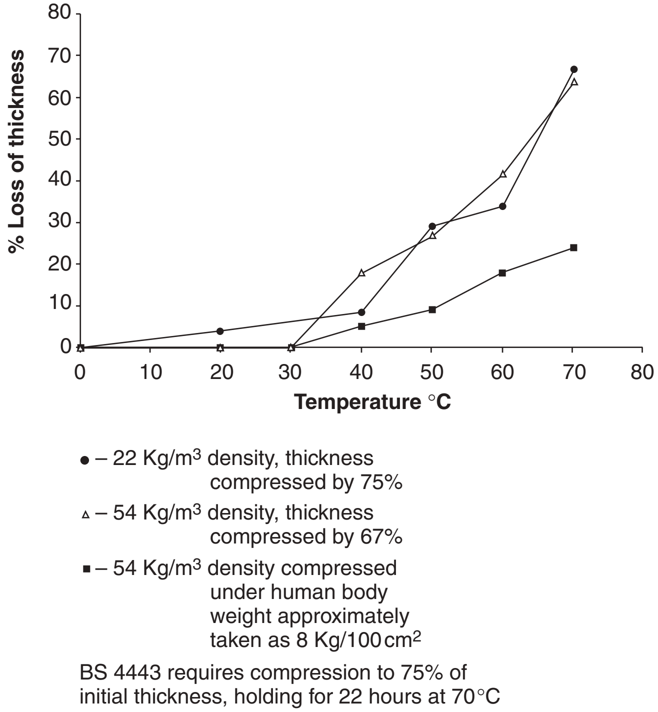


6.2 Compression stress/strain characteristics of some non-woven materials compared to polyurethane foam.

cover laminate but would be noticeable if used in thicker layers especially in place of the squab or cushion foam. BS 4443 however is a test designed for polyurethane foam, realistic tests for nonwoven fabrics used in this application are still to be established and standardized. The 'touch' of these materials is quite different from polyurethane foam however, and if this is a problem it is not likely to be overcome easily because of fundamental differences in material behaviour when compressed locally.[29] The foam has an isotropic structure (3-D) whilst the nonwoven made from a carded fleece is only two dimensional. The slight 'scrunching' sound when spacer fabrics are compressed or sat upon has also been commented upon.

6.2.3.2 Alternatives for seat squab and cushion foam

Several alternatives to polyurethane foam used in the squab and cushion have also been developed. DuPont have introduced polyester fibre 'clusters' which have a coiled and fluffed configuration. The clusters are put into a mould made of perforated metal and hot air is applied which bonds the clusters together. They can be formed into seat cushions and squabs in place



6.3 Polyester non-woven materials; loss of thickness under load and temperature.

of polyurethane foam and the manufacturers claim weight savings of up to 30 to 40% compared to foam. DuPont also claim the same seating support, easier disassembly and recycling, and better comfort through increased breatheability.[30] Very recently, Toyobo have launched a material called BREATH AIR described as random continuous loops of a thermoplastic elastomer; similar claims of comfort and recyclability have been made.[31] Natural materials referred to loosely as 'rubberized horse hair' have also been used. This fibrous matter, believed to include coconut fibre and pig's hair as well as horse hair, coated with a rubber, provides good body support, has high porosity and breatheability and is also claimed to be easily recycled. However it does not provide a smooth surface and the seat cover laminate foam or foam substitute must be relatively thick for a comfortable seat. In addition rubberized horse hair is said to be not a pleasant material with which to work.

All of these substitute materials are not as resilient as polyurethane foam especially when tested at higher temperatures in accordance to BS 4443 (see above), and lose significant thickness. The same considerations dis-

Table 6.1 Loss of thickness of some car seat materials

Material	% Loss of thickness after 22 hours 75% compression at	
	50 °C	70 °C
Polyurethane foams		
Regular ester density 28 kg/m^3	6.6	7.1
Regular ether density 28 kg/m^3	8.2	1.4
Reticulated foam (very open cell)	7.9	5.3
'Water Lily' ('greener foam') ICI	11.6	10.0
Non-wovens, all polyester		
'Struto' density 40 kg/m^3 (early sample)	33.0	50.0
Chemically bonded density 45 kg/m^3	30.0	51.0
Needlepunched density 40 kg/m^3	40.9	49.9
Other materials		
'Spacer fabric' (knitted polyester ex Karl Meyer)	30.7	45.7
Kunit – polyester	39.9	52.2
Kunit treated with silicone elastomer ex Dow Corning	—	65.0
Kunit treated with silicone elastomer ex Ciba Geigy	—	65.0
Multinit – polyester	50.7	61.8
Kunit made from recycled polyester	50.5	67.7
Natural rubber	6.9	30.1
Rubberized 'horse-hair'		
RG30 (low density) density 30 kg/m^3	26.2	42.3
RG60 (higher density) density 60 kg/m^3	39.0	46.2
Ecofil spheres DuPont polyester	—	50.0

NB: Test method BS4443 Part 1 (6A) requires compression to 75% of original thickness. This generally requires a force which exceeds human body weight.

cussed above relating to laminate foam alternatives also apply to the squab and cushion foam, see Fig. 6.2 and 6.3 and Table 6.1. Natural fibres, jute, sisal and kapok, are also being considered for use in seats as alternatives to polyurethane foam. As well as environmental advantages, benefits relating to comfort such as moisture absorbency are claimed. The ability of these alternative materials to dampen vibration when used in conjunction with – or in the absence of – seat springs, needs to be established. Alternative foam materials must also stand up to the continual mechanical pounding that seat components are subject to when car occupants get in and get out of the car and move about in the seat. Seat makers attempt to simulate this with the so called, 'jounce and squirm' test.

