Part II

Automotive interiors

6

Design of automotive interior textiles

N B POWELL, North Carolina State University, USA

Abstract: The challenges for designers across the automotive supply chain for textile products include the development of textile characteristics within high performance and low cost parameters. Consumer lifestyles and fashion trends also influence the development of distinctive brand offerings.

This chapter describes the textile design process in automotive and identifies the fabric characteristics for interiors application and the changes in the market factors influencing the need for innovative products. The range of textile characteristics developed within performance and cost parameters considered are fabric constructions, pattern, color, hand, luster, and scale. The demand for rapid prototyping, cost effectiveness and streamlining of supply systems is also identified.

Key words: design management, interior textiles, automotive trim selection process, color and textile design.

6.1 Introduction

Transportation textiles are considered high performance technical fabrics but must also meet the esthetic demands of changing markets. Designers are often the first to envision innovation and initiate new concepts in vehicle exteriors and interiors. Textile designers and the design services they provide to OEM stylists and designers are a critical first step in the introduction of new products for vehicle interiors, and potentially for composite parts. Textiles will be utilized to solve existing and future challenges in building innovative means of transportation. In this chapter, the challenges for designers across the automotive supply chain for textile products, where art meets engineering through the design process, will be considered. The range of basic textile characteristics developed within high performance and low cost parameters to be considered are fiber characteristics, fabric constructions, pattern, color, hand, luster, and recyclability. Furthermore, the influences of consumer lifestyles and fashion trends continue to grow in the differentiation of brands in the wide choice of vehicle offerings.

The Journal of the Textile Institute has kindly granted the author permission to use excerpts from the article Powell, N.B. 'Design management for performance and style in automotive interior textiles', *Journal of Textile Institute*, Vol. 97, No. 1, pp. 25–37 in this chapter.

6.2 Current automotive environment

By 2007 there were an estimated 806 million cars and light trucks on the world's roads with 244 million of those operating in the US. The comfort and safety of drivers and passengers have been greatly enhanced by functional textile products. As the automotive industry developed and vehicle exterior styling created various body shapes and sizes, highly engineered fabrics for performance, safety, and appearance were required. Personal transportation has been influential in the development and integration of products and services including entertainment, fashion, communications, and food services.

6.2.1 Global consolidation

In the changing automotive environment, there has been a drastic consolidation of global manufacturers. Fewer large OEMs are controlling the major volumes of automotive production, and the major players continue their expansion into existing and new markets. Nieuwenhuis and Wells (2003) estimate market growth by 2020 to 25 million in North America, 13 million in Western Europe, and 27 million in Asia Pacific region with a world total forecast of 91 million (p. 35). As new drivers come onto the world's highways, more consumers will experience the emotion of purchasing, owning, and changing their car. As one global car style will not suffice, the multicultural markets will demand vehicles targeted toward their own regional preferences. Designers of these products require knowledge of local markets and their cultures even if the product development and manufacturing takes place elsewhere.

6.2.2 Cost pressures

More and more component engineering, development, and testing is being outsourced to suppliers. During economic crisis, the pressures to reduce costs fall on the suppliers at the same time as the demand for new differentiating products increases. Innovative products introduced at a lower volume level add to the complexity of the manufacturing mix. Internet sourcing also opens up opportunities for new suppliers to enter the global markets. These OEMs publish their component requirements on the Internet and suppliers across the world bid for the business placement (Trott, 2002). This competitive action further increases the pressure on the global suppliers to reduce costs and increases the consideration of textiles as commodity products (WAW's Supplier Survey, 2003). Although the target price is set by the OEM, frequently the business contract is awarded based on the lowest quoted price. Price negotiations are based on current costs and business conditions including the perceived value of the product. Over the development and product launch periods, reengineering or design adjustments may prompt heavy investments in the refinement of the product (Powell, 2006). Once committed to the product, the OEM avoids the difficulties and costs involved in replacing an adopted textile, particularly in bodycloth (upholstery and door panel fabrics).

6.2.3 Speed to market

A company's ability to design and prototype rapidly provides a competitive edge in responsiveness to changes in the market demands. The evolution of digital systems such as Computer Aided Design and Computer Aided Engineering, virtual simulations, electronic supply chain and customer systems, and electronic procurement will be instrumental in expediting this flexible response (Nieuwenhuis and Wells, Table 15.1 by Wells, 2003, p. 199). Reducing time to market without compromising quality can be accomplished through the development of technology 'platforms' which can be common across a collection of products with shared components (Bruce and Cooper, 2000). However, this does not mean that the life cycle of a product can be extended indefinitely if it does not remain viable.

6.2.4 Quality

Consumers demand vehicles and the textile products used in them to be durable and attractive over the period of ownership and to maintain resale value. New products should not be submitted for a production vehicle unless they meet the OEM's standards. Meeting those qualifications on every sample and every shipment is a given if a supplier expects to continue as a meaningful source. The industry requires QS 9000 (Anon., 1996) or TS 16949 certification including Design Control guidelines and documentation of procedures to consistently meet industry standards (Powell, 2006). The New Technical Specification ISO/TS 16949:2002 was initiated by an International Automotive Task Force in conjunction with the International Organization for Standardization (ISO) to coordinate the various OEM requirements into a universal set of management standards. This specification aligns existing American (QS 9000), German (VDA6.1), French (EAQF), Japanese (ISO 9001/2) and Italian (AVSQ) automotive quality systems standards within the global automotive industry. It does not replace existing quality system requirements, but has been accepted as an equivalent, along with customer specific requirements. It has become a mandatory set of requirements for most major OEMs (www.qmi.com/information_center/standards/iso16949).

6.2.5 Changes in lifestyles

As the global availability of affordable personal vehicles grows for various types of travel and functions, so will the expectation for interiors. In the current market, consumer preferences reflect the changes in demographics and lifestyles as diverse as individual personalities. No longer can marketers forecast the majority's choice and build according to generalizations (McKenna, 1988).

Beyond simple commuting, the modern mobile society attempts to socialize, eat, drink, conduct business, and entertain passengers in their cars. A contemporary lifestyle is an attitude, beyond the socioeconomic, demographic statistics including age, income, and family size. Although similar products may be sought across traditional segments of consumers, a single product may not suit all customers or even a large group of customers any more. Products must be differentiated to appeal to specific consumer desires.

Increasingly the consumer has become more discriminating through access to information. More and more new car buyers use the Internet at some stage of the purchase process (Flynn *et al.*, 2002). OEM internet sites will allow you to create your preferred vehicle by selecting standard models and reviewing available colors, options and accessories. This may be considered a first step towards customization within a limited array of factory options. After purchasing, individuals have been influencing the marketing and sales of vehicles by word of mouth, quickly and broadly through internet blogs and independent webpage communications. Understanding how to reach these consumers as they make decisions based on the emotional aspects of purchasing and customizing will be a growth opportunity in targeting niche markets (Cagan and Vogel, 2002).

OEM designers and marketers have responded to these consumer behaviors by shaping the message and the products to appeal to their interests. Toyota recognized the importance of personalization to a new group of independent thinking buyers by offering value and unique features through a marketing strategy. By addressing directly young customers through internet videos and sponsored musical events, the 'mono spec' Scion offers a basic vehicle at an affordable price with the potential to customize with an offering of 40 factory accessories. The standard vehicle becomes very attractive for dealers selling accessories worth on average \$1000–\$3000 per vehicle (www.scion.com, *Toyota Scion Review*, 2003). The value of factory delivered options has been carried over to other vehicles giving the consumer the choice to adapt their vehicle with authentic parts. The 2007 Toyota Tundra was introduced with over 60 factory accessories.

As our diverse societies become more global, manufacturers must respond to the challenges that the desire for individualization and customization bring. A strategy based on volume will not support a continuing competitive advantage.

6.2.6 Brand

An understanding of the current position and any potential repositioning of the brand in the market is critical in developing the contributing components.

Designers are being challenged by the expectation that every aspect of the vehicle should reflect brand character or personality.

6.2.7 Sustainable products

As consumer ecological awareness grows, global consumers will have conflicting perspectives on the transportation industry and its role in the environmental issues from vehicle design and manufacture through use and the end of life cycle. Government legislation, environmentally conscious consumers and their advocates may bring the industry to task in the future on corporate responsibilities in green issues.

Although environmentally friendly products have been explored in the North American market, it has not been seen as a value for which OEMs or consumers have been willing to pay a premium (Anon., 1997). However, there are indications that the OEMs are recognizing there is potential in considering environmental stewardship as a market strategy, particularly as the price of petroleum rises. The use of textile composites, especially from natural fibers, will have a major role in developing sustainable products for all types of vehicles in the future (Powell, 2006).

As automobiles are a major contributor to greenhouse gases and pollution, there is an essential role that OEMs and their suppliers have to play in affecting important change in the global environment. Textiles can provide safety and comfort with renewable materials and composites which can lighten the weight of the vehicle, thus improving fuel efficiency and reducing the carbon footprint.

6.3 Automotive textiles market

Four main types of technical textiles dominate the automotive industry: airbags, preimpregnated fibrous materials for composite molding, tire cord, and interior trim. According to the *Journal of the Textile Committee*, about two-thirds of automotive textiles are categorized as interior trim, including headliners, door panel fabrics, carpet and seat covers and approximately 45 square meters of textiles are used in each vehicle (Anon., 2004a). In the interior of the vehicle alone, textiles are used in the headliner, instrument panel, floor, pillars, package shelf, and seats (Rodgers and Powell, 2006). The development of airbag and seatbelt textiles which protect all occupants of the vehicle cabin continues to provide added consumer confidence.

6.3.1 Design's role

Design contributes to the business success in designing new products, in improving existing products both in their manufacturability and cost effectiveness, in marketing the value, and in advancing research for future innovations in products and processes. Design is not only a differentiator of products and services, but has become a part of a company's intellectual property, a value protected through copyright and in some cases, patents. Establishing and maintaining design standards reflected in products, services, communications, and other activities of the organization is part of design's role in developing the corporate image and brand personality. Strong design management can build the organization's design leadership position in the market.

6.3.2 Design strategy

A corporate strategy for innovation must include design responsibilities aligned with priorities in manufacturing capabilities, product portfolios, marketing, customers, and management goals. As active members of cross-functional teams within the organization and interacting with the market and the supply chain, design is an initiating force for quality in style and function. Working with marketing, the design team can play a key role in developing the right products for the targeted customers to achieve the objectives of the company including attention to the life cycle of products. Without design participation in the early stages and throughout the development process, expensive errors in decision making can affect responses to the customer and productivity of the company. A single poor choice by design can create complexity in the processing of textiles, quality issues, cost issues, and lower productivity. Although design may be the first evaluation point with the customer, the stringent standards for quality and cost parameters are rarely compromised for the sake of design.

6.3.3 Understanding the customer

Although the textile supplier may be separated from the OEM by the first, second and sometimes third tier supplier, fabrics may be developed and purchased directly by the OEM (Powell, 2003). Textile suppliers may be required to ship their goods to laminators, cut and sew companies, seat manufacturers or directly to the OEM. The textile manufacturer remains responsible for any fabric issues and technical services to the customer (Rodgers and Powell, 2006). OEMs prefer to maintain control over selection, pricing and delivery of textile products to support the vision of the branded vehicle. Although some programs have shifted responsibility to the Tier One supplier as an integrator, this has not been adopted as an industry practice (Powell, 2006).

6.3.4 Approaches to different customers

The OEM's color and trim design team are responsible for developing the colors and trim materials such as bodycloth, headliner, carpets, vinyls, leathers, paints, plastics, woods and finishes for vehicles. Color and trim teams communicate to suppliers new material objectives to maintain brand image and to match the quality and design integrity of the vehicle to the needs of the market. The criteria for the vehicle development recognize three distinct stakeholders in the product: design, purchasing and engineering.

In the launch of new vehicle development or freshening of an existing model, the OEM color and trim team announces the opening some two to four years in advance of the model year. During the ongoing relationship with the customer, the textile supplier will prepare for build out or changeover of production vehicles whether the business is their own material or supplied by a competitor. The design team may anticipate new directions through continuous work with the production or concept vehicle teams and with the OEM's advanced studios. Global OEMs have established advanced studios in areas such as northern Italy and California, some distance from their manufacturing plants. These centers for advanced development serve not only in the development of concept cars but as a leader for trends and forecast for consumer preferences for production vehicles.

A preferred technology or fabric construction may be specified in requests for material submissions. The engineering standards and price parameters are established as critical targets of the total specification. Specifications on lamination or additional requirements may be communicated (Sirvio, 2003). Engineering and purchasing have priorities such as performance based on testing standards specific to the OEM and price targets which will be part of the total design brief for suppliers and eventually the sales contract.

Color standards, type of samples, and the format for submissions within a strict timeline are set by the OEM. In order to be awarded the business, the supplier must provide an exceptional performance characteristic or other added value in the product offering. It is common for several suppliers competing for the placement of their fabrics in the vehicle to develop hundreds of samples for submission for each opening. It is also common in the US to have as many as 30 to 40 different openings per year with at least three trim levels (Crabtree, 2005). European vehicles will have as many as seven trim levels in an interior.

The OEM color and trim team communicates information about the new opening through 'reverse presentations' to potential suppliers. As potential suppliers of interior components and seats, Tier Ones are included in the new vehicle launch presentations to trim suppliers. The seat design and seat manufacturer may or may not be chosen or disclosed to the fabric supplier at this point. The seat development may include various manufacturing processes which will dictate specific fabric characteristics, like increased stretch or abrasion qualities for fabric application on certain seat designs. Fabric development may require further engineering based on whether a seat is to be trimmed with a cut and sewn cover or molded. The seat manufacturer will know the expected levels of trim – base, mid level or luxury, but it may be very late in the seat development process when the fabric is finalized. Any innovative textile product may affect the seat design or change established trim processes which may not be aligned with the quality and cost objectives of the Tier One.

6.3.5 Effect of customer priorities on design strategy

Costs

Limitations on cost may affect the choices made by designers on technology, yarn type, fabric construction, color, and finish. The textile designers' challenge is to achieve the original design intent of the OEM's objective within the cost and performance parameters.

Performance and quality in technical textiles

Durability and maintaining an attractive appearance are primary in a consumer's perception of the quality of an interior. In order to become most familiar with the standards and processes of their customer, the textile design and development team may be assigned exclusively to a few or even one OEM and/or Tier One. It is unusual for engineering to compromise on the level of a testing standard to meet design's color or patterning preferences. A color may be developed that is a fashionable color, but the color will not be considered if it does not meet lightfastness standards.

Performance and quality are integrally linked. An expectation of quality is a given, and if it is not met, the customer will quickly have many other options and a choice of competitive suppliers. Consideration of quality standards while under time and cost pressures requires careful attention. Quality is the priority and must not be compromised when adjusting fabric content for other criteria.

Brand esthetics

Craftsmanship in the trimming of the interior and the combination of color, texture, hand, and luster of the materials create the atmosphere of the vehicle cabin and contribute to the overall experience of the brand. The textile designer must be aware of the vehicle brand image to create fabrics that provide strong visual and visceral cues supporting the character of the brand.

Studying the previous models of the particular brand and related accessories and merchandise, advertising and promotional materials can begin to establish a profile of the customer's aspirations. Observing the consumers' use of the vehicle and discussing the perception with the consumer in surveys and focus groups can provide a more comprehensive view of the brand's impact in the market. Brands like the VW Beetle and the BMW Mini have revitalized their brands in a retro/modern way to attract new consumers.

6.4 Establishing the target consumer

6.4.1 Lifestyle

If a textile design and development team does not clearly understand who the targeted consumer is and *will be* by the time the model arrives on the market, the efforts can be misguided. Consumers today are active, enjoy traveling, are concerned about their health, and wealthier than their parents may have been. Beyond traditional socio-economic gender, age, income, education, location and marital status, the designer must consider the psychological and emotional factors influencing buyers' decisions. The values, interests and psychological needs of consumers do not always match up to traditional segmentations.

As global populations acquire wealth or address changes in their lifestyles, product preferences may alter. Designers must stay attuned to the preferences of consumers who can have an impact on the market. Recognition of this fast-paced flow of lead users' preferences and the potential following of larger numbers of consumers can provide valuable input to automotive designers. Attention should also be paid to influential consumer products that are representative of trends in consumer lifestyles. The growth of personal consumer electronics has prepared the consumer to expect their automobiles to support and deliver similar services.

6.4.2 Fabric and fashion

Fashion continues to influence the fabric appeal in interiors of cars and trucks. Automotive companies leverage the recognition of fashion products to influence the style and promote the image of a vehicle. Fabric designs in US automotive markets have traditionally been more akin to menswear than home furnishings patterns in both scale and color. Even though the car seat and interior may be considered as personal an environment as the home, the smaller enclosed space kept interior fabrics plain, simple stripes or checks, and small scale geometrics in neutral colors. In Europe and Asia, even though the vehicles are generally smaller and diverse model production volumes lower, the opportunities for special editions, multiple trim levels and unique multicolored patterns are captured by textile suppliers (Powell, 2006).

6.4.3 Consumer experience

Beyond basic functions of transportation, consumers desire vehicles that provide entertainment and pleasurable experiences. If the aspirations of the consumer are to acquire a higher standard of living, to reflect personality or status to the public, or to escape the stress of everyday life, the automobile can be seen as a means to achieving these goals, even if only in the mind of the consumer during the experience. The interior of the vehicle and the materials can create an ambiance that is essential in this perception.

6.5 Trim selection process

6.5.1 Target vehicles

If supplier corporate priorities are communicated to product development and design, resources can be focused on vehicle openings appropriate to achieving business objectives. Within the established strategy for business growth; the sales, marketing, and development teams can create a concise plan for pursuing the best opportunities for winning the vehicle placements. A valuable component of this plan is a thorough review of all customer input on expectations for the targeted vehicles.

6.5.2 Market research

In benchmarking of competitive vehicles, only current production vehicle information and products may be available, but this will provide an important background for future direction of the vehicles. A study of competitive concept vehicles and the materials employed may lead to insights on future directions in the market place.