6.2.3.3 *Sewing threads*

Sewing thread, which holds all cut panels together, is an engineered material which has to withstand considerable forces both during seat cover manufacture and also during use. The actual process of sewing makes very demanding requirements on the thread, which in typical seat covers include sudden accelerations and tensions while being drawn at high speeds through not only fabric, but also light plastics. Typical sewing speeds are around 2000 stitches a minute, or 30 per second and considerable heat can be generated.

The yarn threads are spun to a high specification, resin-bonded together to prevent fraying and a carefully formulated lubricant is applied during thread manufacture which reduces needle heat and helps promote easy movement through the goods. These processes are critical to sewing performance; the thread must be round, even and balanced in twist, i.e. it must not curl around itself when allowed to hang loose. All of these properties are specified and monitored, to prevent production problems. The thread must of course last the life of the car without breaking down in any way such as snapping, shrinking or stretching. It must be very strong and have very high abrasion and UV radiation resistance in all conditions encountered in the car, including high temperatures and relative humidity. Most car seat thread is produced from continuous filament high tenacity nylon 66 in approximately 800 to 1200 dtex but varies according to specifications set by the OEM. Nylon is best suited for this application because of its abrasion resistance, elastic recovery and wet strength in addition to the ability to withstand the usual conditions inside a car. In a small number of cases, polyester thread is used; thread from this fibre is widely used in seat belts.

6.2.3.4 *Kaptex®*

Deep, well-contoured sewing lines are an aesthetic feature in their own right and can be simulated by a thermobonding technique without any actual sewing. This process, which was developed by Textile Bonding in the UK allows accurate, uniform and reproducible sewing effects and stitch patterns to be produced, in almost unlimited designs, including logos, which cannot be accomplished easily by conventional sewing.

6.2.3.5 *Natural leather*

Automotive natural leather is frequently foam-backed together with a scrim in the same way as fabric before fabricating into a seat cover. The leather is also usually lacquered with a polyurethane resin on the face side to improve abrasion resistance but this is believed to reduce breatheability. In recent years, leather processing has undergone certain changes to comply with environmental laws.[32] Leather is universally regarded as the ultimate in seat luxury but is expensive and a shortage is forecast in the future both because of the increased volumes in car manufacture and also because fewer cattle are being raised for food. At the same time more and more people can afford leather and it is also being used more in design combinations with textiles. The shortage of leather together with the increased preference for leather designs is an opportunity for expansion in man-made leather products – which require textile base materials. The odour of natural leather, generally regarded as part of the overall luxurious image, is believed to be disliked, by some Japanese customers.

6.2.3.6 Man-made leather and suede

At present the most successful man-made products, two grained leathers and eight suedes are entirely Japanese made, and the companies involved have production expansion plans. Toray anticipate a rise in the demand for man-made suede from 16 million m^2 in 1995 to 25 million m^2 by 2005 with a significant proportion going into European cars.[33] This estimate is already looking very conservative. The base materials are generally non-wovens using micro-fibres in polyester, which constitutes 68% of the weight, the remainder being polyurethane resin. For use as car seat covers, the man-made suede is polyurethane foam backed with a scrim fabric in the usual way. The best known is Alcantara,[34] made in Italy since 1975 by a Toray/Enichem joint venture (now Toray/Mitsui) and initially used mainly in Italian cars. Over a million square metres are used at present, but this is likely to increase, especially in Europe with nine car makers making use of it. A second production line for the material is being built. At present very little is used in the USA, but this is likely to change. Kuraray, one of the pioneers of man-made leather has recently entered the European automotive market with their Amaretta product.[35] Man-made products have the important advantages over natural leather of availability in roll form, lightness of weight, uniformity of quality, uniformity of thickness and other physical properties, which allow more efficient production planning, and minimization of waste.

Because Alcantara and other successful man-made suedes are produced by a solvent coagulation process requiring expensive plant and environmental controls, attempts have been made to develop more environmentally friendly aqueous-based methods.[36] One key factor in achieving the quality of man-made suede, is believed to be due to the micro-fibres in the base fabric, and the very latest products use ultra fine filaments of 0.001 to 0.003 dtex. However the polyurethane polymer must have the right properties and there is considerable skill required in the final sueding operation.

In 1994, Enichem launched a new artificial leather called Lorica,[37] which has several advantages over natural leather which include better elongation, tear strength, mouldability and high-frequency weldability. Lorica is made from polyamide micro-fibres and polyurethane and is available in a variety of colours.

6.2.3.7 Flocked fabrics

Flocked fabrics at competitive prices, are claimed to reproduce the appearance and touch of velvet and suede.[38–41] Virtually any fibre, natural or synthetic can be flocked but materials for automotive use are mainly polyester. The manufacturing process involves applying flock by either mechanical or electrostatic means to an adhesive-coated base fabric. Flock fibre is about 0.5 to 1 mm long, about 1.5 to 3.5 dtex and can be matt, bright or semi-matt yarn in any colour. Recent improvements in flock technology have expanded the scope of flocked fabrics and Novalis Fabrics, associated with both Rhone Poulenc and Fiat, have produced material for car seat covers. They have experimental evidence showing improved seat thermal comfort of flock fabrics.[38] Flocked fabrics and other flocked materials (plastics can also be flocked) are finding applications in the elimination of squeaks and rattles. Flocked articles are also useful as seals for example on car windows and they can act as a lubricant for example on the sunroof sliding hatch.

6.2.4 Alternative methods of seat making

Some alternative approaches to seat making replace both seat structure and foam with textile fabric. The main benefits of these methods are reduced weight, space saving by thinner profiles, reduction in the number of components and also reduced assembly costs[10,42–45] Recyclability and ease of disassembly are also important advantages and better thermal comfort has been claimed. One product, Sisiara (Pirelli) has been available since 1974 and has already been used in many production cars. Sisiara depends on a woven rubber/fabric supporting material, which replaces both springs and seat back and pan. The open weave allows better ventilation and the non-rigid structure allows reduced amounts of foam. The foam can be replaced altogether by Pirelli's inflatable 'Comfort Zone' system, developed in the early 1980s, and which can be adjusted to suit individual requirement by inflating the structure.[46] It was designed mainly for lumbar support but can also be applied to other seat areas.