6.5.3 Fabric history

Another important source of information is the ongoing tracking of the actual fabrics used in previous models of the targeted vehicle. The evolution of a vehicle and its customer preferences for certain colors and types of fabrics can assist in shaping fabric submissions supportive of the brand image and performance parameters. Collaboration with OEM designers and market research may provide input on a change in direction for future vehicles. The fabric designer can also bring new influence from leading edge markets such as fashion, sports, and other consumer products. Trade events such as the SEMA (Special Equipment Marketing Association) Show and sources like Material ConneXion® can stimulate new ideas and innovative concepts which are very valuable to designers.

Product development teams may compile various research and detailed information about products and competitors. The cross-functional nature of the team demands an orderly system of reviewing information as a means of making effective decisions and gaining consensus. These systematic tools can be utilized to reflect the voice of the customer or customer requirements organized on a matrix, evaluating the perception of the customer in comparing competitive products. Charts and matrices, conceptual maps, conjoint analyses and other tools can be used effectively to chart the development path forward. The design and development team may create helpful visual charts to map the competitive vehicles and the fabrics, for example a conceptual map comparing characteristics of sporty perception to luxury relative to a cross axis of cost.

6.5.4 Design brief

Once this input has been evaluated and a strategy has been developed, the designer will create a design brief including priorities that must not be compromised (performance and cost) and esthetic variables based on customer input. Color, patterning, scale of pattern, luster, and hand should be indicated along with testing requirements and targeted cost parameters. Based on this brief, the development team will generate samples and finalize a collection to be submitted for the targeted vehicle opening.

6.6 Impact of seat design requirements

Interiors and specifically seats are considered highly complex components and have a significant impact on the comfort and safety of the users (Cagan and Vogel, 2002). Seat systems typically represent approximately 40% of the cost of the total automotive interior (Ward's, 2003) and the trim cover represents about 20% of the seat cost (Rodgers and Powell, 2006). As the complexity of the design of seats and interior compartments has grown, these components are outsourced by the OEMs to Tier One suppliers such as Faurecia and Johnson Control who have specific targets for design, performance, costs, and cycle time.

Within the interior, seat coverings have the highest potential for failure in material durability. The seat system comprises three basic components: a metal frame or support structure, a foam cushion and a covering material. Many manufacturers find that a three-layer composite fabric is most successful in performance, costing, and in the process of upholstering or trimming the seat. The three layers are composed of a top layer which is polyester; a middle layer of polyurethane foam; and the bottom layer, a polyamide warp knit scrim (Ishtalque *et al.*, 2000; Fung and Hardcastle, 2001). Many seat manufacturers have eliminated the textile scrim, substituting cost-effective polyethylene film which minimizes fabric stresses during production cutting and sewing of the cover. Lamination techniques are used to form various composite types and thicknesses depending on the substrates and the required component part's performance criteria. The stiffness or drape of the fabric can affect the ability to properly upholster the seat. This trimmability or ease of application of the fabric to the seat can be a major factor in the acceptance by others in the supply chain. Not only the appearance of the final seat but also the cost of the seat set can be affected by a fabric that needs special requirements in handling in the seat trimming process (Fung and Hardcastle, 2001).

Although many OEMs and suppliers use CAD systems to map and drape a simulation of a fabric on a virtual seat, the final decision is usually based on actual seat designs and trim applications. Tier One manufacturers are given the opportunity to review the candidates for typical manufacturing properties such as cutting ability, sewing ability, ease of assembly, and final appearance before releasing full approval for production.

Within an estimated 42-month vehicle development period, the evaluation, selection, and validation of a seat fabric (bodycloth) occurs early in the process, and the production intent seat system evaluation happens near the end of the development cycle. The selection and approval of automotive bodycloth can require from 10 to 18 months while complete seat system testing on a production seat may require 30 months. The final seat design and sewing pattern and associated fabric requirements may not be finalized or revealed to the textile designer during the development of the samples. The OEMs have full responsibility for selecting the interior materials and typically select numerous fabrics and combinations for seat evaluation to prove functional performance (Dickey, 2007; Rodgers and Powell, 2006).

6.7 New product development process for automotive trim

Each supplier develops a range of designs for each vehicle trim opening or 'carry over' production refinements either as computer aided design simulations or fabric samples in usually one or two customer standard colors. Samples are reviewed by the color and trim team, and a group of fabric styles is selected to go forward to the next review or decision point by the OEM (Powell, 2006).

The initiation of samples is based on ideation of a theme or design brief based on the customer original product launch input. To create desired fabric features to interpret these concepts a designer considers hand, pattern, scale, luster, texture, color, performance, and price of the fabric (Powell, 2003). A proactive strategy is to include advanced design concepts and inspirational samples as a design service to the customer. The textile engineer responds to a more defined brief interpreting the 'qualitative' characteristics into technical, quantifiable requirements (Vincenti, 1990). Delivering numerous design concepts, performance test data, theoretical costs and engineering yardage can be very costly to the fabric manufacturer, and it is important to rely on the cross-functional perspectives of the entire team.

The textile designer initiates pattern development on the computer aided design (CAD) system and selects colors to be dyed in yarn or fabric to match the customer's plastic standard. These simulations and sample blankets are designed as the engineer may be facilitating the yarn and sample production requests, running finishing trials through the plant, and expediting the samples' progress through the mill and testing labs. Samples are evaluated to meet specific customer standards, and the results are archived as a reference for future designs. The textile engineer plays a critical role in the selection of yarns, constructions, back coatings, finishes or lamination required to meet specific customer certification and manufacturing processes. The engineer must prepare the required construction test packet and certification information supporting the final fabric submission to the OEM's engineering department. According to the Chemical Fabrics and Film Standards (2005), a production part approval process (PPAP) packet on a new product would include a process flow, a process FMEA (failure modes effects analysis), a control plan, complete performance and dimensional test results, and for esthetic parts, an appearance approval report. Any change in raw materials or process would prompt a new submission of documentation and may also be requested as part of an annual inspection (www.chemicalfabricsandfilm.com/pdfs_researchSection/standards/ppap, 2005). The engineer may also prepare a theoretical cost for the sample constructions as the designer creates a merchandizing package or appropriate presentation of the sample fabrics to deliver the total offering to the OEM (Powell, 2003). OEMs prefer and often demand that samples be confined and developed exclusively for their projects. Maintaining the integrity of the design vision through this confidentiality is the foundation of outsourcing of components. Selected designs progress through several refinements as the time schedule will allow and are reviewed by the customer decision makers (Powell, 2004).

6.8 Sample development

6.8.1 Yarn type

Although polyester is the predominant fiber in automotive for interiors, other parts of the vehicle will use nylon, polypropylene, and even carbon fibers (Fung and Hardcastle, 2001). Wool, polypropylene and acrylics may be used in other modes of transportation such as aircraft, rail, and coach; but polyester remains the leader in world automotive markets because of its performance in durability, UV resistance, cleanability, and its relative low cost and availability. Continuous filament air textured polyester yarns' high abrasion resistance provides a consistent strength for weight advantage over nylon and polypropylene fibers (Fung and Hardcastle, 2001). Designers seek a variety of fiber lusters, textures, dyeability, and novelty yarn structures to differentiate fabrics and deliver added value in performance or look (Powell, 2006).

The fiber and fabric properties that yield the desirable esthetic characteristics are often conflicting with performance and cost requirements. Many applications require soft hand that requires lower DPF, denier/filament. For good abrasion and resiliency higher DPF is required. For better coverage you need larger yarns or more density, which means more weight and cost (Manley and Powell, 2004). Although other non-petroleum-based fibers may be of interest to the designer, none have met the critical performance standards at a competitive price.

6.8.2 Textile technology

The automotive industry focuses on just in time manufacturing techniques and expects its suppliers to respond quickly to any demand changes in volume, style, and color. Flexibility in manufacturing is key to responding to the fluctuations in the assembly line, and can be very costly to all in the supply chain if the choice of textile technology is not capable. Fabric suppliers must produce and deliver the exact yardage required in the specified technology and color within very short delivery times. As performance standards evolved, every major textile technology and many types of fibers have been engineered to meet testing requirements and consumer expectations (Powell, 2006).

From flat woven and velours to circular knits and microdenier nonwoven materials, automotive designers have explored the gamut of textile technologies. By 2002, flat woven fabrics held 47% of the European market versus 14% in the US and 12% in Asia. The US market preferred woven pile fabrics at 30%. Double needle bar knit pile fabrics also captured 23% of the US bodycloth market, and flat circular knitted fabrics held 21% of the European market. Tricot knits dominated the Asian market at 44% during this period. Flat wovens continue their high market share in Europe for interior fabrics with growing strength in US markets (Anand, 2003). By 2003 flat wovens continued to grow at approximately 55% of the world market versus warp knits at 25% and circular knits at 20% (Rigby, 2003, p. 10.8). Leather continues to be perceived as a luxury cover in the US but remains at approximately 20% of the market as delivered from the assembly plant (Anand, 2003). The introduction of sueded or sanded nonwoven products from Asian and US suppliers at various price points and weights complemented leather trims and responded to the desire for a non-pile textile product with a smooth, skin-like hand.

The analysis of the use of major textile technologies by product type is shown in Table 6.1.

6.8.3 Knit

Both warp and weft knit technologies are used to create various types of structures in automotive fabrics. Tricot, double needle bar, and circular knits from both flat and circular machines are employed for flat and pile fabrics. The stretch requirements for better trimmability combined with mounting cost pressures encourage the application of circular flat knits provided that they meet all performance characteristics. Knits are perceived by the automotive industry to deliver the desirable characteristics of low cost, low weight, and high performance (Fung and Hardcastle, 2001). The European automotive industry views weft knits favorably due to their design flexibility, stretch characteristics, appearance, and comfort. This design flexibility may provide the type of short run color and pattern complexity with minimal changeover time required by European markets (Anon., 2004b). Knitted fabrics' stretch characteristics provide ease of application especially in shaped parts like head rests and molded parts like headliners, and door panels (Rodgers and Powell, 2006).

6.8.4 Woven

Designing for flat and pile woven fabrics begins with yarn and color development for warp planning which will be the foundation for the subsequent pattern and filling yarn trials. Standard loom set ups and constructions, whether dobby or jacquard, are developed to meet the cost, color, and performance standards of the customer. Editing from computer aided design

Table 6.1 End use consumption analysis by product and fabric (vol., '000 tonnes)

End use product	Woven fabric	Knitted fabric	Nonwoven fabric	Total*
World totals, 2000				
Woven & knit trim	5.6	22.2		27.8
Nonwoven trim			109.7	111.6
Upholstery	53.2	53.8		106.9
World total forecast, 2010				
Woven & knit trim	4.2	16.9		21.2
Nonwoven trim			150.5	152.5
Upholstery	74.3	53.6		127.9

*includes other fabrics
Source: David Rigby Associates, Mobiltech: Detailed Forecast Tables, 2003.

simulations and sectional warping of sample blankets can expedite the efficient development of woven samples. While velours have been more popular in the North American market, a move to flat fabrics will depend on the acceptance of the hand and cleanability of the fabric by consumers and the amount of stretch provided for trimming seats.

6.8.5 Dyeing

Piece dyed fabrics have dominated the market with the convenience of quick color development from small sample dyeings, and the economies of large volume production. When more patterning was desired, piece dyeable fabrics could be woven or knit with a combination of yarns of different luster levels or yarns which dyed differently or resisted dyestuffs, such as deep dyeable polyester, bright nylon or accents of solution dyed polypropylene. Piece dyed pile fabrics used for inserts (the more decorative panel used down the center of the seat) can be patterned with cut out, omits or areas where there is no pile and the backing construction shows. Small scale repeating motifs, usually geometric or stripes controlled by the fabric constructions can be formed as dobby or jacquard structures. It may be better for color matching to other interior materials and more cost efficient to take the bolster or plain fabric and emboss, print, or etch the pattern through mechanical or chemical methods (Powell, 2006).

The interest in multicolored products has been influenced by fashion directions, jacquard home furnishing fabrics, and female consumers' preferences. The use of computer aided design systems to simulate possibilities accelerated the development of larger scale or random repeat patterns in kaleidoscope colors. Jacquard technologies provide pattern capabilities in geometric, abstract and organic designs, and novelty motifs. As most true pile fabrics are produced by weaving or knitting a double layer sandwich, the designer must balance the design to accommodate top and bottom fabric pieces with mirror image differences. This issue and other yarn wastes and total weight of these fabrics push the limits of most targeted cost brackets (Powell, 2006).

6.8.6 Color development

Organizations such as The Color Marketing Group® and the UK Color Group® bring together industry professionals whose main responsibilities are developing and marketing color trends in products as diverse as building materials, home textiles, and cosmetics. The automotive group within Color Marketing brings together OEM, Tier One, textile, and raw materials suppliers who also tap into other consumer product color forecasts as a resource.

Customer color standard

Color development is carefully controlled by the OEM and color standards, small plastic rectangular plates or chips with a smooth and a textured surface are provided to suppliers. Fabric master standards with a limited range of variation are set to which the sample submissions and final production carefully adhere.

All materials will be matched under specific lighting and reviewed in an area specified by the OEM such as a closed room with a light box and neutral grey walls and controlled lighting. A further visual check may be done by draping the fabric over a seat in daylight. Matching of multiple materials to one color standard and then coordinating finished components in the interior or on the individual seat may present problems, such as metamerism, where materials may match under certain lightning conditions but not under other lighting situations. Many color and trim studios will ask for fabric samples to be developed in a medium shade of their standard neutral color, and in the darkest value in order to evaluate the pattern under specific lighting conditions.

As dyestuff technology has moved forward to meet increasing performance standards, colors have moved from dark shades of blues and browns to lighter colors. To enhance the cockpit closeness of the smaller interior with increasing number of electronics, gages, and switches facing the seats, neutral colors are matched on plastics, fabrics, carpets, and other trims materials. A grey or beige interior could be standard for any exterior paint colors. Fewer stock keeping units or component parts streamlines the production process for assembly.

Dyed yarns

In the early 1990s, the market saw a drastic move to yarn dyed products. This opened up a palette of expressive patterns and colors for the color and trim designers. Yarn dyed products brought matching, performance, and development time issues to the suppliers. A few fabric suppliers invested in their own dye houses while others relied on sample equipment and the expertise of their suppliers to meet complexity and quick response challenges. Companies such as Unifi, Trevira (Neckelmann) and Autofil responded to the volume and performance expectations of the automotive industry with accompanying risks and rewards.

The approval of yarn colors from a yarn pom, skein or small knitted ‘sock’ of dyed yarn is a time-consuming process relying on the communications between the dye house, the designer, and the customer in interpreting adjustments in the color range. The art and science in refining a shade to match the customer’s input is complicated by fabrics that contain multiple colors and yarn types.

Solution dyed polyester products have been considered, but realistically are most viable in large volume colors such as black. Specific color development on lower volume shades is still an issue as minimum quantities would be prohibitive as most yarn dyeing companies require 50 ton lots or merges. The partial solution to this problem is to develop the colors as package dyed yarns, and then transfer the high volume shades (usually the predominant background color) to solution dyed products before the final approval and product launch. Small makes may be available at a premium price, but package dyed is still the viable option for inserts and most bolster fabrics (Pfeiffer, 2007).

Accent colors

Textile designers may use the customer's standard neutral color – beige, gray, or black – as a background shade and use various colors to create patterns, highlight motifs, or enrich the complexity of the fabric color. These accent colors may be dictated by the exterior paint colors or by the overall theme of the interior color story. Care must be taken not to cast the overall shade away from the standard by the amount or intensity of the accent colors.

Space dyed yarn is a fancy effect yarn which was introduced in apparel and home furnishings. Intermittent lengths of as many as five colors in a single yarn brought a random multicolor effect to flat and pile fabrics. A designer creates a color combination in a single yarn which could include a range of accent colors such as the vehicle's exterior paint colors. This simplified the necessary yarn s.k.u's for the style construction and to be carried in yarn inventories. However, the inherent patterning in the package dyeing process created a repetitive banding or flaming across the fabric face. Also the amount of yarn waste to minimize banding causes an increase in the real cost of the yarn. This led to cost controlled limits in the use of the space dyed yarn and also the plying of this type of yarn with other solid filament or spun yarns (Powell, 2004).

Printing

Although the printing process is an effective mechanism to deliver color to fabric, the technology has had a limited success in automotive fabrics. Print bases can be knit, woven, or nonwoven constructions, but the piece dyed plain fabrics are preferred for their cost effectiveness. In the late 1980s printed automotive fabrics were reported to be about 30% in the Japanese market and companies such as Milliken and Guilford lead the development of print technology for the North American market (Milliken, 1997). Ford was one of the first US OEMs to evaluate print systems' effectiveness using

Guilford's print replication of a yarn dyed circular jacquard knit pile fabric but this was replaced with a conservative patterned piece dyed knit. Ford also placed a Milliken rotary screen printed fabric, a traditional geometric in its design and color, which ran in production. More prints were adopted by the market but never met the expectation of cutting development lead times and possible mass customization potential (Powell, 2006).

The development of pigments and other chemicals which can be screen printed allow the creation of patterns, textures and three-dimensional characteristics in the fabric surface but must maintain a pleasing hand and pattern integrity during actual wear. The latest development in printing has been the development of dyestuffs suitable for digital or inkjet printing of automotive fabrics requiring high standards for lightfastness. A Japanese manufacturer, Seiren, established Viscotec® as the first production level supplier of digitally printed automotive fabrics to the global markets (Powell, 2006).

Other surface processes related to printing would be etching or removing the fiber or yarn from the fabric in a pattern to give three-dimensional effects. Embossing is also a patterned pressing of the fabric used to create high and low areas in the fabric. Although these special effects are more visible on pile fabrics, they are used on different types of knitted, woven, and nonwoven fabrics.

6.8.7 Finish

Fabric finishing can enhance a plain or patterned fabric with improved surface effects, and is critical in those areas showing a wide expanse of fabric to the consumer at close range, such as headliner and bench seat upholstery. Specialized equipment and technical expertise in finishing different constructions of fabrics are a major investment for a textile company. Most manufacturers maintain this process within the assets of the company, but others may choose to outsource this process to other expertise, often aligned with a lamination line.