A foam and spring replacing system introduced by DuPont known as Dymetrol has also been used in automotives around the world.[47] It is a woven fabric structure and described as being 100% polyester; the warp yarns are of DuPont's Hytrel polyester resin, the weft of regular polyester and the whole is therefore readily recycled.[30] The manufacturers claim that the yarns stretch to take the exact shape of the seated person, but later return to the original dimensions, and it can do this thousands of times without fatigue. Dymetrol is woven in the USA by ACME Mills of Detroit.

DuPont have publicised the possibility of a 100% polyester seat; cover, cushion and seat frame. It would comprise a polyester face fabric, laminated to a polyester non-woven fabric, covering a squab and cushion made from DuPont polyester Fibre Cluster material. The seat frame would be made from injection-moulded Rynite thermoplastic polyester and compression-moulded DuPont XTC thermoplastic polyester. The whole assembly would therefore be constructed from all DuPont polyester materials requiring minimum disassembly for recycling and would also weigh less than a conventional seat.[30]

Ultra-Flex Corporation using Hoechst Celanese Elastomer monofilament fibres developed a lightweight fabric seat suspension system, space-saving and requires less foam. Better height control, less noise and greater long-term durability are also claimed. Milliken have also developed a family of fabrics known as their Gemstone range, some of which combine seat support with aesthetics.[48] This means that the seat is a single fabric without foam or springs underneath, saving even more weight and increasing useable space within the car. Inland Fisher Guide, now Delphi, produced an elastomeric screen-like material known as Optiride which is unique in having a dual modulus depending on the strain level. Below 30% the modulus is relatively low, but above this figure, it becomes significantly higher. Delphi has used the Optiride system with their 3-D knitted seat covers.[42] Very recently a further seating assembly using a warp knit fabric has appeared in the USA.[49]

The appearance of multipurpose vehicles (MPVs) has introduced a need for the seat layout to be flexible. Seats which can be removed and refitted by the customer must be light in weight. OEMs and seat makers have worked on this and also taken the opportunity to use new lighter-weight materials and to combine several components. Daimler-Benz have produced such a seat for their 1997 V-Class minivan which replaces 20–30 seat-back components with just a single piece in Durethan BKV from Bayer, and the whole seat is 30–50% lighter with cost savings of 10–20%. This particular seat also features a built-in seat belt. The feature of designing seats with built-in safety belts is being developed, especially for children, and some are in commercial use.[50]

The concept of moveable seats may lead to replacement seats, which in turn could lead to customized fabric patterns, perhaps requiring slightly less demanding performance specifications. The latter factor would allow softer cover fabric handles and a wider variety of colours. The use of composites and carbon fibres in seat frames of high volume production cars is a development not likely to appear for several years, but the price of carbon fibres is coming down. This development would not only save weight, it would also provide more space inside the car by allowing seats with thinner profile.

6.2.5 Introduction to seat comfort

The car seat must be comfortable in all senses of the word; psychologically, physiologically and thermally. Researchers believe that driver discomfort is an important factor in inducing driver fatigue and so improved comfort should contribute to road safety. The seat needs to provide the body with support under all road conditions including cornering, accelerating and braking. Seat pressure distribution has been carefully studied and foams of different density are used to give support to the body in different areas of the seat. The effect of vibration on driver health and discomfort has been researched extensively,[1,2] and indeed there are international standards which state how much vibration the human body can withstand without ill effect, e.g. ISO 2631. Springs and foam in a car seat contribute to, and complement the vibration-damping action of the car suspension. Full foam seats used with a 'dead pan', i.e. with no seat springs, need to be specially developed because the foam alone must do the job of effective vibration damping.[2] Textile technologists who seek to replace springs and foam using non-wovens and other textile materials should be aware of all the facets of seat manufacture and design, and should work in conjunction with an OEM or seat maker from the start.

6.2.6 Seat thermal comfort

The thermal comfort of a modern fabric seat cover is a significant improvement compared with PVC which was widely used during the 1960s and 1970s, but in hot weather, modern car seats can still be very uncomfortably hot and sticky. A popular simple solution has been the 'bead' seat, which is used all over the world. There is little doubt that they are cooler, presumably because polished wooden or plastic beads are cooler to the touch in hot weather than fabric and also because they create an air gap between the skin and the car seat thus allowing some air circulation and sweat evaporation. However the bead seat is far from ideal when aesthetics and other comfort aspects are considered.

Thermal comfort has been defined, as 'that condition of mind which expresses satisfaction with the thermal environment; the person does not know whether he or she would prefer a warmer or a cooler environment', (ASHRAE standard 55–56).[51] The human body core temperature must be kept within fairly narrow limits for survival. 'Overheating' is prevented by losing heat by conduction, convection, radiation and by loss of moisture which has a cooling effect due to latent heat of evaporation. A certain amount of heat is lost through the mouth by breathing – the respiratory heat loss, but this is quite small. In hot weather or during physical activity, the most important mechanism the body has for keeping cool is by exuding perspiration through the skin, i.e. sweating. This sweat must be allowed to evaporate to produce cooling. When the car interior temperature, approaches body skin temperature i.e. about 37.5 °C, sweating is the only way the body can lose heat. For a person to be comfortable, this sweat must evaporate and be removed from the skin, to prevent the feeling of stickiness or dampness.

A significant proportion of the seated human body is in contact with the car seat cover, which can be regarded as another layer of clothing through which perspiration must pass. Underneath the seat cover, are the squab and cushion, made from much thicker pieces of polyurethane foam which are additional barriers to the escape of perspiration. Thin layers of foam will allow a certain amount of perspiration to pass through, but the thicker the foam, the less the 'breathability'. Some data on the breathability or moisture vapour permeability of materials used in seat making are presented in Table 6.2, together with data on some materials known to be sufficiently breathable for comfort. Foam is also a good insulator of heat and in a normal car seat, the body will sink into the soft foam which will wrap around it, thus further reducing the ability of perspiration to evaporate. Deep sew lines in the seat cover, which can act as channels for air circulation, and as an escape route for perspiration would be expected to be beneficial to seat thermal comfort.

The issue of seat thermal comfort has been very extensively studied,[52–59] and several methods have been proposed to measure it.[60,61] Seat thermal comfort is a very subjective quality and depends on the interplay of a number of factors including the seat cover fabric itself, the laminate material in the seat cover, the squab and cushion and the seat design as a whole – not to mention the individual person's body metabolism, fibre type in clothing and layers of clothing. There is evidence that on long journeys the material forming the back and sides of the seat also affect driver comfort.[57]

Polyester face fabric is not ideal for thermal comfort because of its very low moisture absorbency, but as recorded earlier, it alone satisfies the important requirements of abrasion resistance, UV degradation resistance and cost. Application of a hydrophilic finishing agent to the polyester has been shown to have some beneficial effect but finishing agents generally only have a limited life.[56,57] Wool or wool/polyester blends face fabrics are more costly and more moisture absorbent but will have lower abrasion resistance than 100% polyester. However some OEMs do use wool or wool

Table 6.2 Water vapour permeability (breathability) of some car seat materials

Material	Weight (g/m^2)	Thickness (mm)	Porosity	Water vapour permeability (g/m^2 24 h)	
				LDF (21 °C)	HDF (34.5 °C)
Seat cover material					
Polyester woven fabric	297	1.44	4.0	628	3799
Polyurethane foam	295	8.53	14.0	491	2336
Tri-laminate (includes scrim)	648	9.42	3.0	472	2256
Polyester knitted fabric	236	1.39	26.0	659	3788
Polyurethane foam	180	4.07	8.0	536	2941
Tri-laminate (includes scrim)	455	4.99	6.0	540	2689
Woven velvet trilaminate includes backcoating	829	10.70	3.2	388	1721
Natural leather 1	727	1.61	0	204	1511
Natural leather 2	890	1.29	0	217	834
Alcantara/scrim	404	1.26	1.0	596	3541
Lorica/scrim	510	1.30	0	526	2835
PVC 1/scrim	568	0.92	0	15	416
PVC 2/scrim	818	1.58	0	30	168
Other seat materials					
Seat squab foam	1200	20.00	13.5	294	1168
Seat cushion foam	1050	15.00	14.0	352	1458
Rubberized 'horse hair'	606	2.00	Infinity	703	1779
Polyester needle-punched non-woven	405	5.38	50+	556	2881
Kunit	422	12.40	22.00	627	2807
Spacer fabric	240	3.60	50+	601	3377
Adhesive films					
Polyurethane adhesive film	42	0.10	0	68	263
Polyurethane adhesive film after lamination	—	—	—	260	1673
Polyurethane adhesive film with holes	31	0.22	—	351	1124
Polyolefin adhesive film	42	0.10	0	68	263
'Breathable' films					
Gortex Clothing Triple Laminate (WL Gore)	172	0.40	0	423	2862
Sympatex Clothing Double Laminate (AKZO)	137	0.31	0	532	3343
Porelle Film Only (Porvair)	28.4	0.11	0	576	3196
Scotch Microporous Polypropylene Film (3M)	29.4	0.11	0	576	3196

Test methods
ASTM E-96 80 (evaporative method) with an airgap of 2.0 cm.
LDF = low driving force, 21 °C ambient, 21 °C inside test vessel.
HDF = high driving force, 21 °C ambient, 34.5 °C inside test vessel.
Porosity (air permeability) BS 4442 Pt 6 Method 16.
Source: Reference 57 and BRITE EURAM PROJECT 5549.

blends in seat cover laminates both in face fabric and also in the backing to reduce the stickiness feeling.

Any barrier to air and moisture permeability is therefore very likely to reduce seat thermal comfort, and care must be exercised when adhesive films or barrier films for vacuum forming techniques are used in seat construction. Any measurements of breathability must be compared with realistic standards, e.g. Goretex (WL Gore), Sympatex (AKZO) or Porelle (Porvair) membranes, which have proven performance properties in protective clothing, see Table 6.2. Measurement of breathability is a complex subject because test results are very dependent on the test method, as anyone in the protective-clothing industry knows well. In recent years several other apparently suitable products have been introduced, for example films by Wolff Walsrode (Bayer) and by 3M. Driving a car is not a high energy activity, in fact some researchers have shown it is comparable with sleeping and walking slowly along a flat road.[62] However, temperatures inside a car in sunny weather, with the occupants inside, can easily exceed, say, 30 °C and even at this temperature the amount of perspiration exuded by an average person at rest can be equivalent to the amount exuded in high-activity situations at normal ambient temperatures.

Several attempts have been made to achieve enhanced thermal comfort by use of carefully chosen assemblies of fibres to first absorb moisture, then to transport it away from the skin.[63] In one novel development a natural fibre Ramie, is used as a moisture transport medium.[64] Other methods to improve seat thermal comfort have been made by the use of ventilated seats using air driven by electric fans. This has been used in commercial vehicles, lorries and buses, but in early 1998, Saab featured this luxury item in their 9–5 saloon car in the USA – the first for a volume production car. The problem of seat thermal discomfort should be significantly alleviated by air conditioning in volume production cars. Installation of air conditioning in new American cars has been increasing and reached over 90% by the 1990s. In Europe, Installation of air conditioning in vehicles has also been growing steadily from about 12% in 1990 to 56% in 1998 and is expected to reach 70% by 2000.[65] This luxury item, now becoming regarded as standard, is typical of how quality is being raised by the OEMs and how the general consumers' expectations and demands are increasing. Air conditioning units however add to cost, weight and fuel consumption.