As the economic pressures and the dictates of fashion move away from heavier pile fabrics, more flat wovens and flat knits are seen in the market. OEM designers want clearly defined textures and patterns to complement the technical appearance of highly engineered vehicles. The visual complexity of a fabric must be balanced with the feel of the material. It is critical to avoid a hard and raspy hand in the fabric in achieving a crisp design appearance. Achieving an acceptable hand on a flat fabric relies primarily on finishing techniques such as napping or needling to soften the surface feel but at the risk of deteriorating the integrity of the design or the structure. There remains a high expectation of comfort and the durability which automotive fabrics must meet, especially in any tactile or visible wear or loss of color or pattern.

Leather interiors have been perceived in the market place as a luxury level option. Achieving the feel or hand of sueded natural leather is a technological challenge to meet the stringent automotive standards for lightfastness and crocking of fashion colors within narrowing price parameters. Toray's Ultrasuede™ brand is well established in the apparel market and a version of this nonwoven sueded product is trimmed across many vehicle platforms in Europe as ALCANTARA™ with various product weights for application in different parts of the interior (Hansen, 2005). Milliken's Preferred Suede™ and other competitive suede-like polyester products are available to be trimmed out in combination with leather or fabric in the interior.

Textiles are coordinated with leather, plastic, wood, and metal finishes, and are expected to complement the tones, luster, and visual cues of these non-fibrous elements. Within the trim materials, a combination of different types of fabric constructions may be used in vehicle interiors. Bolsters are lower cost plain fabrics usually used on side and back panels of seats and in door panels. When used in combination with more expensive materials, a more interesting seat may be created and the total cost of the seat covering may be lowered. For example, a yarn dyed jacquard woven may be used on the insert or central front panel of the seat and a piece dyed tricot knit used as a cost-effective bolster (Powell, 2004).

6.8.8 Fabric testing

Textiles are evaluated to assure quality, analyze any potential failure of the material, and lower the risk of product failure in the market place. Evaluation of materials can also be seen as a way to identify opportunities for product development and improvement (Rodgers and Powell, 2006). An interior is expected to maintain its appearance over the lifetime of the vehicle's use and to increase resale value. The median age of automobiles in operation in the US in 2000 was 8.3 years (Ward's, 2002) and vehicles like SUVs and other light trucks are expected to travel global roads for more years and many miles. The level of expectation for a highly functional and durable interior during the ownership of a vehicle demands extreme performance of the seat and its cover (Powell, 2006).

The textile producer conducts the initial basic physical performance testing of the automotive textile in accordance to the OEM engineering specification. The OEM materials engineer reviews an evaluation of the tested samples and data and may conduct repetitive or additional testing based on the initial results. Most fabrics are screened by width, thickness, weight, and construction (Bhagwat, 2005) and the physical tests are conducted in three directions (warp/fill/bias). Each OEM has a preference on physical performance tests (Rodgers and Powell, 2006) but most are from the primary list of over 30 individual tests certified by British (BS), American (ASTM) and German

(DIN) standard methods including evaluation for characteristics such as flammability, abrasion/durability, lightfastness, seam strength and dimensional stability (Fung and Hardcastle, 2001).

Beyond the standard tests, there may also be additional tests for specific technologies and the OEM may determine the method or format of fabric submission. Fabrics can be tested face only rather than as a laminate, or as a laminate. Physical tests for abrasion, pilling, and snagging can be the most critical for flat fabrics. Additionally, pile fabrics are particularly reviewed for pile crush, lint retention, pile whitening, and resulting seat application issues caused by ingress/egress of the seat occupant (Fahy, 2005).

6.8.9 Application testing

Beyond the basic material evaluation, each fabric application has a unique set of requirements that affect the overall performance of the final component. In the case of bodycloth, it is the final seat product that is evaluated by the consumer. Tier One seat engineers have developed further methods for testing the materials in its final application. Two particular tests evaluate the overall performance of the fabric within a seat system: jounce and squirm and ingress/egress.

Jounce and squirm testing is widely used to evaluate the foam cushion integrity and trim cover attachments. This test is designed to simulate an occupant sitting on a vehicle seat during use. During 'jouncing', the seat part (loaded by a body form representing an occupant's back (for seat back evaluations) or buttocks and thighs (for seat cushion) is attached to a table that can be moved up and down a specific distance at a set rate. With the body form loading the seat, it is rotated left and right around a pivot point ('squirm'). Numeric measurements of the seat contour and foam integrity are taken, typically at 100 000 cycles. If the fabric is visibly worn and/or the shape or integrity of the foam is reduced beyond a specified standard, further engineering of the components and testing is required (www.seattesting.com).

The ingress/egress test, also known as sliding entry, involves simulating an occupant's movements while entering (ingress) and exiting (egress) a vehicle. A metal or plastic buttocks form is attached to a multi-axis robot, which is programmed to simulate human movements based on pressure mapping of a statistical sampling of moving occupants in a designated vehicle (Lentz, 2005). The robot duplicates this movement for testing of each vehicle's unique path. Entry and exiting of a vehicle is dependent on the door opening, vehicle height, and seat design position (Rodgers and Powell, 2006). Although this test can be adjusted to a specific vehicle for load, cycle count or additional squirm features, this method is essentially the same for most OEM manufacturers. A team of engineers evaluates the automotive seating materials and the seats' performance throughout the required cycles. Successful completion of this critical evaluation releases the material into a production ready status. The common failures are pile distortion, pile loss, hole formation, severe creasing, and seam separation (Rodgers and Powell, 2006).

6.9 Communicating value and design services

Design service provides value to the customer in the interpretation of trends, consumer behavior, new technologies, new materials, and other influential factors on automotive materials. An OEM evaluates the supplier's design capabilities based on design expertise, sample quality, technology proficiency, market research and professional merchandizing of the products. The supplier's design group may also provide updates on exhibitions, fashion, media, and other events in a relevant design package to automotive designers.

6.9.1 Presentation

Critical opportunities to deliver the value story of the textile range may occur in a small or large venue with days' or months' notice. The design team is prepared to formally present to the customers including OEM color and trim designers, marketing managers, engineering and purchasing, and possibly the Tier One representatives. A well crafted script should introduce the product, describe the response to color and trim's launch direction, and explain refinements on subsequent preliminary submissions. The presentation should focus on design solutions to the initial launch goals, and provide optional perspectives on the vehicle trim. If an interpreter is to be used, it is important to rehearse timing, clarify any misunderstandings, and set the pace of the presentation. Immediate feedback from the audience may be a general indication but the editing and refinement of samples will take place working specifically with the design team.

The collection's concept must be fresh and stimulating while delivering function, performance, and style. The developed theme should be comprehensible at an obvious visual level and in the subtle development of color and fabric design complexity. The presentation should include an understanding of the brand personality, its current status in the market relative to its competition, and any new direction for the brand. Competitive fabrics and colors currently used in leading production vehicles should be benchmarked. The textile design team may have collaborated on advanced vehicle projects or concept show vehicles, and the final presentation is an opportunity to build on the success of these projects.

A range of textile designs and samples from the basic bolsters and coordinating plain or textured fabrics to the advanced 'reach' conceptual fabrics can be showcased. Large hanging samples of approximately 18 × 36 inches (46 cm × 91 cm) are submitted to the customer along with some type of archival swatch on A4 (8.25 × 11.75 inches) sample cards, or other swatch documentation notebooks. Reference samples must be clearly and accurately identified to facilitate development and future trim orders. CAD simulations of the fabric designs applied to a generic seat may be utilized. If time, logistics, or budget do not allow full seats to be trimmed, simple shaped forms or other framing may be mocked up to show the fabrics in a three-dimensional application. These samples, presentation boards, promotional materials, and color stories may be used as the color and trim's recommendations to internal management or may set the standard in interpreting objectives for other suppliers.

6.10 Future trends: innovative materials

In a market where cell phones are named after flavors of chocolate and sportswear is merchandized as having intelligent properties to enhance performance, the consumer has high expectations of automobiles delivering value on a significant investment of personal income. The smart consumer wants ease of use, affordable price, and products that reflect status and individual personality. The textile designer may consider influential consumer products aligned with the targeted consumer in the fabric development, enhancing the vehicle appeal to consumers.

OEM designers responsible for seat and interior components are seeking innovative textile components to match their advancements in multiple materials performance, ergonomic safety and comfort, improved acoustics, and the increasing electronic interface with the vehicle (Rodgers and Powell, 2006). The development of technical fabric incorporating antistatic, antimicrobial, or even self-cleaning attributes into interiors can provide further product convenience and satisfaction to driver and passenger. Interactive features will provide interfaces between drivers and their vehicles, other vehicles, and other ports of communication. New opportunities exist for e-textiles or smart materials to provide and react to valuable information; for example, sensors may alert the seat to adjust to occupant's body size, temperature or cognitive status and driving alertness. The development of fabrics with thermo physiological properties is also a focus of continued research.

Global economic development will face the conflicting goals of profitability and quality of life, and may balance these objectives through advanced technologies (Powell, 2006). The development of green products may be based on not only corporate responsibility statements and global regulations, but also on the real business opportunities coming from a market desiring sustainable products and processes. The design of fibrous components will be a major factor in developing greener products. Renewable raw materials are being sought that meet performance standards, but at a competitive price. Natural fibers such as flax, hemp, coconut fibers, Ingeo™, and kenaf continue to be evaluated in exterior and interior panels as composites or utilitarian materials to reduce weight resulting in lower emissions through fuel efficiencies (Anon., 2007, p. 8). Also the reduction of back coating and foam lamination used in seating products is a concern for recycling. The further application of spacer or sandwich knitted fabrics to replace foam is growing in practicality (Ishtalque *et al.*, 2000; Fung *et al.*, 2001). Open structured elastomeric fabric which can be applied to a seat or head restraint and minimize the need for foam and springs, thus reducing weight and increasing space in the interior cabin have been introduced by companies like Milliken's M-Flex™ and Quantum Group's Tech-Style™ fabrics (Fig. 6.1; www.Quantum, 2007; Milliken, 2000).

The reconfiguration of the industry and the demands of customers at every point in the complex supply chain are leading to increased importance of automotive advanced materials and the development of innovative products. Future developments in this area will be centered on textiles as the appropriate sustainable solution to provide safe, comfortable, lightweight, cost effective, and high performance materials.

Design's role will continue to expand in understanding the spoken and unspoken needs of the customer, interpreting these needs into viable and attractive products, and communicating that value to the market place. Sophisticated consumers will demand seamless technology which provides a new interface between humans and personal transportation systems. This

6.1 Quantum fabrics interior shown on Mazda Kabura concept car shown at the 2005 NAIAS. Source: Quantum Group, 2007.

interaction is facilitated by the interior flexibility, comfort, and safety provided by well designed textiles.

6.11 Sources of further information and advice

6.11.1 Books

Fung, W. and Hardcastle, M., 2001. *Textiles in Automotive Engineering*, Woodhead Publishing Ltd., Cambridge, England.
Wilson, A., 2007. *Automotive Textiles: The global supply chain to OEMs*, Textile Media Services, Keighley, UK.

6.11.2 Publications

Automotive Engineering International www.sae.org/automag/technewsletter
Car Design News www.cardesignnews.com
Automotive News www.autonews.com
Automotive Design Line www.automotivedesignline.com
MobileTex www.mobile-tex.com
Interior Motives www.interiormotivesmagazine.com
View on Color Magazine, United Publishers, S.A.

6.11.3 Major trade/professional bodies, research and interest groups, web sites

American Association Textile Chemists and Colorists www.aatcc.org
Wards Auto Interiors Show www.autointeriors.com
Society of Automotive Engineers www.sae.org
Color Marketing Group www.colormarketing.org
The Color Group www.city.ac.uk/colourgroup
CAUS www.colorassociation.com
Society of Dyers and Colourists www.sdc.org.uk
Industrial Fabrics Association www.ifai.com
Automotive Aftermarket Suppliers Association www.aftermarketsuppliers.org
Division of MEMA www.mema.org
Material ConneXion www.materialconnexion.com

6.11.4 Education

Art Center College of Design, Pasadena, California www.artcenter.edu
Center for Creative Studies, Michigan www.ccscad.edu
NCSU College of Textiles, North Carolina www.tx.ncsu.edu
Royal College of Art – Vehicle Design, London www.rca.ac.uk

Philadelphia University – Philadelphia, Pennsylvania www.philau.edu/textiledesign/ms.html
Rhode Island School of Design, Providence, Rhode Island
Reutlingen University, Reutlingen, Germany
University of Huddersfield, Queensgate, Huddersfield, England
Central Saint Martins College of Art and Design, London, England
Loughborough University, England www.lboro.ac.uk

6.11.5 Events

International Engineered Fabrics Conference and Expo www.inda.org/IDEA08/
TechTextil http://techtextil.messefrankfurt.com
Specialty Equipment Market Association www.sema.org

6.12 References

Anand, S., 2003. Recent Advances in Knitting Technology and Knitted Structures for Technical Textiles Applications. *International Isparta Textile Congress (Istek) Conference Proceedings*, May, 2003.

Anon., 1996. *Quality System Requirements* – QS 9000, International Organization for Standardization.

Anon., 1997. 'Car Seating Fabrics – Suppliers & Trends', Automotive Seating Review, *Inside Automotives International*, pp. 28–37.

Anon., 2004a. Technical Textiles: Emerging Opportunities, December 9, 2004, *Journal of the Textile Committee*. Downloaded from www.bharattextile.com/library/003035.php

Anon., 2004b. Weft Knits Drive Forward, *Knitting International*, July, Vol. 111, Issue 1316, pp. 28–29.

Anon., 2007. Nothing New about Natural Fibres in Cars, *MobileTex*, Vol. 2, no. 1, January, p. 8.

Bhagwat, V., 2005. Testing of Automotive Textiles, *Asian Textile Journal*, Vol. 14, No. 1/2, p. 79.

Bruce, M. and Cooper, R., 2000. *Vantage Case Study*, Creative Product Design, pp. 106–132, Chap. 6. John Wiley & Sons, Chichester, England.

Cagan, J. and Vogel, C., 2002. *Creating Breakthrough Products*, Chapter 9, Automotive Design, Prentice Hall, Upper Saddle River, NJ.

Crabtree, N., Correspondence with Crabtree who retired from Chrysler Color and Trim, 2005.

Dickey, C., 2007. 'Developing New Products: The Competitive Advantage' Textile Apparel Manufacturers and Merchants Annual Conference, Savannah, Georgia, May 15.

Fahy, L., Personal Interview, Automotive Design Director, Melba Industries, May, 2005.

Flynn, M., Belzowski, B. and Haas, S. 2002, 'E-CRM and the Automotive Industry: Focusing on Customers', Office for the Study of Automotive Transportation, Ann Arbor, Michigan.

Fung, W. and Hardcastle, M., 2001. *Textiles in Automotive Engineering*, Woodhead Publishing Ltd., Cambridge, England.

Hansen, O., 2005. Telephone Interview, Automotive Business Manager, Toray Industries.

Ishtalque, S., Yadav, P. and Sharma, N., 2000. A New Approach to Improve the Performance of Spacer Fabrics for Automobiles. *Man–Made Textiles in India*, March, pp. 67–74.

Lentz, J., 2005. KUKA Robot Handles Ingress/Egress Seat Testing, http://www.roboticsonline.com/public/articles/index.cfm?cat=104, Retrieved April 24, 2006.

Manley, R. and Powell, N., 2004. The Development of Woven Velours for the Transportation Market, www.tx.ncsu.edu/jtatm/volume3issue4/Articles/Powell/manley_full.

McKenna, R., 1988. '*Marketing in an Age of Diversity*', Markets of One, Harvard Business Review Book, Boston, MA.

Milliken Prints, 1997. *Promotional print booklet*, Milliken & Company, Spartanburg, SC.

M-Flex™, Milliken, 2000. Promotional Materials, Milliken & Company.

Nieuwenhuis, P. and Wells, P., 2003. *The automotive industry and the environment: A technical, business and social future*, CRC Press, Woodhead Publishing Limited, Cambridge, England.

Pfeiffer, M., 2007, Guilford Europe Automotive, Telephone interview, June, 2007.

Powell, N. B., 2003. Mass Customization in Transportation Textiles through Shaped Three Dimensional Knitting, *Proceedings from International Textile Design and Engineering Conference*, Edinburgh, Scotland, Heriot-Watt University, Netherdale, Galashiels TD1 3HF, UK, September, 2003.

Powell, N. B., 2004. Design Driven: The Development of New Materials in Automotive Interiors, *Journal of Textiles Apparel and Technology Management*, *Transportation Textiles Issue*, Vol. 3, Issue 4, www.tx.ncsu.edu/jtatm.

Powell, N.B., 2006. Design management for performance and style in automotive interior textiles, *Journal of the Textile Institute*, Vol. 97, No. 1, pp. 25–37.

Rigby, D., 2003. Mobiltech Chapter, *Technical Textiles Report*, 2003.

Rodgers, S. and Powell, N., 2006. 'Automotive Textile Durability 2D Testing in a 3D Application', Autex Conference Proceedings, June 13, 2006, College of Textiles, Raleigh, N.C.

Sirvio, K., Personal Interview. General Motors, June 5, 2003.

Trott, P., 2002. *Innovation Management and New Product Development*, 2nd Edition, Prentice Hall, Pearson Education Limited, Harlow, England.

Vincenti, W. G., 1990, *What Engineers Know and How They Know It*, The Johns Hopkins University Press, Baltimore, MD.

Ward's Automotive, 2003. WAW 24th Annual Supplier Survey. Southfield, Michigan.

Ward's Automotive, 2001 & 2002. Motor Vehicle Facts & Figures 2002, Southfield, Michigan.

www.chemicalfabricsandfilm.com/pdfs_researchSection/standards/ppap.pdf, downloaded July 15, 2005.

www.quantum5280.com/index.html, retrieved July, 2007

www.qmi.com/information_center/standards/iso16949, 2002 retrieved April 24, 2006.

www.Scion.com, 2003. *Toyota Scion Review*, downloaded August, 2003.