6.2.7 Seat comfort – the complete picture

Comfort is a neutral condition and garment comfort researchers regard garments as comfortable when the wearer is physically unaware of them. Researchers conduct their studies by measuring *discomfort.* In a similar manner to the clothing situation, seat comfort is influenced strongly by fabric properties, but it is dependent on a very large number of interrelating factors which merge to provide an overall largely subjective assessment of comfort in the car.[66] There are, however, established measurable scientific data relating to comfort such as the vibration frequencies at which the human body is known to be sensitive and levels of noise at which health begins to suffer. However many quantities are highly subjective, depending on the individual's personal preference and culture, past experience, level of tolerance, metabolism and state of health. National preferences for comfort factors are known to exist, for example the hardness of cushion foams can vary by more than 50% when measured by compression stress/strain. Textiles play a significant role in improving comfort in other ways, not only by vibration and sound damping in interior trim components including the carpet and headliner, but also by noise insulation under the bonnet and under wheel arches. Textiles allow the production of overall mentally relaxing interiors by fabric design and colour.

Psychological comfort includes the following quantities: overall aesthetic appearance; fabric construction/yarn type; design/colour; seat contours; current fashion; prejudice; and suitability for vehicle.

Physiological comfort or sensorial – next to the skin sensation is influenced by: softness; abrasion – roughness; smoothness; initial cold/warm feel; not too slippery; fibre shedding; prickle/tickle; and allergy.

Other relevant factors include: seat support/pressure distribution/seat geometry; suspension factors/vibration/smoothness of ride; wind/tyre/engine noise/squeaks/rattles/other noise; ventilation/air flow; interior temperature/humidity; availability, positioning of controls; ease of getting in and out of the vehicle; and visibility out of the car in all weathers.

The OEMs, universities and associated research institutions are carrying out considerable research on all aspects of car interior comfort. Entering and getting out of the car, especially by the elderly and disabled are problems to be overcome. Regular conferences and symposia such as those hosted by the Italian Associazione Tecnica Dell' Automobile in Bologna, are held to present and to discuss the latest findings. The ergonomics of seat design such as, suitability for drivers of different shapes and sizes, ease of reaching controls, visibility, getting into and out of the car etc., have also been studied intensively.[67,68] Textiles are eminently suitable for sound and vibration insulation and damping and also for eliminating squeaks and rattles. Seat discomfort contributes to driver fatigue, a recognized cause of accidents and as such is taken very seriously by the OEMs and seat makers. Recent research efforts are being directed towards improving the comfort and thermal comfort of seats for very young children and babies.

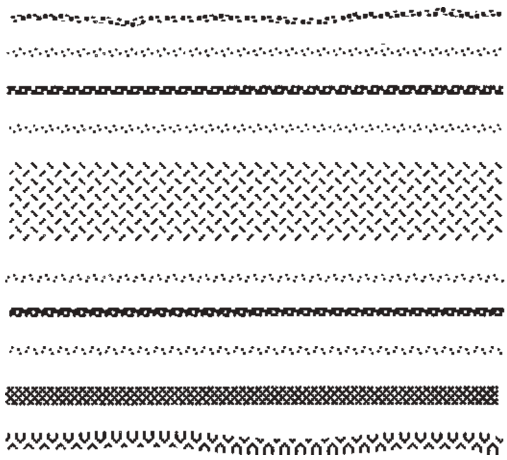
6.3 Headliners

At one time the headliner was simply a covering for the metal roof inside the car and consisted of a piece of fabric, PVC or some other material sometimes simply 'slung', i.e. held in place only at a few points. It has developed over the last 20 years into a sophisticated module component, important for sound and vibration insulation, as well as contributing to the overall interior appearance and actual structure of the car. There are also the usual performance requirements of interior trim although not quite as rigorous as seating material. Headliners now incorporate items such as driving mirrors, interior lights with wiring, assist handles, sunvisors, sunroofs and even brake lights in some models.[69] Other important requirements are lightweight, thin profile but rigid without any tendency to buckle, flex or vibrate, dimensional stability, aesthetically pleasing and preferably with a soft touch. A recent report noted that headliners seem to be touched more often, and this may lead to anti-soiling requirements. Future headliners are also likely to incorporate safety devices especially in the USA as FMVSS 201, the safety requirement for head protection is phased in. Certain interior designers have suggested that because instrument panels are becoming so overloaded with controls, some items should be relocated to the relatively vacant space in the headliner, although other designers disagree because of safety considerations.[70] If controls do appear on the headliner, anti-soiling is likely to become a requirement.

6.3.1 Headliner structure

The modern headliner is a multiple laminate of up to seven or more components all joined together, see Figs 6.4 and 6.5. Each layer is there for a specific purpose either for aesthetics, to provide sound insulation, vibration damping or to provide rigidity to the whole structure. Research work has been carried out to optimize the sound and vibration damping.[71–73] The centre core is generally a layer of semi-rigid thermomouldable polyurethane foam, initially about 15–30 mm thick or alternatively composed of waste fibre (recycled garments) bound with semi-cured phenolic resins. The centre core of polyurethane is bonded to two layers of chopped fibreglass rovings, one on each side. The fibreglass rovings are bound together and embedded in thermoplastic material, i.e. hot-melt adhesive powder or hot-melt adhesive film, e.g. Xiro film, or a combination of both.[74] These materials also act as the adhesive when the layers are joined together. Opinion differs whether continuous or slit film adhesives contribute the most to noise reduction. The layers of glass-roving help impart rigidity to the structure and are not always necessary when phenolic-resinated waste

6.4 Automotive headliner covered with nonwoven fabric. Courtesy of Cosmopolitan Textile Company Ltd.



6.5 Typical multilayer headliner constuction. The central core is semi-rigid polyurethane foam, resinated shoddy waste fibres or some other material. Heat is applied to the assembly in a flat-bed laminator to join all the components together. The material is then cut into lengths, heat is applied and the headliner is press-moulded to the required shape. During the latter process the assembly is compressed to about one-third of its original thickness. The adhesive film or powder permeates through the chopped glass mat and consolidates it. The chopped glass mat contributes to rigidity and acoustic insulation.

fibres are used. Attached to the side facing inwards is the decorative material, a non-woven polyester scrim is usually attached to the other side. All layers are joined together by action of the hot-melt adhesives in a flat-bed laminator, taking care not to damage the aesthetics of the decorative material nor to reduce the thickness of the centre core. The correct temperature and pressure must be optimized.