7

Three-dimensional textiles and nonwovens for polyurethane foam substitution in car seats

H ERTH and B GULICH, STFI, Germany

Abstract: Seat cover materials are present as multi-material composite systems of textile and foam layers with permanent fixed connection. Three-dimensional textile structures offer novel possibilities in construction of seat cover materials. These structures can be manufactured by different technologies. Nonwovens and warp-knitted spacer fabrics with strong three-dimensional properties will be described within this chapter. The achieved elastic properties of such materials are comparable with actual used material. When PUR foam is replaced by a textile structure, the seating climate comfort will be improved. Furthermore, the system consists of 100% textile materials. This fact permits the recycling and re-use in textile structures. It is even possible to manufacture the material system as a single-material composite system.

Key words: upholstery, PUR foam substitution, composite materials, recyclability, stitch-bonded nonwovens, warp-knitted spacer fabrics, lamination process, performance requirements for seat-cover fabrics, environment.

7.1 Introduction

Textiles have been used in cars for a long time. Looking at both the expected future number of cars and the developments in the field of quality, textiles stand a good chance of being more and more widely used (see Table 7.1). It is up to the textile industry to convincingly outline their advantages since textiles are selected with regard to their manufacturing processes, raw materials, design, combinability, functionality, recycling and cost. In areas like the

Table 7.1 Trends of textile use in passenger cars

	Year		
Amount of textiles in a typical mid-range car (kg)	2000	2010	2020
Total	20	26	35
Products and applications like those in 2000	20	14	10
New product for known application (e.g., cushioning by textiles)	–	9	15
New product for new application (e.g., shielding by functional cushioning)	–	3	10

USA, Japan and Western Europe, customers expect more comfort and improved safety, which could be achieved by the use of textiles. A particularly high growth potential is expected for the business sector that equips higher-class motor vehicles. One trend is the substitution of synthetic and other materials in common applications with well-known functions by textiles, e.g. the substitution of polyurethane (PUR) foam in upholstery components by polyester nonwovens [1].

The structure of composite materials used for upholstery in vehicle interiors, in particular for seat-covers, has remained unchanged for more than 30 years. Three different components are connected by means of adhesive layers. Various woven, warp-knitted and knitted fabrics are used in order to produce textile top-layer materials, polyester (PES) being the predominant fibre (about 90 per cent of these particular materials) [2]. A 2 to 8 mm thick (average: 3 to 5 mm) PUR foam layer is added beneath the top layer, followed by a meshed material made from PES or polyamide (PA). The adhesive agent for the two adhesive layers of the laminated composite is PUR foam.

Why is the automotive industry questioning the use of a composite seat-cover material that has been optimised and well-proven for decades? The two reasons are that the car driver is asking for greater comfort and that there are now stricter laws on the protection of the environment. The advantages of PUR foam upholstery, such as excellent elasticity and a well-proven manufacturing technology, are now being called into question owing to a number of drawbacks that have come to light in recent years, in particular the fact that as a result of the flame lamination process used, toxic fumes are produced from combustion during manufacturing. Their disposal into the air is subject to stricter regulation and they may cause emissions in the completed vehicle, resulting in fogging and unpleasant odours. Furthermore, the low air and water-vapour permeability of composite materials can make passengers less comfortable [3].

Another reason for finding a substitute for the current seat-cover composite material is its non-recyclability. In particular, it is impossible to re-use the production waste from the manufacturing cycle since the composites are made of several materials which cannot be separated. This is also important in the context of achieving eco-friendly disposal [4].

7.2 Properties and performance requirements for car seats

Properties and performance requirements are set and evaluated for both the complete composite of the seat-cover fabric and the cushioning layer. All these requirements are influenced by the different targets of customers' comfort, manufacturers' guidelines, laws on the environment and total cost that should be fulfilled by each product. The main elements of these requirements are listed below.

Composite

- number of layers
- emissions
- electrostatic behaviour
- recyclability
- microclimate of seats
- manufacturing cost.

Cushioning layer

- thickness
- mass per unit space density
- elasticity to compression
- compressive strength
- permanent deformation
- elastic elongation
- air permeability of cushioning layer
- moisture transport
- resistance to ageing
- combustion behaviour
- necessity of fire retardant finishing

Every car manufacturer sets its own requirements for seat-cover composite properties in its delivery conditions. Some selected and summarised numbers and data for the requirements listed above are shown in Table 7.2 [5–7].

7.3 Types of materials used as cushions

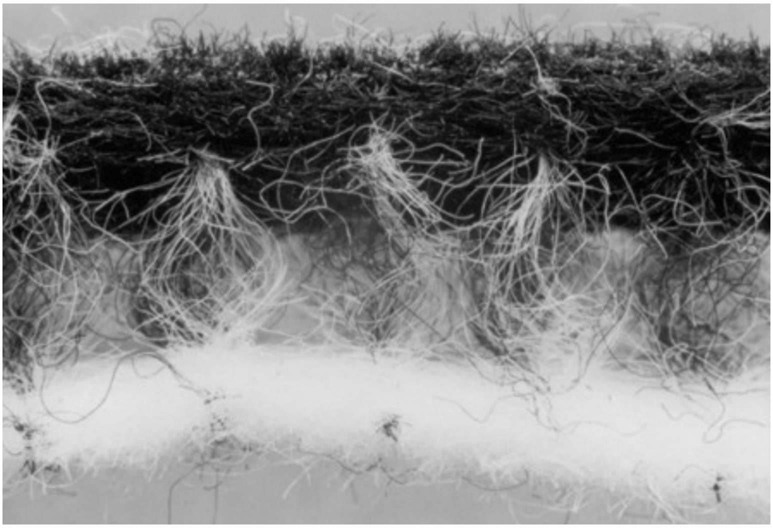
The substitution of PUR foam is, in theory, achievable by a wide range of textile materials including:

- thermal bonded/heat-set nonwovens
- needle-punched nonwovens or nonwoven composites (Fig. 7.1)
- velourised needle-punched nonwovens
- vertically lapped and thermal-bonded nonwovens, e.g. Struto or Wavemaker
- stitch-bonded nonwovens, e.g. Malivlies
- stitch-bonded nonwovens, e.g. Kunit, Multiknit, Caliweb®
- spacer woven fabrics
- spacer circular-knitted fabrics
- spacer warp-knitted fabrics.

There are some specific technical and financial restrictions on the range of materials that can be used for PUR foam substitution. With regard to their

Table 7.2 Selected and summarised requirements for seat cover composite and cushioning layers

Property of cushioning layer	General range possible	Recommended range
Mass per unit area (g/m^2)	170–600	230–330
Thickness (mm)	2–8	3.0–4.5
Density (kg/m^3)	50–100	70–75
Remaining deformation, dry (%)	15–25	17–20
Remaining deformation, dry (%)	10–25	20–23
Compressive strength (kPa)	2–20	5–7
Elasticity to compression (a30-5H) (%)	30–50	35–40
Elasticity to compression (a30-E3) (%)	90–98	92–95
Air permeability (l/m^{2}s)	> 200	500–1200
Short-term water vapour absorption (g/m^2)	> 2.5	> 4.0
Combustion behaviour according to SMVSS 302 longitudinal/crosswise	A/A	A/A



7.1 Needle-punched spacer nonwovens composite type NAPCO®.

price and their flexible properties, nonwovens are reasonably suitable for use as textile structures for upholstery material, being directly produced from fibres or filaments, without any production of yarn. In order to provide the upholstery characteristics required, however, only a few voluminous kinds of nonwovens are available. A good rebound to pressure is only shown by products which contain fibres arranged perpendicularly to the length of the material.

In addition, some other three-dimensional knitted and woven textiles, especially warp-knitted spacer fabrics, show good elasticity properties.

7.4 Key technologies for replacing polyurethane foams in car seats

Several flat nonwovens, such as stitch-bonded or needle-punched products, are already in use in car seats. Mercedes-Benz has used the Malivlies type of material as a supporting layer, glued directly onto the seat-cover fabric, since 1992. However, such materials do not function as a cushioning layer in the same way as PUR foam.

Textile materials with thicknesses from 2 to 3 mm up to 7 or 8 mm are required for upholstery use. Until now, such textiles have only been produced for end-use application from stitch-bonded and thermal-bonded nonwovens and warp-knitted spacer fabrics.

Investigations into the use of textiles as substitutes for PUR foam in car seats have been carried out by several European car manufacturers. Today, the three-dimensional, stitch-bonded nonwovens, Multiknit/Caliweb®, are used in several types of car from Audi, BMW and Mercedes. The nonwovens are manufactured by TWE Vliesstoffwerke GmbH & Co. KG, Emsdetten/D and TECHTEX GmbH Vliesstoffe, Mittweida/D (Figs 7.2 and 7.3).

J.H. Ziegler GmbH & Co. KG, Aachern/D, produces a three-dimensional thermal-bonded nonwoven, called Haco®, as an upholstery material for Audi car seats. 3mesh®, a special type of warp-knitted spacer fabric made by Müller Textil GmbH, Wiehl/D, is current used where perfect comfort in

7.2 Three-dimensional stitch-bonded nonwoven type CALIWEB® laminated with cover fabric.

7.3 Three-dimensional stitch-bonded nonwoven type CALIWEB® laminated with cover fabric.

climatic and ventilated seats is requested. This material fulfils all the requirements such as the highest possible distribution of air, soft cushioning effects and excellent rebound after pressure, but, because of its higher price, it is currently only used in higher-class cars, like the Mercedes S-Class and Audi A8.

7.5 Environmental advantages of using substitutes

Between seven and nine million used cars are disposed of annually within the European Union. The quantity of recyclable materials currently only amounts to about 75% of the total vehicle mass. The remaining 25% are hazardous waste products from light shredded material, which consists of plastics, textiles, glass and metal waste. The disposal procedure is regulated by a number of national and international directives, such as the European Directive on the Transfer and Eco-friendly Disposal of Used Cars (Directive on Used Cars – AltautoV) of 1997 and the Self-commitment concerning the Eco-friendly Recycling of Used Cars (limousines) in the framework of the Law on the Economic Cycle of 1996 (both Directives being effective from 1 April 1998) as well as the EU Directive on Used Cars of 2000. They require both material- and design-related alterations to the components currently used, with regard to effective material recycling.

That is why recyclability is an impetus to the search for a substitute, which is currently hard to find, for the current composite seat-covering material. Laminated composites are available to seat producers as lengths of material. Even optimal cutting cannot avoid waste which, depending on the seat shape, may amount to five to ten per cent. As the materials used all display different properties, and separation from the polyurethane foam is not practical, it is not really possible to re-use this waste in the production cycle. Great importance is attached to this when considering the eco-friendly disposal of used seat covers.

Furthermore, emissions may result from the flame lamination process used for PUR foam layers. Their disposal into the air is being regulated more and more and they may also cause problems in a new vehicle, resulting in fogging and unpleasant odours.

As mentioned previously, PES is applied as a fibre material for the manufacture of nonwovens in a similar way to the material used for the upper fabric. The use of equal polymers guarantees that most of the seat-cover composites can be re-used. This has led to an investigation into the use of reclaimed fibres. Reclaimed PES fibre waste can be purchased for use in motor vehicles and it may be used as a substitute for up to 50% of primary fibres in the manufacture of nonwovens, depending on the quality of the reclaimed fibre. The physical properties will remain well inside the requirements for seat-cover composite materials and the cost of manufacturing will also be reduced. Almost all the processes available for the application of hot-melt adhesives may be used to bond the upper material and the nonwoven upholstery. The advantages of wholly textile composites include eco-friendly laminating, low emissions, and good air and water-vapour permeability [8].

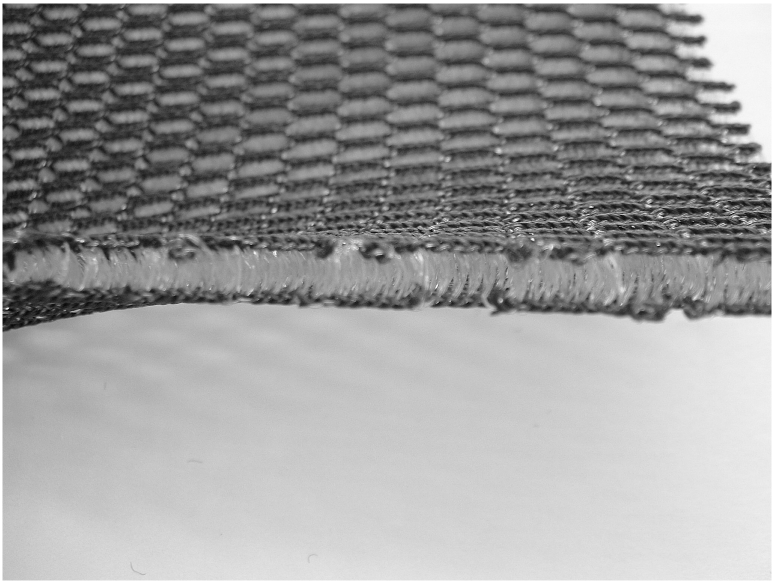
7.6 Future trends

The use of textiles as upholstery material beneath the seat-cover fabric is strongly influenced by the price. Despite any advantages that might be gained from new constructions for seat-cover composites, they must not cost more than 10–15% more in comparison with today's commonly used foam-cushioned materials.

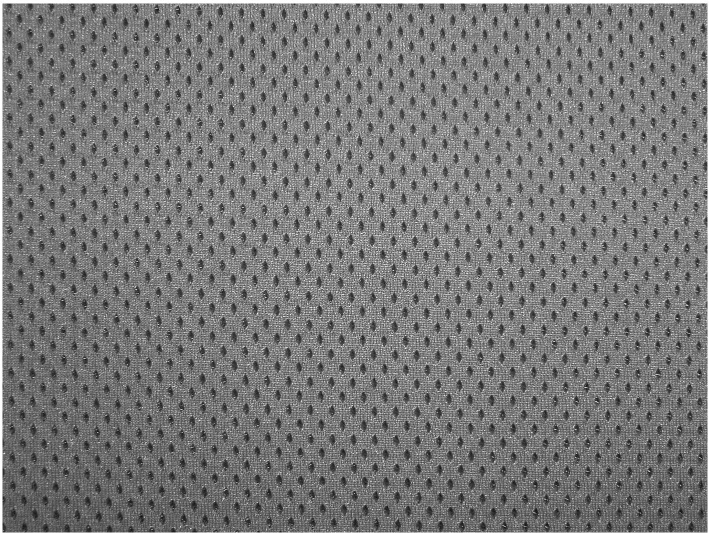
Because of the large quantities used, costs are of special interest. Nonwoven-based composite materials, in particular, will be fully competitive compared to the PUR foam composites that have been used until now. This is because the warp-knitted backing side of the foam layer is no longer necessary, and neither is the adhesive layer that was needed for it. The resulting process optimisation and improved recyclability will bring about a further reduction in cost.

Technical trends are influenced by the integration of functional materials to improve comfort or, alternatively, to install more features in the car. The use of anti-static fibres in the cover or the cushioning layer will improve anti-static behaviour. The integration of activated carbon in the cushioning layer could create a good microclimate in the seat. The increasing numbers of requirements for driving comfort, safety and infotainment lead steadily to a higher proportion and a rising packing density of electronic car components and control devices in cars. Thus, more requirements for ensuring electromagnetic compatibility (EMC) for the entire car system as well as for car components have to be fulfilled. Safe, economic and light-weight shielding for electronic components is needed and metallised fibres or areas in the cushioning layer will assist this shielding.

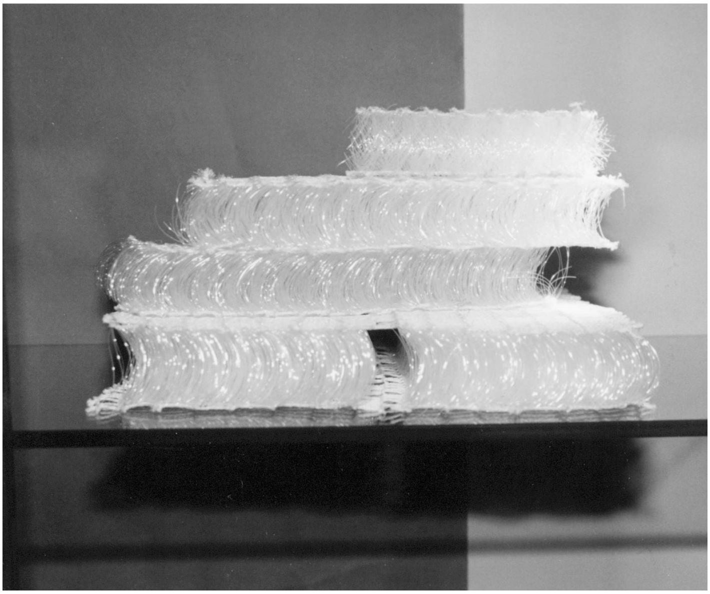
Warp-knitted spacer fabrics, which today are only used in high-priced cars in thicknesses of 8 to 12 mm (Fig. 7.4), will be used in single-layer materials containing the seat-cover fabric and cushioning layer all in one product (Fig. 7.5). Furthermore, warp-knitted spacer fabrics will be installed more and more as substitutes for the foam core in the seat. This will lead to the replacement of foam by nonwovens for the cushioning layer of seat-cover fabrics and by warp-knitted spacer fabrics from 30 to 60 mm thick for the foam core squab (Figs 7.6 and 7.7). Within ten years, the amount of foam used in most car seats will be reduced to nil [9–11].



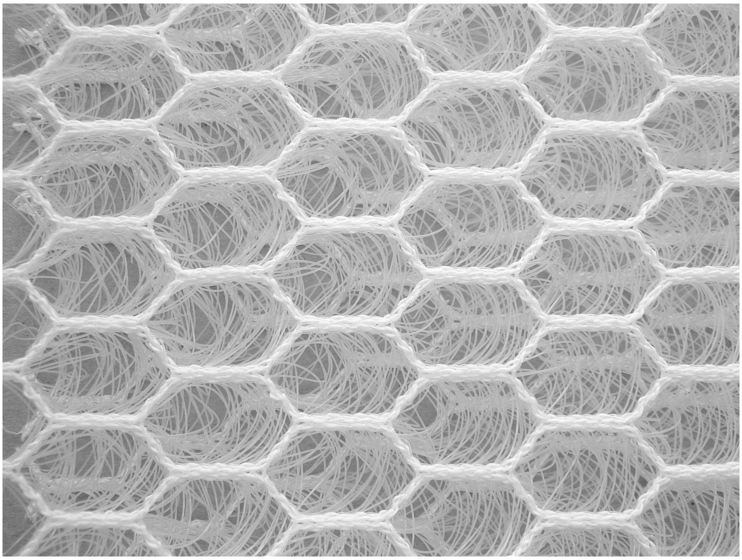
7.4 Warp-knitted spacer fabric.