The composite sheet is then moulded to produce the required shape. The usual procedure is to preheat the assembly with infra-red heaters just before placing it into an unheated mould where pressure is applied. During this moulding operation the semi-cured phenolic resins are fully cured and the thickness of the central core is reduced to about one-third of its original thickness. All of the hot-melt adhesives have to be selected to meet the heat resistance specifications. A corrugated cardboard material, used as the central core in some models is relatively inexpensive, and can be recycled. However corrugated cardboard does not always allow sharp well-defined lines when moulded. Phenol-resinated cotton is relatively low cost, has good formability and acoustic properties but is heavy and if damp, can distort and give off odours.

Another well-known method of bonding the structure together, the Tramivex method,[72] involves dipping the polyurethane foam into a bath of liquid chemicals, while in other cases spray adhesives are used. The patented 'high calorific transfer medium' (HCTM) process, which makes use of superheated steam to activate hot-melt adhesives, is used for headliner construction as well as for door casing and seat making. Headliners are sometimes bonded to the car roof to become a part of the car structure, helping to eliminate roof bows, but other opinion believes this procedure increases noise. Fibreglass is not strong enough to be bonded directly to the roof and so a layer of a corrugated cardboard-type material is used in between the roof and the fibreglass. Headliners in larger vehicles generally have more layers to ensure rigidity and they may also be thicker in luxury cars for more effective sound proofing.

In the USA alternatives to fibreglass are being explored, because of dermatitis complaints by workers, who handle the fibreglass.[75] In addition, because headliners have become more complex and incorporate more items, the fibreglass is more easily damaged during the assembly process; phenolic-resinated fibreglass is especially brittle. Fibreglass began to be used because of its exceptional properties in sound absorption. Non-woven researches are attempting to replace fibreglass and the centre semi-rigid polyurethane, with polyester non-woven, to achieve a 100% polyester article, which should be more easy to recycle. Another material being considered is natural fibre-reinforced urethane (NFRU) which is energy absorbing and may contribute to meeting the safety requirement, FMVSS 201 for head protection.

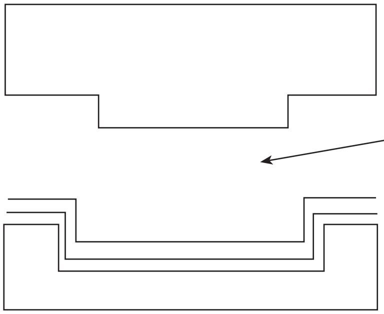
In the USA knitted headliners are losing ground to non-wovens which are used extensively in Europe and Japan.[76–78] Non-woven cover fabrics have the advantages over knitted fabrics of less cost and fewer in-moulding operations, they do not try to shrink back, but stay in place allowing deeper draws. The latest developments in headliner non-wovens include the use of fine denier polyesters, 3–6 denier per filament (dpf), which have good covering ability at low weight. Polyester fibre has a higher melting point than polypropylene, which means that in thermal moulding operations, a higher temperature with shorter processing times can be used. Typical non-woven headliners are about 200–220 g/m^2.

In the USA, FMVSS 201 requires that by 1999, 10% of all new vehicles must have some safety feature for head protection, by 2000 this will increase to 25%, by 2001 to 40% and by 2002 to 70%, increasing further to reach 100% by the year 2003. This could be satisfied by some type of airbag, or possibly even by a layer of foam up to an inch thick, although the latter option may lack available space.[79]

6.4 Door casings

Face fabrics for door casings are generally similar to seating fabrics and in many cases the same material is used for both applications in the same car. The textile/polyurethane foam laminate (there is generally no need for a scrim), is almost invariably used on a door casing in combination with a foil or film made from polyolefin (known as TPO – thermoplastic polyolefin), polyurethane, PVC, or PVC/ABS to produce a two-tone or two-design effect. Wood, wood-veneer or a natural or synthetic leather are also used. In some car models the textile is just a small insert panel or 'window'. Closed cell polypropylene foam, such as Alveo (Sekisui) has appeared in some models in place of polyurethane foam to provide a slightly firmer soft touch to the cover stock, which is preferred in some up-market models. At the bottom of many car doors is a piece of non-woven covering material, usually a needle-punched polyester or polypropylene felt, the so-called 'kick panel'.