7.5 Warp-knitted spacer fabric with closed surface containing seat cover fabric and cushioning layer in one product.



7.6 High distance warp-knitted spacer fabrics for replacement of the foam core squab – cross section.



7.7 High distance warp-knitted spacer fabric – top view.

7.7 References

1. Schmidt G F (1992), ‘Kaschierung von Autopolsterstoffen mit Faservliesen’, *Melliand Textilberichte* 6, 479–486.
2. Nagl F (1998), ‘PES-Filamentgarne für textiles Autointerieur’, *Technische Textilien* 11, 184–185.
3. Coll-Tortosa L, Schilde W, Erth H (2000), ‘Development of Recyclable Upholstery Textiles for the Automotive Industry and Public Transport’, EU Research Report EU-BRPR-CT 96 0292.
4. Erth H (1999), ‘Recycelbare Polstervliesstoffe für die Automobilindustrie’, *STFI-Kolloquium ‘Reißfaser ’99*’, Chemnitz/D 1999.
5. Schmidt G F (1999), ‘ “CALIWEB” substituiert Schaumstoff’, *Kettenwirk-praxis* 4, 31–34.
6. Erth H, Fuchs H, Wegner A (2000), ‘Recyclable three-dimensional nonwovens for upholstery in car seats’, *Textiles for Mobility – Hightex from Germany*, Atlanta/USA 2000.
7. Lutz S (2007), ‘Technische Anforderungen an Textilien im Automobilbau’, *Textilveredlung* 5/6, 26.
8. Erth H, Schilde W, Schmalz E (1998), ‘Einsatz von Wirkvliesstoffen mit Polstruktur als Unterpolstermaterial für Fahrzeugsitzbezüge unter besonderer Berücksichtigung deren Recyclefähigkeit’, *13th. Hofer Vliesstoffseminar*, Hof/D (1998).
9. Erth H, Gulich B, Fuchs H (2005) ‘Mobile Textiles – Future Trends to 2010’, *44th International Man-Made Fibres Congress*, Dornbirn/A 2005.
10. Erth H, Gulich B, Fuchs H (2006), ‘Development of Nonwovens for Transportation’, *8th International Dresden Textile Conference*, Dresden/D 2006.
11. Stegmaier T, Erth H (2007) ‘Market Data and New Developments in Textiles for Mobile Applications’, *Techtextil Symposium*, Frankfurt/D 2007.

8

Physiologically optimised car seats

V T BARTELS, Hohenstein Institutes, Germany

Abstract: A particularly important aspect of comfort in cars or other vehicles is the seats. The performance of a driver over long distances significantly decreases if car seats do not support posture and heat balance. This chapter reviews how seats can support the thermoregulation of the body via heat and moisture transport, ways of evaluating the thermophysiological aspects of vehicle seats at the developmental stage, and the use of textile materials to optimise the comfort of car seats.

Key words: car seats, comfort, thermoregulation.

8.1 Introduction

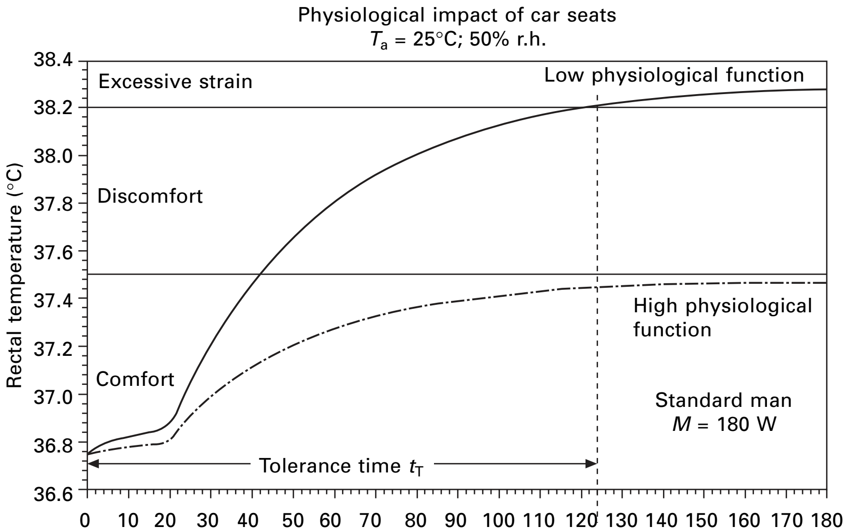
Today, comfort has become a major quality criterion of cars. Comfort in a car is a complex phenomenon and comprises such different aspects as, for example, noise, driving behaviour, or ease of handling (ATA, 1997). One of the most important factors influencing passenger convenience is thermal comfort. Therefore, car manufacturers are paying a lot of attention to this aspect, as can be seen by an increased application of air conditioning in the car, for example.

A particularly important aspect of vehicle comfort is the seats. Seats do not only have to have an attractive design or meet specific design criteria for safety reasons, they must also have optimum comfort properties. But seat comfort is much more than just passenger convenience. Scientific findings show that the performance of a driver over long distances significantly decreases if the car seats do not support posture and heat balance as required (Umbach, 1999, 2000a, see Fig. 8.1). This leads to exhaustion and loss of concentration, which, in extreme cases, could result in serious accidents.

In addition to ergonomic considerations, again the climatic or thermophysiological comfort of the seat is of particular importance. This indicates whether the seat is able to support the thermoregulation of the body via heat and moisture transport, as described in Section 8.2.

Today, the thermophysiological comfort of car seats can be obtained by a set of laboratory test apparatus, which are introduced in Section 8.3. Using measurements taken with the skin model and seat comfort tester (cushion testing device), it is now possible to evaluate and optimise the thermophysiological aspects of vehicle seats at the developmental stage.

Using a number of examples, it is demonstrated in detail in Section 8.4, how the physiological seat comfort of vehicle seats can be improved in real



8.1 Rectal temperature of a car driver as a function of time while sitting on a seat with high physiological function (lower line) or a seat with low physiological function (upper line) (Umbach, 1999, 2000a).

terms by using modern technical textiles. Only if the material and design of a seat are optimally coordinated will the driver enjoy optimum seat comfort. Otherwise, heat and moisture can accumulate, which feels unpleasant and can have a negative physical effect on the driver, limiting performance and concentration.

8.2 Thermophysiological comfort of car seats

From the physiological point of view, seat comfort comprises the following four parameters:

1. The initial heat flow following the first contact with the seat. In other words, the sensation of warmth or cold in the first few minutes or even seconds after entering the car.
2. The dry heat flow on long journeys, i.e. the amount of body heat transferred by the seat.
3. The ability, known as ‘breathability’, to transport any perspiration formed away from the body. In so-called ‘normal’ sitting situations, there is no perceptible perspiration, but, nevertheless, the human body constantly releases moisture (so-called ‘insensible perspiration’), which has to be taken away from the body.
4. In the event of heavy perspiration (a car in the summer heat, stressful

traffic situations) the ability to absorb perspiration without the seat feeling damp.

In the following sub-sections, the physiological background of these four parameters are described. In Section 8.3 their testing, and in Section 8.4 their optimisation by advanced textile materials is discussed.

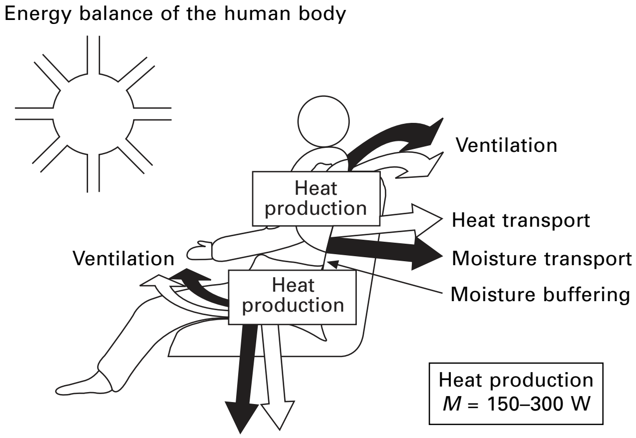
8.2.1 Energy balance of the human body

Thermophysiological comfort is based on the principle of energy conservation. As shown in Fig. 8.2, all the energy, which is produced within the body by metabolism, has to be dissipated in exactly the same amount from the body (Umbach, 1986, 1999). In terms of a mathematical formula, this principle gives (Mecheels, 1998):

$$M - P_{\mathrm{ex}} = H_{\mathrm{res}} + H_{\mathrm{c}} + H_{\mathrm{e}} + \Delta S/\Delta t \tag{8.1}$$

On the left-hand side of this formula, the energy production is given by M, the metabolic heat production. In a car, M usually ranges between 150 and 300 W. P_{ex} is the external physical work, which in a car is mainly due to steering, shifting the gears, etc., and which is much smaller than M.

On the right-hand side of equation 8.1, the heat dissipation is quantified. Here, H_{res} is the respiratory heat loss because of breathing, which is typically about 10% of the metabolic rate M. H_{c} is the dry heat flux comprising radiation, conduction and convection. H_{c} is strongly dependent on the car seat, the passenger's clothing and the cabin climate. The same holds for the evaporative heatflow H_{e}, which is caused by sweating.



8.2 The energy balance between produced and dissipated heat as a prerequisite for a good thermal comfort (Umbach, 1986, 1999).

If more energy is produced than dissipated, the body suffers from hyperthermia. On the other hand, too high a heat loss implies hypothermia. Both lead to a change in the body's energy content ΔS with time Δt. ΔS may be either positive (leading to hyperthermia) or negative (hypothermia) and is zero for the steady state.

This steady state (i.e. $\Delta S = 0$) is desirable, and it has to be the aim of a car seat manufacturer to achieve energy balance. M, P_{ex} and H_{res} cannot be influenced by a car seat, but H_c and H_e can. Therefore, all the physiological testing apparatus described in Section 8.3 are intended to measure H_c and H_e. And all optimised constructions of car seats given in Section 8.4 are intended to improve H_c and H_e.

8.2.2 Warmth sensation

Initial perception of warmth (entering the car)

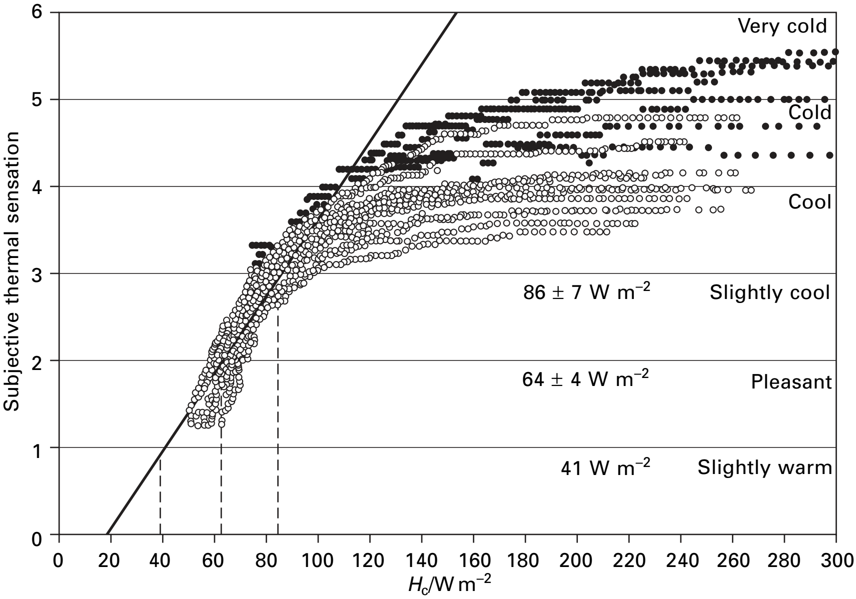
The passenger is already sensing his first thermal impression of a car seat while entering the vehicle. This initial perception of warmth after sitting depends on the heat flux between person and seat within the first few minutes or even seconds. The heat flux should be as low as possible, otherwise a car seat feels cold in the winter time or hot during summer.

Although this initial feeling may last only a few minutes, it is nevertheless very important for the user's acceptance, as it is being repeated frequently. If a car is used every day during the winter time and each morning the driver is dissatisfied when entering the car, acceptance can be significantly decreased.

For the initial perception of warmth, the dominant seat components are the cover and (if present) heating. For the covering material, the main parameter influencing the initial perception of warmth is heat capacity (Bartels and Umbach, 1997, 2005; Bartels, 2003; Umbach, 1999). For the heating, both its heating power and its position are of great importance (Hänel *et al.*, 1995, 1997).

The exact relationship between (a) the heat flux between seat and person on the one hand and (b) the subjective thermal sensation on the other hand was surveyed in Bauer and Bartels (2005) and Bauer *et al.* (2005). In Fig. 8.3 the initial thermal sensation of warmth is shown as a function of the heat flux H_c between seat and skin. These results were obtained under cool climatic conditions during the first 10 minutes after getting seated.

Figure 8.3 shows a clear correlation between the subjective and the objective data. In particular, the sensations 'pleasant' and 'slightly cool', which are most important for achieving comfort under the conditions considered here, can be attributed to heat fluxes of H_c = 86 W/m^2 and 64 W/m^2, respectively.



8.3 Initial subjective thermal sensation of test persons as a function of the heat flux H_c between seat and skin (Bauer and Bartels, 2005, Bauer *et al.*, 2005).

Steady state heat flux (long journey)

During long journeys it is favourable if the seat offers a *high* steady state heat flow, to minimise the tendency to sweat (Umbach, 1999; Bartels and Umbach, 2005), whereas for the initial perception a *low* heat flux is required (see page 153). Hence a conflict arises between these two scenarios.

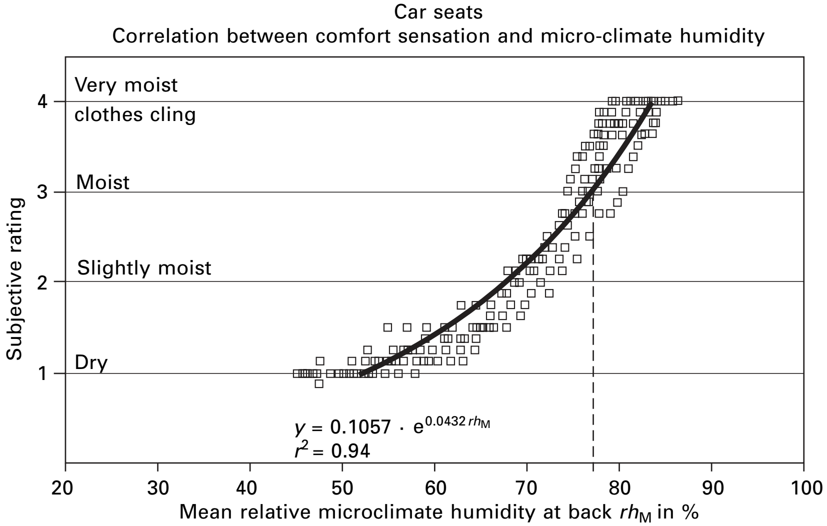
This conflict can be overcome, because the cover, which determines the initial perception, is only of minor influence on the steady state heat flux, which is mainly determined by the thermal insulation of the seat. Owing to its greater thickness and, hence, higher thermal insulation in comparison to the cover, the cushion becomes the dominant part.

On the other hand, the heat flux is also dependent on the ventilation in the seat and between seat and passenger (see Fig. 8.2). Ventilation itself is determined by the design of the seat (side supports, surface grooves), the elasticity and air permeability of the cushion (e.g., foam or 3-D spacer fabric), and, if present, a fan to enforce ventilation.

8.2.3 Moisture sensation

Water vapour transport (normal sitting)

The moisture sensation of the passenger is very important for perceived overall seat comfort. As shown in Fig. 8.4, a seated person does recognise



8.4 Subjective moisture sensation of human test subjects as a function of the relative humidity in the microclimate between seat and skin (Umbach, 1999).

differences in the microclimate humidity between seat and skin (Umbach, 1999). Especially a rating of ‘moist’ (corresponding to a mean relative humidity in the microclimate of 78%) or poorer has to be avoided. Otherwise, the acceptance of the car seat by the passenger is severely impaired.

In order to achieve a dry microclimate, the ability, known as ‘breathability’, of the seat to transport any perspiration formed away from the body is crucial. Not only under warm summer conditions is good water vapour transport necessary, but even when there is no perceptible perspiration. The human body constantly releases moisture, the so-called ‘insensible perspiration’. As the skin is not totally water vapour tight, our body loses at least 30 grams of moisture per hour. Because a car seat covers large areas of the body, the seat has to manage a large part of the perspiration formed, and, hence, a considerable amount of moisture.

But we do not only sweat insensibly, we sensibly perspire in order to ensure the body’s thermoregulation and to cool down the body core temperature by sweat evaporation (see Fig. 8.2). The amount of moisture produced can be up to one litre per hour or even more, e.g. during sports or if the ambience is extremely hot.

In the case of sensible perspiration, the sweat glands inside the skin are actively producing moisture. But only if this moisture can readily evaporate can the desired cooling effect be achieved. This is a direct demand on the seat, which has to allow this evaporation.

Apart from thermoregulation, we additionally sweat because of mental stress. While driving a car, this ‘stress driven perspiration’ may appear due to difficult traffic situations. But no matter how the sweat production originates, the seat has to cope with it.

Hence, for most sitting situations, it is essential that a seat offers a high water vapour transport to allow the evaporation of sweat. Technically speaking, the seat needs to have a low water vapour resistance (i. e. a high ‘breathability’). As further discussed in Section 8.4, all components of the seat have to be water vapour permeable, because just one single impermeable layer would impede water vapour transport.

Sweat buffering (heavier sweating)

When entering a hot car in the summer or because of stressful driving situations, we start to sweat more heavily. This additional amount of sweat has to be ‘buffered’, in order to keep the microclimate as dry as possible. The dominating parts for the buffering capacity are seat cover and lining.