As with seat making, the process of door making was labour intensive with even simple operations such as turning down edges of covering fabric or foil presenting manufacturing problems. A variety of different manufacturing methods using several different polymers, see Table 1.5, are now being used in continuing efforts to reduce costs by integrating various individual steps into fewer operations and also to achieve the more complex shapes now required by the designers.[80–87] Textile-insert low-pressure moulding techniques, for example using polypropylene resin, can produce a covered door panel in a single operation, see Fig. 6.6. No lamination process and no adhesive is necessary but barrier materials are sometimes



6.6 Component manufacture by 'one shot' textile (or decorative film) insert moulding. The process involves introduction of the polymer, either in molten or liquid form into the space between the top and bottom mould and over the fabric and barrier material. This is carried out by injection through an orifice in the top mould or by some other means. For long components, more than one orifice or gate may be needed. Skill and technical knowledge are required to obtain consistently satisfactory results. Care is needed to prevent damage to the face fabric; polyester begins to soften below 100 °C, well below its melting point. Application of pressure increases the risk of damage to fabric texture or pile. The barrier material is to prevent the liquid or molten polymer penetrating through to the face fabric before it solidifies to become the rigid carrier component. This general principle is used to make door casings, A, B and C pillars, parcel shelves. This single process, combines the following: 1. Fabrication of the rigid carrier. 2. Thermoforming the component to shape. 3. Lamination of the face fabric (or foil) to the rigid carrier.

required on the back of cover laminates to prevent the molten resin from penetrating to the face of the fabric. In some operations, the armrest is produced as an integral part of the textile-covered door panel in a single moulding operation combining what used to be several individual steps, see Figs. 6.7 and 6.8. The thickness of the cover laminate, i.e. the thickness of the polyurethane foam, is critical in some operations.

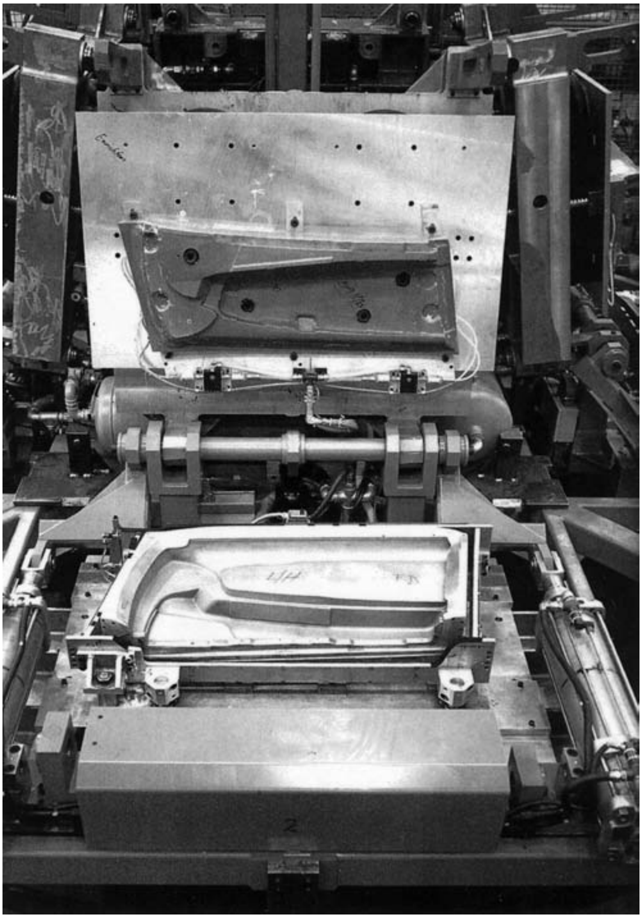
Textile/polyurethane foam-cover laminates joined to a material produced from wood chips and polypropylene is widely used to make door panels, but more process steps are required and this method is slowly losing ground to the single operation techniques. In the former method spray adhesives are used in some cases. Textile 'window' insets on door casings are sometimes produced using pressure-sensitive adhesive-backed (PSAB) components. Welding methods are also sometimes used in place of adhesives but the materials to be joined must be thermoplastic and capable of forming a good non-brittle join.

6.7 Integral door panel and arm rest.

The use of natural materials is being examined and in fact is being used in some cars in efforts to make the car 'greener' in response to pressure groups and governments. An example is Mercedes' use of natural fibres in a polyurethane matrix for the rigid door panel. There are also benefits to be gained since some natural materials have mechanical properties, which allow weight savings when used in composites.

Modern door casing manufacturing techniques, and the newer curvaceous designs are necessitating additional quality control tests to check suitability. Integral armrests produced by a single operation, may require fabric stretchability of up to 30% or more for deep drawer mouldings, see Fig 6.7. It is necessary to achieve well-defined contours, without pile distortion or crushing during moulding. The fabric laminate/door casing bond must withstand environmental tests and many years' use in the car without the textile lifting or delaminating over the sharp concave curves.

The Tier-1 companies continue to examine car door construction very thoroughly with the objective of integrating as many steps as possible in order to further reduce costs. Safety aspects have assumed more prominence recently, and side-impact protection units, designed to absorb and direct impact energy away from passengers, need to be incorporated into the door structure without reducing interior passenger space. In the USA side-impact protection for cars and light trucks is a legal requirement, FMVSS 214.



6.8 Door panel moulding. Reproduced by kind permission of Paul KIEFEL GmbH.

6.5 Parcel shelves

Parcel shelves, also referred to as package trays or the 'hat rack' are now almost invariably covered with needle-punched non-wovens mainly in polypropylene or polyester. At present, in Western Europe about 60% is polyester, the rest is in polypropylene. In Japan the usage is virtually all polyester; in the USA, it is virtually all polypropylene, but polyester is used in Japanese transplants in the USA. Parcel shelves range in size from relatively narrow components in saloon cars, to a much larger and wider article in hatchbacks. The textile-insertion low-pressure moulding method is sometimes used with a polypropylene covering to produce an all-polypropylene component. Polypropylene needle-punched fabrics used, are typically of

210 g/m^2 weight for flat components, ranging up to 298 g/m ^{2} for more curvaceous designs which require deep draw moulding. At present, however, the more traditional method of laminating the cover fabric to a rigid component made from shoddy (waste fibres) or wood fibre is still widely used.

Both the parcel shelf and the dashboard are directly under the large sloping glass windows of the car and their UV, lightfastness degradation and thermal resistance against delamination and distortion requirements are amongst the highest in the car interior. The face fabric must have reasonable abrasion resistance and the component as a whole must have sound absorption properties. Both polyester and polypropylene fibres are used and which is to be preferred is a matter of opinion and equipment available. Some producers report that higher production rates are possible with polyester because it can withstand higher temperatures and therefore shorter processing times. Others prefer polypropylene, because it is lighter, requires lower production temperatures and is easier to recycle.