In general, for a good water vapour buffering capacity, both the water vapour transport and the water vapour absorbency are important. As shown in Bartels (2003), the water vapour transport is especially of interest for the seat cover. Only if the excessive water vapour can be transferred from the body and into the seat can a dry microclimate be achieved.

When looking at the whole car seat, the influence of water vapour transport on water vapour buffering becomes smaller. Just due to its thickness, a car seat is already a considerable barrier against diffusion. Therefore, for the whole car seat, water vapour absorbency determines the water vapour buffering capacity (Umbach, 1999). In order to achieve fast absorption, the covering material and the lining beneath it in particular should be hygroscopic.

8.3 Measurement of seat comfort

8.3.1 Seat trials with test persons

One way to test seat comfort is seat trials with human test subjects. They can be performed as so-called ‘field trials’, as they are frequently carried out during test drives. The greatest advantage of these test drive results is that they represent ‘the practice’. However, these types of tests cannot be reproducible, as the weather and the traffic conditions change. If, for example, one day there are a few more clouds in the sky than another day, solar irradiation is much smaller and, hence, also the driver’s tendency to sweat.

Therefore, in order to have confidence in the results of the seat trials of the investigated seat construction, it is recommended to perform the experiments in a climatic chamber, which controls ambient temperature, humidity and radiation. In a modern climatic chamber, climatic conditions can be adjusted to range from arctic to tropical.

Using a driving simulator (see Fig. 8.5), different traffic situations can be adjusted such as the type of street (small, rural roads, highways, streets in cities, etc.), the traffic density, or the behaviour of other road users. In addition, unexpected incidents can be added, like a staggering cyclist or a deer that suddenly jumps into the road.

During the trial, the test person has to steer the wheel, shift gears, accelerate and break as in real driving situations. Thus, the test person not only performs the same body movements as in a car, but also shows the respective metabolic heat production. Ventilation due to pumping effects caused by the car's movements can be simulated by a small vibration of the board on which the car seat is mounted.

8.5 Seat trial with a human test subject on a driving simulator in a climatic chamber.

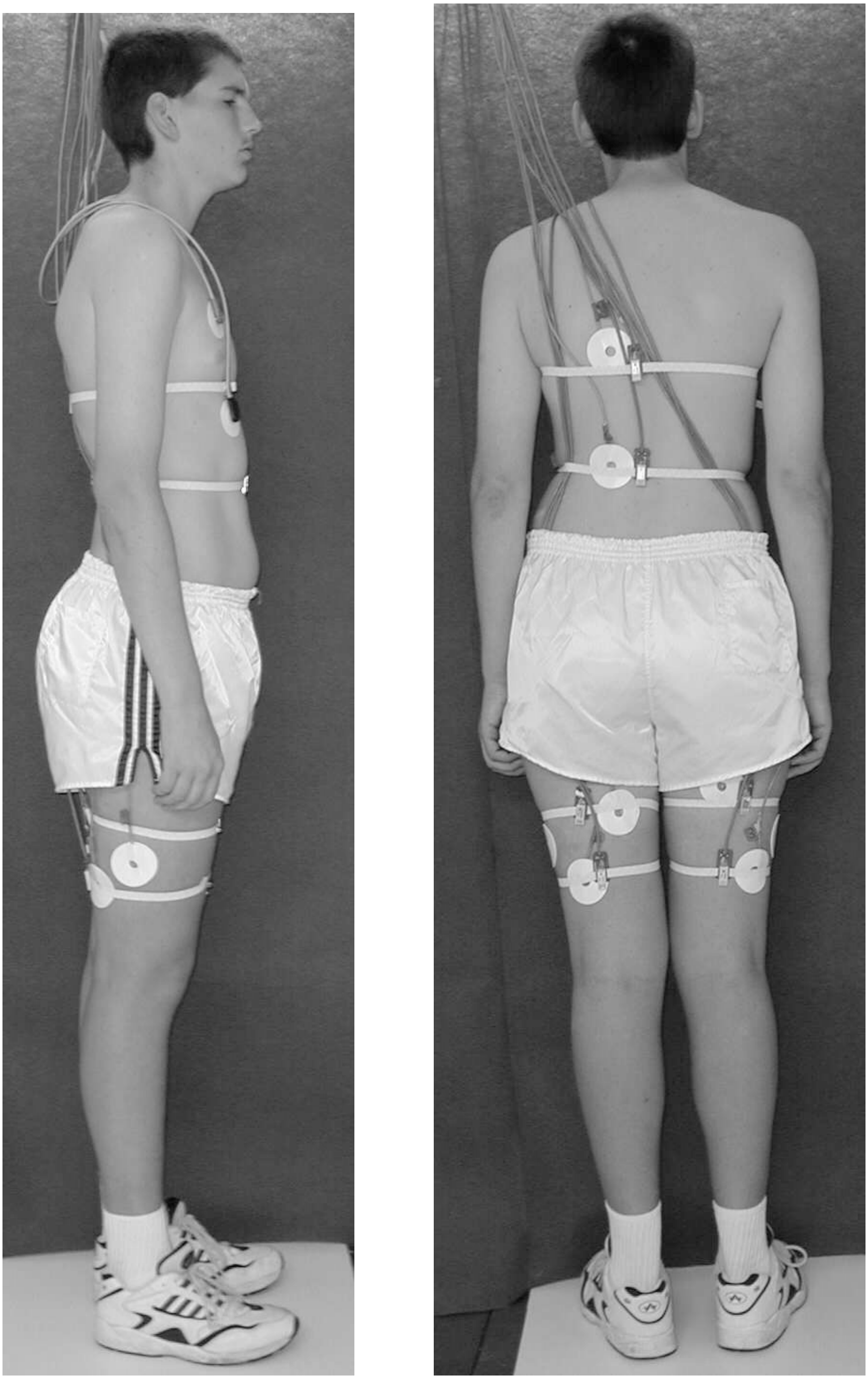
A big advantage of a modern driving simulator is that it can record errors. As already mentioned in Section 8.1, if a driver feels uncomfortable on the seat or even suffers from heat stress (see Fig. 8.1), mental performance is decreased. The number and seriousness of errors is a way to quantify this decrease.

Seat trials can be easily adjusted to the problem under investigation. Not only can climatic and driving conditions be set in a climatic chamber, but also a variety of objective data can be obtained. If, for example, the 'moisture management' of a car seat is of interest, humidity sensors can be attached between skin and seat, which monitor the relative humidity in the microclimate (Frankowsky and Umbach, 1995; Bartels and Umbach, 1997; Umbach, 1999; Bartels, 2003). In addition, the test person, clothes and the seat can be weighed before and after the test to determine the sweat production of the person as well as the moisture uptake of the clothes and the seat. Rectal and skin temperatures can be measured using thermocouples. For testing the initial sensation of warmth, heat flux sensors can be adjusted to the skin (Bauer and Bartels, 2005; Bauer *et al.*, 2005). Also the metabolic rate can be determined by an analysis of the exhaled air concerning oxygen consumption and carbon dioxide production (ISO 8996). Last but not least, the heart rate is monitored via ECG electrodes. A typical set of probes attached to a test person's body is shown in Fig. 8.6.

For the evaluation of subjective comfort sensation, ISO 10551 can be employed. Via subjective judgement scales, the test persons' sensations can be quantified. For example, the humidity sensation could be assessed using the following scales: 0 = dry, 1 = back slightly moist, 2 = back moist, 3 = body moist, 4 = body moist and clothes cling, etc.

However, seat trials also have some severe disadvantages, which make them ineffective for product development or quality control. In order to obtain statistically significant results, a large number of test persons and repetitions is required. Additionally, test persons react differently in the morning than in the afternoon, hence tests have to be performed at both times. Test subjects have to be acclimatised to the climatic and activity conditions in pre-tests. Data have to be extensively statistically analysed, etc. This makes seat trials time-consuming and expensive and laboratory test methods, as they are described below, a faster and cheaper alternative for many applications.

In conclusion, seat trials with test persons are best positioned at the end of a development process, in order to prove conclusively the physiological performance of a car seat. In addition, seat trials are needed as a 'calibration' for the laboratory test procedures, which are introduced in the next sections. In particular, mathematical regression analyses between the laboratory tests on the one hand, and wearer trials data on the other hand have to be carried out, in order to ensure the practicability of the laboratory tests, and to interpret



(a) (b)

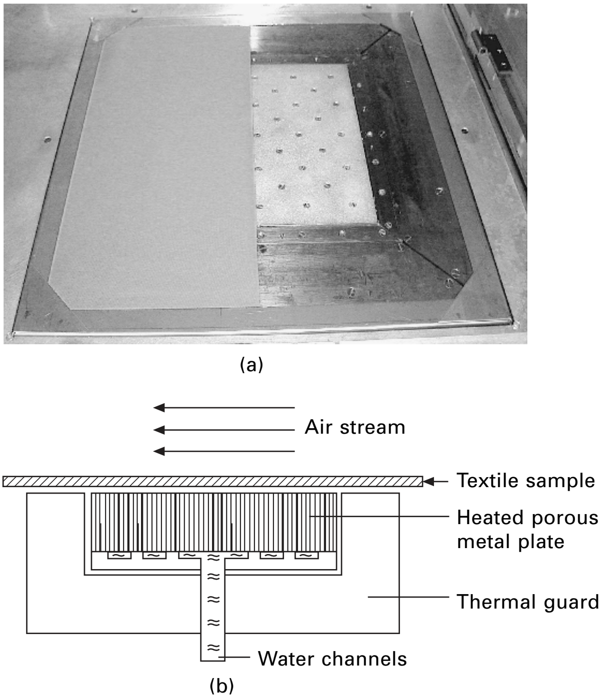
8.6 Seat trials. Probes attached to the body of a human test subject.

their data (5I3M, 2003). This is a crucial criterion for laboratory techniques and, in fact, only a few test methods lead to results which correlate to real human subject data (Bartels and Umbach, 2003; Bartels, 2003).

8.3.2 Skin model

An important laboratory test method that fulfils the above mentioned criterion of correlations to seat trials data is the so-called skin model. The skin model is a thermoregulatory model of the human skin. It tests the thermophysiological seat comfort of materials and compounds. The skin model is internationally standardised in ISO 11092, EN 31092.

A photo and a schematic drawing of the skin model is given in Fig. 8.7. The measuring unit shown is made of sintered stainless steel and sized 20 × 20 cm^2. Water, which is supplied by channels beneath the measuring unit, can evaporate through the numerous pores of the plate, just like sweat out of the pores of the skin. Additionally, the measuring unit is kept at a temperature of 35°C. Thus, heat and moisture transport are comparable to those of the human skin.



8.7 Photo and schematic drawing of the skin model for testing the thermophysiological properties of materials and compounds.

The car seat specimen is placed on the skin model with its upper surface facing the plate. To simulate the static pressure a person exerts, the sample is loaded by lead weights to a pressure of 14.7 cN/cm^2. To simulate the movements and vibrations of a car, a pneumatic pivot presses onto the specimen with a frequency of 2 Hz and a dynamic load of 5 bar.

With the skin model different seat situations are possible (Umbach, 1999; Bartels and Umbach, 1997, 2003; Bartels, 2003):

1. Normal seat situations, as they are characterised by an insensible perspiration (see page 154). For normal seat situations, especially, the thermal insulation R_{ct} and the water vapour resistance R_{et} ('breathability') according to ISO 11092, EN 31092 of the textiles are important, both should be as low as possible.

   If samples are identically constructed, the thicker one always has the higher (and thus poorer) water vapour resistance R_{et}. In order to take the different thicknesses into account, the ratio

   $$i_{mt} = 60 \text{ (Pa/K) } R_{ct}/R_{et} \qquad 8.2$$

   is defined as the water vapour permeability index, which is a measure of breathability with respect to a sample's thermal insulation. High values of water vapour permeability index are favourable.

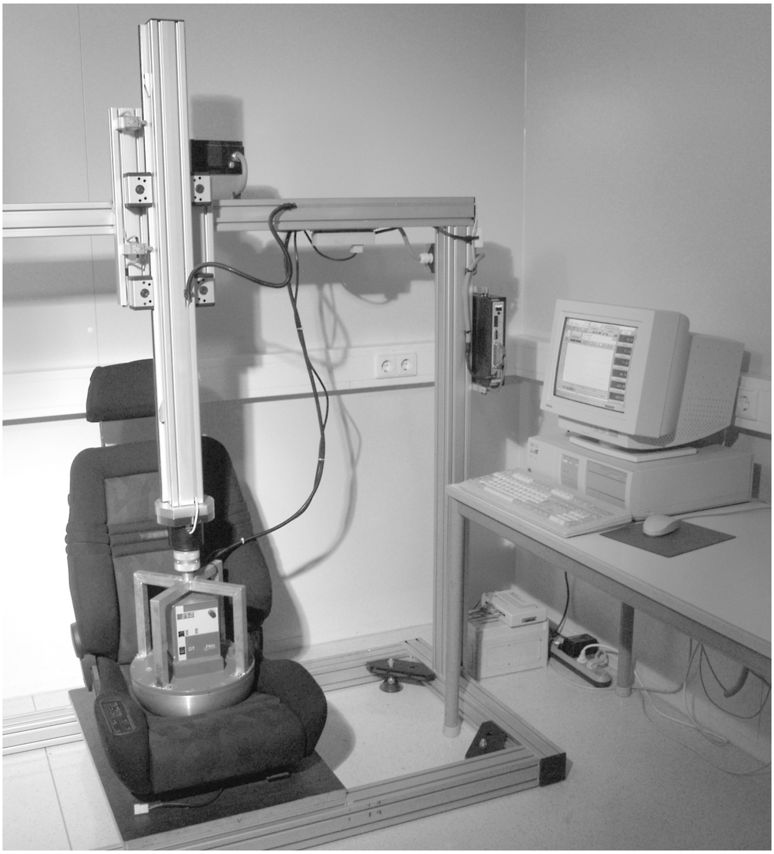
   Last but not least, water vapour absorbency F_i is part of the picture in normal seat situations. Therefore, the test is run for exactly two hours. F_i is determined by weighing the specimen before and after the test. High values are advantageous.

   These tests can be divided into 'static' and 'dynamic' measurements (Frankowsky and Umbach, 1995; Umbach, 1999). During static tests, the pneumatic pivot is switched off, during dynamic tests the pivot is turned on. By comparing the difference between the two, the ventilation rate (in per cent) can be quantified. In the case of the water vapour resistance, it is indicated as ΔR_{et} and should be high.
2. Heavier sweating (see also page 156) is simulated with the skin model by measuring the buffering capacity against vaporous sweat F_d according to BPI 1.2 (1994). In this case, 4 cm^3 of water are suddenly evaporated, creating a 'sweat impulse'. Using a humidity sensor, which is placed between the plate and the sample, the time-dependent amount of moisture in the microclimate is monitored. The lower the microclimate humidity, the better, which is expressed by a higher value of F_d.

8.3.3 Seat comfort tester

The seat comfort tester (or upholstery tester) is a device, which was originally built by Hänel and co-workers (Hänel *et al.*, 1995, 1996, 1997). The photo in Fig. 8.8 shows a slightly modified version (Bartels and Umbach, 1997; Bartels, 2003). The seat comfort tester shows good correlation to quantities objectively measured in human test subjects, both for the initial sensation (Bauer and Bartels, 2005) and for long-term sitting (Bartels, 2003).

With the seat comfort tester, entire car seats (seat cushion as well as back rest) can be tested. Its main part is an 'indentor', an aluminium stamp with a rotational elliptical shape, which simulates the contours of the human body. The surface temperature of the indentor is kept constant at 35°C. A telescopic arm presses the indentor into the car seat with a defined force of 440 N on the cushion and 75 N on the back rest, respectively, simulating a person with a weight of 75 kg. Via four heat flux sensors distributed over the indentor's surface area, the initial heat flux H_{ci} into the car seat can be measured (which should be small), as well as the steady state heat flux H_c, which is determined after two hours of testing and should be high. From H_c



8.8 Photo of the seat comfort tester (upholstery tester) for testing the thermal properties of entire car seats.

the seat's thermal insulation R_c can be calculated (low values are favourable). The seat comfort tester is placed in a climatic chamber, which maintains the climatic conditions.

8.4 Improving comfort properties of car seats

The following shows how the described physiological test methods can be used to improve the comfort of car seats. Therefore, some recent results are given, which in particular exhibit the advantages of modern technical textiles in comparison to currently used materials.

8.4.1 Seat cover and lining

In Table 8.1 the physiological parameters as obtained with the skin model and the seat comfort tester are presented for six different covering materials (Bauer and Bartels, 2005). If one compares the textiles with the leather, it turns out that all textiles are advantageous to leather concerning nearly all physiological parameters. Because of its high thermal conductivity, leather feels significantly cooler when entering a cold car in the winter ($H_{c\,max}$ = 520

Table 8.1 Thermophysiological properties of different covering materials. Abbreviations: R_{ct} = thermal insulation, R_{et} = water vapour resistance ('breathability'), i_{mt} = water vapour permeability index (see eq. 8.2), F_i = water vapour absorbency, F_d = buffering capacity against vaporous sweat impulses, $H_{c\,max}$ = maximum initial heat flux in the cold (data taken from Bauer and Bartels, 2005)

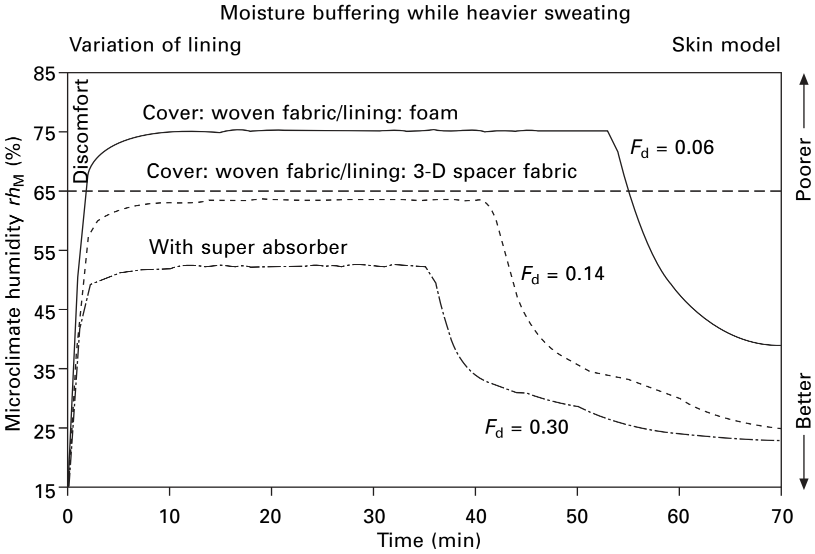
Material	R_{ct} (10^{-3} m^2 K/W)	R_{et} (m^2 Pa/W)	i_{mt} (no units)	F_i (g/m^2)	F_d (no units)	$H_{c\,max}$ (W/m^2)
Woven fabric wool/polyamide 95/5, 400 g/m^2	28	5.7	0.30	21.2	0.52	410
Flock, bulk material polyamide, flocked with polyester (65%) and cotton (35%), 270 g/m^2	25	12.5	0.12	3.8	0.32	350
Textile leather imitate, polyester with polyurethane and a cotton lining, 420 g/m^2	26	8.5	0.21	3.1	0.49	390
Velour, cotton/polyester/polyamide, 975 g/m^2	93	19.4	0.29	36.9	0.30	310
3-D spacer fabric, polyester, thickness 4 mm, 355 g/m^2	57	8.9	0.43	0.5	0.51	320
Real leather, 865 g/m^2	33	86	0.02	4.4	0.06	520

W/m^2) than the textiles. Its water vapour transport properties are poor, especially water vapour resistance of R_{et} = 86 m^2 Pa/W, which is too high. This is a consequence of the finishing process of the leather, which is usually covered with a thin film of polyurethane of which the water vapour permeability is small. Modern finishing procedures improve the water vapour resistance of leather by up to 45% (Bauer and Bartels, 2005), but textiles are still much better. An interesting alternative for those who would like to have the 'leather look', is the textile imitation, of which the physiological properties are much better than those of a real leather.

For a pleasant initial sensation of warmth, the thermal conductivity of the cover should be small. Best results are found for textiles that include a high amount of air, such as, for example, a velour or a three-dimensional spacer fabric ($H_{c\ max}$ = 310 or 320 W/m^2, respectively).

The water vapour absorbency can be improved by using hygroscopic materials like wool or cotton. The woven fabric made of 95% wool presented in Table 8.1 is able to absorb 21.2 g/m^2 of water vapour. On the other hand, the three-dimensional spacer fabric made of polyester absorbs just 0.5 g/m^2.

For the buffering capacity against vaporous sweat impulses F_d of the whole car seat, the water vapour absorbency of the cover and its lining are of great importance. In Fig. 8.9, the influence of different linings is presented (Umbach, 2004). In combination with the same cover, the three-dimensional spacer fabrics lead to significantly lower microclimate humidities than a



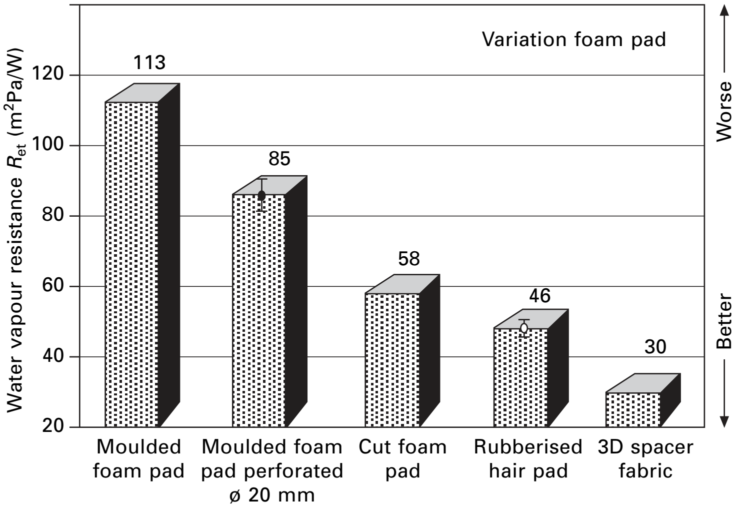
8.9 Influence of different lining materials on the buffering capacity against vaporous sweat impulses (Umbach, 2004).

foam lining, and, in addition, humidity values drop faster after the simulated sweat impulse. Consequently, the buffering capacity of the combination with the spacer fabric lining is $F_d = 0.14$, whereas the compound with the foam lining only reaches $F_d = 0.06$.

The up-to-date best lining alternative from a physiological point of view is also textile based, a nonwoven with super-absorbent-polymers (SAP) (Thill and Krause, 2005). As shown in Fig. 8.9, such a lining leads to the lowest microclimate humidity and obtains $F_d = 0.30$.

8.4.2 Cushion

Not only for the covering material but also for the cushion do textiles offer great potential in improving the physiological performance of car seats (Bartels and Umbach, 1997, 2005; Umbach, 1999, 2000b; Bartels, 2003). In Fig. 8.10 the water vapour resistance as measured with the skin model of different cushion materials is presented. These tests clearly demonstrate that moulded foam pads, which are quite popular in the automotive industry due to their comparably low costs, lead to only a poor (i.e. high) water vapour resistance of $R_{et} = 113$ m^2 Pa/W. Sometimes even higher values occur, because for the moulding process a thin film on the back of the cover may be required, which prevents foam material from penetrating through the cover, but which impedes water vapour penetration. In this case, a breathable membrane would be preferable to that film, but due to the higher costs, breathable membranes could not find their way into the actual production of moulded car seats.



8.10 Water vapour resistance R_{et} of different cushion materials (Bartels and Umbach, 2005).

As an additional problem, many foams only have pores, which are not or are only very loosely interconnected with each other. For a water vapour molecule, this further handicaps the diffusion through the foam. A perforation improves water vapour transport. In the example shown in Fig. 8.10, the water vapour resistance can be significantly lowered to a value of $R_{et} = 85\,m^2$ Pa/W. However, each of the holes should have a diameter of at least 20 mm, otherwise they collapse when compressed by the weight of the passenger, and, thus, lose their function.

A perforation improves the water vapour transport, but a cut foam with pores, which are connected with each other, is better. It decreases the water vapour resistance to $R_{et} = 58\ m^2$ Pa/W, which is only approximately half of the non-perforated moulded foam pad (i.e., doubled 'breathability'). Hence, cut foams are frequently used in the car industry, although they are more expensive to handle than moulded foam pads.

A further improvement is achieved by a rubberised hair pad ($R_{et} = 46\ m^2$ Pa/W). Owing to its high content of hygroscopic hair, this construction can also absorb a considerable amount of water vapour. As a disadvantage, rubberised hair pads often offer only poor ergonomic comfort. Hence, they have to be combined with softer cushion or lining materials.

From the physiological point of view, today the optimum cushion alternative is a three-dimensional spacer fabric. It offers the smallest water vapour resistance of only $R_{et} = 30\,m^2$Pa/W, i.e. approximately the doubled 'breathability' in comparison to the best (cut) foam pad. This advantage is due to the very open structure of the spacer fabric that supports water vapour diffusion. Another benefit is that air can easily move through the spacer fabric, which enhances ventilation and pumping effects due to the car's or the passenger's movements and which can be enhanced by a fan (see Section 8.4.4).

Today, spacer fabrics are often combined with other cushion materials, especially foams. Just a few years ago this was necessary, because the thickness of the spacer fabrics was limited to approximately 1 cm. Today, spacer fabrics can be up to 6 cm thick (Helbig, 2006), which allows a complete or nearly complete substitution of the foam. In Fig. 8.11, an example of an experimental aeroplane seat is shown, in which the foam in the cushion and back rest is extensively replaced by a 4 cm thick spacer fabric (Bartels, 2003).

From the physiological point of view, a spring coil construction is also favourable over a foam cushion (Faust and Umbach, 1984a, 1984b; Bartels and Umbach, 1997). A spring coil construction includes a thick air layer, in which warm and humid air can obey convection. Hence, the physiological effect is similar to that of a seat including a three-dimensional spacer fabric. However, owing to their high costs and heavy weight, spring coil constructions are not found in modern cars.

8.11 Modification of an aeroplane seat by means of a spacer fabric (Bartels, 2003).

8.4.3 Surface design

In addition to the selection of the materials, the seat's design is important (Umbach, 1999, 2000b). Surface grooves enhance ventilation, which leads to a higher exchange of moist air with the drier environment. On the other hand, large side supports, as they are frequently used in sport seats, hinder ventilation. In this respect, today's car seat design trends are often in contradiction with improved physiological properties.

8.4.4 Active climatisation

During approximately the last ten years the inclusion of active elements played a significant part in car seat production. For both cold and hot climate, active elements are available, which support the physiological function of the seat and improve comfort.

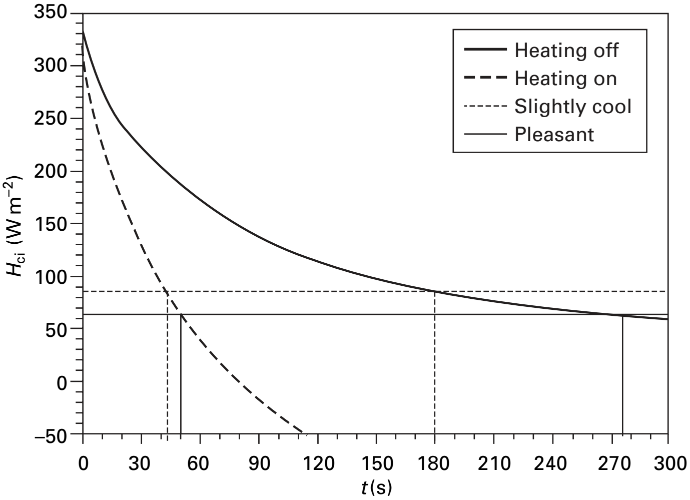
Today standard in upper class vehicles – but available in nearly all car classes – is seat heating (Weiss and Ulbrich, 2003). Many of the heating systems require a carrier. For this purpose, today apart from foams various technical textiles are employed, such as nonwovens, knitted fabrics, waddings, or three-dimensional spacer fabrics.

Recent developments include conductive textiles (Möhring, 2005; Möhring *et al.*, 2005). This new generation of 'smart textiles' is not yet used in car seat heatings, but offers great opportunities for the future, also for sensor technology, illumination and design.

Apart from the materials used for the heating, fundamental investigations of Hänel and co-workers (Hänel *et al.*, 1995, 1997) showed that their placement is as important. Only if the heating elements are near enough to the passenger and their distribution in the seat leads to an entire warming of the whole seat surface in contact with the person can a pleasant sensation soon be achieved.

If all components of seat and heating are attuned to each other, the heating can lead to a significantly faster warming of the car seat. In Fig. 8.12 the time dependent initial heat fluxes H_{ci} as measured with the seat comfort tester are given for a car seat with a jacquard woven fabric on top and (a) the heating switched off and (b) the heating turned on. After an identical starting point at $t = 0$ with a maximum heat flux of $H_{c\,max} \approx 330\ W/m^2$, the heating leads to a much faster decrease of the heat flux, i.e. warming of the seat. If the heating is switched off, it takes 180 s until a heat flux is achieved, which is perceived as slightly cool, and 275 s until a pleasant heat flux is reached. If the heating is turned on, it only takes 43 or 50 s, respectively.

In modern 'climate seats' active elements are included which not only improve comfort in the cold, but also in the heat. These seats employ a



8.12 Influence of seat heating on the initial sensation of warmth. Initial heat flux H_{ci} as a function of time t, monitored by means of the seat comfort tester in a cool environment. The seat heating is either switched on or off.

Table 8.2 Steady state heat flux H_c as measured by means of the seat comfort tester after 2 hours of testing for two car seats with a different cushion design. High values are advantageous

Cushion construction	H_c
Forced ventilation	64 ± 13
Foam	16.0 ± 0.2

ventilation layer made of a three-dimensional spacer fabric, in which a forced air stream driven by a fan exchanges warm air with the cooler ambience. In Table 8.2 the great benefit of a cushion construction comprising a forced ventilation is shown with the example of two seats with a Jacquard cover (Bartels and Umbach, 1997). The steady state heat flux H_c, as measured by means of the seat comfort tester after two hours, is about 16 W/m^2 for a seat with a foam cushion. But the seat with forced ventilation is able to dissipate 64 W/m^2, i.e. a factor of four.

In most of today's cars air conditioning is built in, leading to a significant reduction of the thermal stress of the driver and the passengers in the summer time. However, forced ventilation in a seat is still of great benefit. Owing to their thickness, which is necessary to be able to carry the weight of the passenger and ensure ergonomic comfort, all cushions and back rests have a high thermal insulation, which is comparable or even higher than that of warm winter clothing. Thus, even in a pleasant cabin environment, a ventilated seat guaranteeing a higher heat flux is more comfortable.

8.5 Conclusions

Today, comfort is one of the most important properties of a car seat. Modern technical textiles used as covering, lining and cushion materials can significantly improve climatic comfort, especially in comparison to non-textile materials like leather or foam:

- Textile covering materials show better water vapour resistance ('breathability') and feel less cold in the winter time than leather.
- Three-dimensional spacer fabrics as linings or cushions transport more heat and moisture than foams and, thus, reduce the accumulation of sweat. They can be combined with a fan, which enforces the ventilation, to further improve the dissipation of heat and moisture.
- Linings made of textiles including super-absorbent polymers are able to absorb high amounts of perspired moisture, even during heavier sweating.

The seat comfort can be tested via the physiological laboratory apparatus skin model and seat comfort tester, which lead to reproducible results, which are in good agreement with practice, and are much faster and cheaper and, thus, highly efficient for a product development process. Seat trials with test persons are best positioned as a validation procedure at the end of such a process. If seat trials are performed in a climatic chamber, test conditions can be kept reproducible.

8.6 Future trends

It is foreseeable that in the future the importance of comfort in the car will be even more significant as one of the main factors in the competition between car manufacturers. The car seat is that component in the car, which has the largest contact area with the passenger, and it stays in direct touch throughout a journey. Thus, the car seat is one of the main components for comfort. Consequently, modern climate seats are increasingly desired by the consumer – and ordered.

Owing to their physiological benefits in comparison to concurrent materials, the demand for technical textiles for use in car seats will increase. As approximately 3.5 kg or 10 square metres are used per car just for the upholstery (Erth *et al.*, 2005), textiles for car seats possess interesting market potential.

8.7 Acknowledgements

We are grateful to the Forschungskuratorium Textil for the financial support of the research project (AiF-No. 13495 N), which was funded by the German Ministry of Economy and Technology via grants of the Arbeitsgemeinschaft industrieller Forschungsvereinigungen 'Otto-von-Guericke'.

8.8 References

5I3M (2003), *5th International Meeting on Thermal Manikin and Modelling*, Strasbourg, September 29–30.

ATA (1997), *4th International Conference and Exhibition on Comfort in the Automotive Industry – Recent Developments and Achievements*, Bologna, Italy.

Bartels V T (2003), 'Thermal comfort of aeroplane seats: influence of different seat materials and the use of laboratory test methods', *Applied Ergonomics*, 34, 393–399.

Bartels V T and Umbach K H (1997), 'Laboratory tests of thermophysiological seat comfort', *4th International Conference and Exhibition on Comfort in the Automotive Industry – Recent Developments and Achievements*, Bologna, Italy.

Bartels V T and Umbach K H (2003), 'Messverfahren zur Beurteilung der Atmungsaktivität von Schutzbekleidung und Fahrzeugsitzen', *Technische Textilien*, 46(1), 58–61.

Bartels V T and Umbach K H (2005), 'Physiologically optimised car seats – latest findings and trends', *13th Techtextil Symposium*, Frankfurt a.M., Germany.

Bauer B and Bartels V T (2005), 'Entwicklung von textilen Bezugsstoffen für Fahrzeugsitze und Polsterungen mit optimiertem Initialwärmeempfinden', technical report No. AiF 13495 N, Hohenstein Institutes, Bönnigheim, Germany.

Bauer B, Bartels V T and Umbach K H (2005), ‘A study of the initial perception of warmth of car seats – the important first impression’, *Kettenwirk-Praxis* 39(4), 16–18.

BPI 1.2, ‘Measurement of the buffering capacity of textiles with the thermoregulatory model of human skin (Skin Model)’, Hohenstein Institutes, March 1994.

Erth H, Gulich B and Fuchs H (2005). ‘Mobiltextilien – Entwicklungstendenzen bis 2010’, *44th International Man-Made Fibres Congress*, Dornbirn, Austria.

Faust E and Umbach K H (1984a), ‘Climatic comfort in car seats – Part 1’, *Automobiltechnische Zeitschrift*, 86, 99–102.

Faust E and Umbach K H (1984b), ‘Climatic comfort in car seats – Part 2’, *Automobiltechnische Zeitschrift*, 86, 399–405.

Frankowsky B and Umbach K H (1995), ‘Quantitative Erfassung des klimatischen Sitzkomforts von KFZ-Sitzen’, *Hohensteiner Forschungsbericht*, July.

Hänel S E, Dartman T and Shishoo R (1995), ‘A new method for measuring mechanical and physiological comfort in car seats’, *34th International Man-Made Fibres Congress*, Dornbirn, Austria.

Hänel S E, Dartman T and Shishoo R (1996), ‘A comparison of measuring methods for comfort rating of beds’, *Advances in Occupational Ergonomics and Safety I*, 2, 783–788.

Hänel S E, Dartman T and Shishoo R (1997), ‘Measuring methods for comfort rating of seats and beds’, *International Journal of Industrial Ergonomics*, 20, 163–172.

Helbig F (2006), ‘Neue Dimensionen für funktionelle, reguläre 3D-Gewirke’, *Melliand Textilberichte*, 87, 718–720.

ISO 8996, ‘Determination of metabolic heat production’, 1990.

ISO 10551, ‘Assessment of the influence of the thermal environment using subjective judgement scales’, 1995.

ISO 11092, EN 31092, ‘Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test)’, 1993.

Mecheels J (1998), *Körper – Klima – Kleidung: Wie funktioniert unsere Kleidung?*, Berlin, Schiele & Schön.

Möhring U (2005), ‘Conductivity in innovative textiles for automotive applications’, *13th Techtextil Symposium*, Frankfurt a.M., Germany.