The continued development of injection moulding techniques will lead to further test methods and standards for resin penetration through the textile cover. Other interior trim components are already made by textile insert injection moulding methods, i.e. A and B pillars. Back injection techniques when used for larger items, may need multiple gate equipment.[87] As molten polymer is being injected, cooling is occurring all the time and the sideways flow possible from a single nozzle or gate is limited. Thus two or more gates may be required but the point at which the molten polymer from different gates merges is a potential area of weakness and these operations must be skilfully designed and carried out.

6.6 Other interior trim

6.6.1 Dashboard

The dashboard, probably the hottest area in the car interior, offers some opportunity for textiles, although only a very limited number of car models use fabric at present in this very demanding application. Some Italian cars make use of textile inserts with the usual plastic foil as the main covering material. The dashboard shape being highly curved and also complex, to accommodate controls and instruments, presents many problems for the textile technologist. It could probably only be obtained by knitting, and 3-D knitting would be eminently suitable. Performance requirements of the dashboard are amongst the highest within the car interior but textiles could be made to fulfil the necessary criteria, i.e. low gloss (no glare or reflections on the windscreen), soft touch, pleasant aesthetics, non-fogging, non-odorous, UV stability, resistance to heat ageing, resistance to low temperature and high abrasion resistance. Cleanability would be limited but the ability to be thermoformed in mass production would be the most difficult problem to overcome.

6.6.2 Sunvisors

In the USA, sunvisors are produced from raised-warp knit fabric, whereas in Europe PVC is still extensively used. Some sunvisors are produced by injection moulding, others are composed of metal frames and rigid foam or cardboard are also used. The article is close to the windscreen and UV, light and heat resistance must be of the highest standard. Passenger safety is also an important consideration. There are opportunities for textiles, especially non-wovens in this area to produce a recyclable product.

6.6.3 Boot or trunk linings

With the advent of hatchbacks and split rear seats, the boot has become an extension of the car interior requiring better quality décor than before. About $4\,m^2$ of fabric are needed for this area and needle-punched polyester or polypropylene are the main covering materials. The boot also requires noise insulation and a variety of materials are used for this purpose including natural fibres such as hemp and sisal and also shoddy waste fibre. The main requirements are low cost, light weight and mouldability, achieved by resination. Up-market cars are likely to have thicker linings for extra noise insulation and some cars have interior wheel-arch liners.

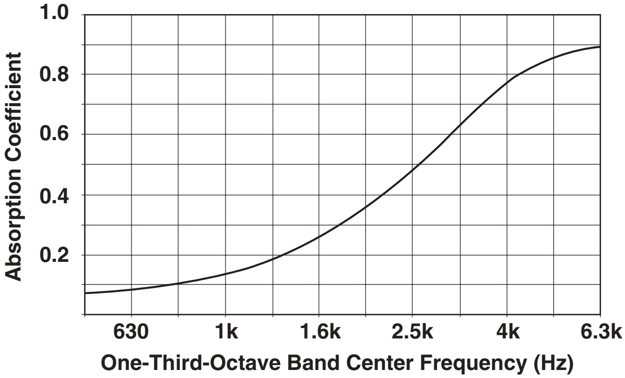
6.6.4 Further new materials

DuPont Thermolite acoustic insulation, a matting of 100% DuPont Dacron polyester has been developed to reduce noise in the passenger compartment. It is an alternative to fibreglass and polyurethane foam but has the advantages of light weight, cost effectiveness, easier and cleaner installation and recycleability. It could be used in the headliner or in door panels of luxury cars. Thinsulate brand acoustic insulation made by the 3M company has the novel properties of high acoustic absorbency performance at exceptionally light weight and reduced bulk, see Fig. 6.9.

Recycled polyester non-woven fabric produced from bottles is already used under the dashboard in some high volume Japanese cars. Very recently it was announced that Visteon and Kafus are to produce interior components from composites made from kenaf and other natural fibres. [88]

6.6.5 Ancillary textile items

Textiles are also present inside the car in a variety of ancillary products such as luggage netting on the backs of seats and luggage restraints or coverings



6.9 Sound Absorbing Properties of Thinsulate™ Acoustic Insulation. Sound Absorbing properties of Thinsulate™ Acoustical Insulation material AU1220, measured according to ASTM E1050, Dual Microphone Impedance Tube Method measuring Normal Incidence Sound. Thinsulate™ acoustic insulation provides especially good results at the high frequencies which are particularly unpleasant to the human ear. Diagram produced by 3M Company and reproduced with kind permission of 3M Deutschland GmbH.

in estate cars. Fibre flock has already been mentioned. Knitted fabric is used as bellows for handbrakes and gear levers. In far-Eastern countries curtains and loose covers are seen in many cars.

6.7 Complete modular interiors

The process of combining individual operations in the outsourced production of interior components is being progressed yet a stage further.[89–93] The car interior will eventually be made up from a small number of complete modules, i.e. the seat module, the headliner module etc. and the ultimate is the *entire car interior* being integrated into one combined operation by a single supplier to the OEM. The Lear Corporation have already declared that this is desirable – a whole car interior will be put together at a single negotiated price. The advantages of this operation are that very many separate steps can be combined together simplifying manufacturing procedures, reducing the number of components, reducing interfaces, reducing administration and overheads and producing significant overall cost savings. As this happens it is inevitable that the responsibility for design will shift towards the Tier-1 module suppliers and to a certain extent away from the OEMs. Certain Tier-1s are becoming very large and influential entities in the auto industry and some analysts have referred to this as the emergence of the 'Tier-0.5 suppliers'.

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