Möhring U, Neudeck A and Gimpel S (2005), ‘Textile innovation in the autocar by conductivity, sensory and lucent structures’, *44th International Man-Made Fibres Congress*, Dornbirn, Austria.

Thill U and Krause U (2005), ‘Absorber comfort automotive seat’, *13th Techtextil Symposium*, Frankfurt a.M., Germany.

Umbach K H (1986), ‘Physiological aspects of seat comfort’, *Symposium for Airlines and for the Aircraft Industry*, Frankfurt a.M., Germany.

Umbach K H (1999), ‘Parameters for the physiological comfort on car seats’, *38th International Man-Made Fibres Congress*, Dornbirn, Austria.

Umbach K H (2000a), ‘Physiologischer Sitzkomfort im Kfz’, *Kettenwirk-Praxis*, 34(1), 34–40.

Umbach K H (2000b), ‘Climatic comfort of car seats’, *Technical Usage Textiles*, 3(35), 34–38.

Umbach K H (2004), ‘Messung und Beurteilung des klimatischen Komforts von Kfz-Sitzen’, *Forschungskuratorium Textil e.V. Jahrestagung 2004 – Technische Textilien im Fahrzeugbau*, Eisenach, Germany.

Weiss M and Ulbrich T (2003), ‘Automobil-Sitzheizungstechnologie im Wandel’, *42nd International Man-Made Fibres Congress*, Dornbirn, Austria.

9

Smart textiles in automotive interiors

F BOUSSU, C COCHRANE, M LEWANDOWSKI and V KONCAR, ENSAIT, l'Ecole Nationale Supérieure des Arts et Industries Textiles, France

Abstract: In this chapter different smart textile structures suitable for use in car interiors are presented. One of the main interests of smart textile integration in car interiors is also related to the 'customization' trend. Designing very low weight car seats with heating fabric and achieving space saving and comfort thanks to a more breathable structure are now possible. However, only few applications can be found today involving smart textile structures comprising sensors, actuators, and computing and storage devices integrated into internal car elements. On the other side, car interiors contain a range of textile surfaces that may host textile-based sensors and actuators adapted to this specific space. They may be classified in function of the measured parameters and effects they are able to generate. This classification is given below:

- Sensors: temperature, humidity, strain, UV radiation, acceleration, light intensity, etc.
- Actuators: heating, cooling, different kinds of alert signals, flexible screens and displays, security systems, etc.

Flexible devices integrated into textile structures of a car interior could also be used as physiological sensors for various vital parameters. Heating textiles can be developed to be suitable for flexible structures as car seats, steering wheel, etc.

The potential use of shape memory alloys in car seats, so that they always have the same 'new' look, is also very interesting. Their price is currently the main problem. Nevertheless, they may be used in small quantities and mixed with traditional textile threads to achieve costs attractive for luxury cars

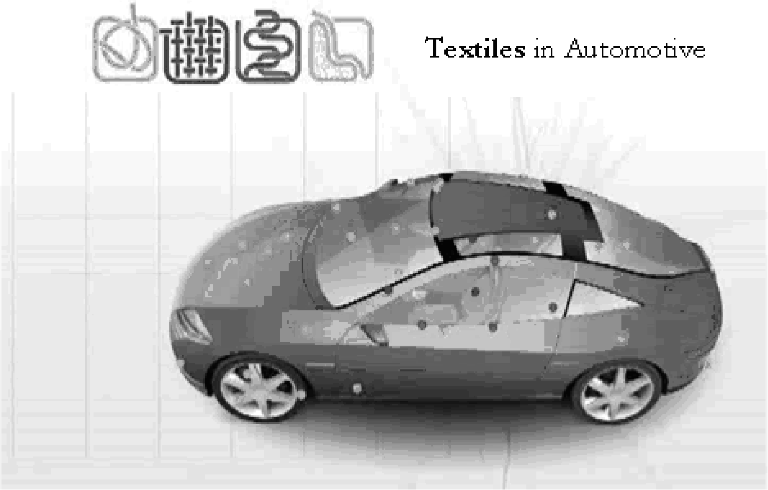
Keywords: actuators, sensors, shape memory alloys.

9.1 Introduction

9.1.1 Textile structures in car interiors

During the recent 'Futurotextiles' exhibition,[1] various car makers and most of the automotive suppliers made a brief review of the existing textile solutions used in car design and fabrication. Figure 9.1 indicates the textile parts that may be found in a car made at the present time.

- The first logo identifies non-woven parts such as: bonnet cover, fuel filter, oil filter, air filter, carpets, petrol tank, sun visor, roof panel, window shelf, silencer and driveshaft tunnel.



9.1 Textiles in automotive.

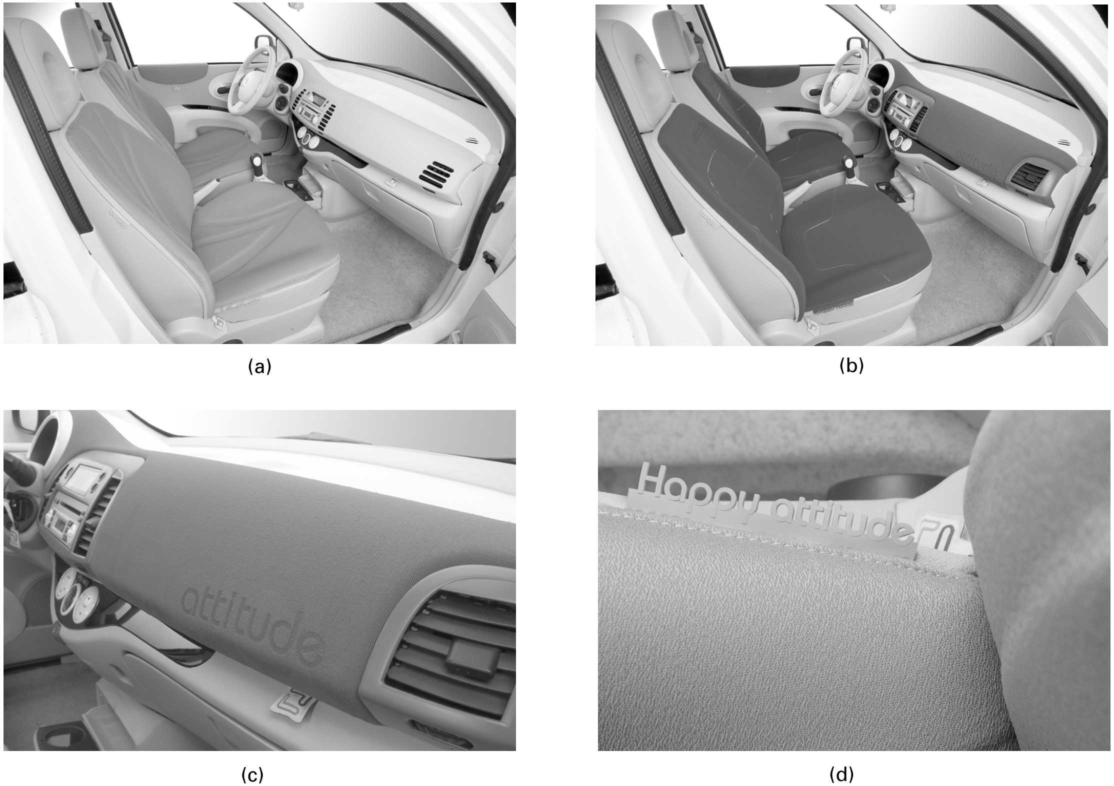
- The second logo is used to show woven parts such as: airbags, safety belts, bucket seat fabrics, convertible roof.
- The third logo indicates knitted parts such as: bucket seat covering, headrest covering and storage shelf net.
- Finally, the fourth logo is used to show composite parts such as: car body, tyres, brakes, bumpers, belts, hoses, dashboard and armrests.

Moreover, the actual bucket seat of the car can be recovered with a knitted or woven fabric, or with leather upholstery. The material used for seat recovering needs to meet several criteria. First, it must match the car interior's style and coordinate with different parts such as the dashboard and roof-panel colours. Second, there are numerous constraints resulting from the use of the bucket seat, such as: tensile strength, good drape behaviour, abrasion and pilling resistance, wet and dry resistance, UV resistance, ease of cleaning and recycling. Finally, costs must be kept as low as possible.

One of the future trends for bucket seats is 'customization' like the Happy attitude concept (see Fig. 9.2) described on the Faurecia web site (http://www.faurecia.fr/pages/happy/home.asp). Car interior themes can be swapped quickly and easily by the customer and a different theme can be chosen to match the current mood of the driver.[2]

Thanks to this new concept, the dashboard can be printed on demand and can also be made of the same textile material as the bucket seat covering. This customized material can be easily removed for cleaning.

Another future trend for bucket seats is to replace the foam by a textile material able to match various constraints such as resilience and resistance



(a) (b) (c) (d)

9.2 Faurecia Happy attitude concept.

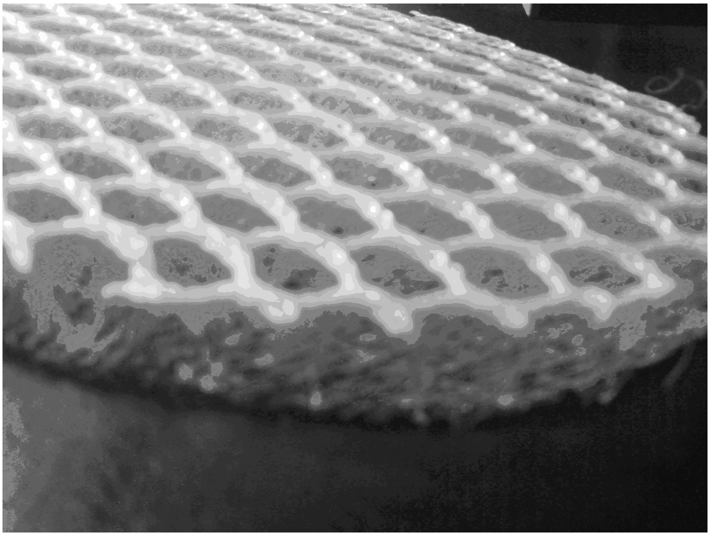
to fatigue. As a result, the chemical agents used in foam production and the different solvents used during the production process are totally avoided, which may lead to a more easily recycled material such as the Banex ™ seat[3] (see Fig. 9.3).

Banex is an automotive seat fabric that achieves the cushioning effect of springs through machine-made warp-knitting and finishing using special polyester yarns. This makes it possible to design a seat with greater weight reduction, space saving and comfort than ever before, since a single sheet of fabric provides the same elastic function as the urethane foam and springs. The ability to add an anti-bacterial treatment to the fabric is another advantage.

Another solution using leno fabric has been produced by the quantum group (www.quantum5280.com) (see Fig. 9.4). The advantages of this method are numerous, including: polyurethane foam replacement, weight reduction of the car seat, a more breathable structure and space reduction of the entire car seat.

9.3 Banex car seat solution.

9.4 Leno fabric for car seat fabric fitted for baby.



9.5 Double face warp-knitted solution.

Better ageing of a car seat can be achieved by the use of a double-face warp-knitted fabric called spacer fabric (see Fig. 9.5). This fabric, coupled with reducing the height of the foam inserted in the final car seat structure, may help achieve new functionalities such as cooling or heating, breathable performance and foam fatigue reduction.

On the other hand, only a few applications can be found involving smart textile structures comprising sensors, actuators, and computing and storage devices integrated into the car interior. This is probably due to the fact that smart textiles are relatively new, insufficiently known and mostly applied to garments. For example, a smart shirt or wearable motherboard developed in the 1990s by S. Jayaraman from GaTech, was one of the first applications of smart textiles in garments. On the other hand, it is well known that a car interior contains various textile surfaces that are possible hosting structures for sensors and actuators. As an illustration, airbags are made from textiles and, in the case of an accident, need to be controlled in a smarter way than they are at present. Car seats and carpets are very large areas that are in permanent contact with occupants and they are excellent interfaces for the integration of sensors and actuators. There are already some applications such as heated seats or sensors that detect passenger presence in order to suggest seatbelt fastening. However, in all these cases the devices are not really integrated into the textile structures, they are more or less hidden behind them.

Nevertheless, it is possible to find an example of fully integrated smart textiles in an airbag control system comprising a restraining apparatus adapted to be connected to the occupant side of an airbag.[4] This extension/retraction device is used to adjust the degree to which the restraining apparatus can be extended, and a control device directs the extension and retraction of the device. In operation, the restraining apparatus can be retracted by the extension/retraction device in response to a signal sent by the control device to limit the physical extent to which the airbag can deploy to prevent injury to a vehicle occupant adjacent to the airbag.

The aforementioned airbag control system contains sensors and actuators interconnected via the apparatus for controlling airbag deployment. Generally, sensors and actuators adapted to a car interior may be classified as a function of the values they measure and the effects they generate:

- Sensors: temperature, humidity, strain, UV radiation, acceleration, light intensity, etc.
- Actuators: heating, cooling, different kinds of alert signals, flexible screens and displays, security systems actions, etc.

Different applications of smart fabrics inside the car seat can be envisaged[5] for discriminating between adult and child occupants and being able to make safety adjustments to the actual load to be supported by seatbelt actuators during an accident. From an aesthetical point of view, smart fabrics can be inserted in the car interior to improve illumination and replace the present switch systems.

Smart textile systems are defined in a more structured way in the following sections.

9.1.2 Smart textiles

The term 'smart textile' describes a class of apparel that has active functions in addition to the traditional properties of clothing. These novel functions or properties are obtained by utilizing special textiles or electronic devices, or a combination of the two. Thus, a sweater that changes colour under the effect of heat could be regarded as a smart textile.

Finally, all smart textiles can operate in manual or automatic mode. In the case of manual operation, the person who uses the textile can trigger these additional, intelligent functions, while in automatic mode the textile structure can react autonomously to external environmental parameters (temperature, humidity, light, etc.).

The informal taxonomy proposed by Swallow and Thompson[5] may help to define the combinations available by considering the association of different components of a smart fabric, such as being active or passive, sensor or effector.

9.2 Technical elements enabling the production of smart textiles

In this section, the building blocks for integration into smart textile structures are further described.

9.2.1 Peripherals

The main peripherals usually found in smart textiles are mentioned and briefly analyzed in the next few paragraphs.

9.2.2 Control interfaces – near the 'human interfaces'

The use of textiles in a car interior as supports for control interfaces is interesting because the control interfaces can then be close to the appropriate parts of the body.

In contrast to certain miniaturized communication devices, textile surfaces in a car interior have a greater surface area, which enables them to offer more functionality. For example, the small keyboard of a mobile phone that fits in the palm of one's hand becomes much more readable when transposed to the surface of a piece of fabric that is three times larger. New properties guaranteeing resistance to use and to washing should also be taken into account.

9.2.3 Sensors

Car interior textiles could be used to detect different actions, in particular recognizing the posture of the driver and passengers and their gestures, in order to facilitate certain commands that are intuitive or to adapt and prepare security systems such as airbag deployment or seat belt pretensioning and positioning. Moreover, when these sensors are connected to computing facilities and the control unit, they may allow the recognition of a situation and its context for a better interpretation of reality.

Sensors integrated into the textile structures of car interiors could also be used as physiological sensors for various parameters. This term refers to the sensors used to record the health or personal parameters of a driver and passengers in a broad sense and to raise an alert if necessary. The applications arising from the use of these sensors are numerous. We can, for example, use sensors to provide a physical performance analysis of a car driver or even a racing car driver, or to conduct a medical check-up for passengers in real time.

9.2.4 Interfaces for displaying information and actuators

For many applications, it is necessary to display or reproduce the information supplied by the communication systems that are integrated into a car interior's textile structures. Therefore traditional interfaces, such as displays, screens and loudspeakers, have to satisfy the same ergonomic and mechanical resistance criteria as those quoted for control interfaces. For example, the current characteristics of colour liquid crystal displays, rigidity, weight and power consumption, have to be adapted. Solutions such as micro-screens embedded in glasses and the use of technologies including flexible supports, such as flexible displays and optical fibres, have begun to appear.

In addition, the proximity of these textile structures to the natural human senses opens up new possibilities for the transmission of information. Visual and auditory ways of collecting information (such as screens and loudspeakers), which at present are largely developed the way they are because they do not require direct contact with the user, could soon be joined by tactile and olfactory methods. The seat fabric that changes the environment by diffusing a combination of perfumes is about to leave the realm of science fiction.

9.2.5 Data processing

The hardware elements of memory, computation and data processing (RAM, hard disks and processors) will certainly not evolve much in the short term unless they do so in the direction of miniaturization. Even if progress is made on developing flexible substrates, they remain fragile and require partly rigid protection in order to be integrated into smart textile structures. However, their integration has become entirely possible, as seen by the incorporation of a micro PC into the loop of a belt. It is also conceivable that only a small quantity of information would need to be processed locally in smart textiles, and that more complex functions and more significant memory requirements could be handled by higher-powered remote servers. This difference between local and remote processing requires the development of specific algorithms, as for the case of intelligent vehicles.

9.2.6 Connectors

Connection problems are another major issue for state-of-the-art smart textiles. The principal question is how to transport information and energy among the various components of the electronic system with optimal efficiency. The concepts of weight distribution and ergonomics must be taken into account in distributing the different components around various parts of the vehicle.

In addition, it would seem to be an advantage to have only one energy source distributing power to the disparate electronic interfaces, thus allowing better energy management. On the other hand, each electronic interface could have its own computation and storage capacities, which would allow resources to be allocated and weight to be distributed in a better way.

It is important to examine the problem of control and the centralization of information distribution. In fact, to be able to manage all of the functions of a complex communicating device, it is necessary to combine output control and information input on a single interface. This means that accessing emails or directions on a map web site, for example, must be done on a single screen.

9.2.7 Energy

Energy autonomy is still a major handicap for the majority of mobile electronic devices. Many users of wireless devices have no doubt dreamt of never having to recharge their mobile phones. Even if electronic circuits now require increasingly less power, new features keep being developed and create an additional need for energy (a larger screen size implies a need for greater power consumption).

An interesting alternative seems to be the use of renewable energy sources. Solar energy and wind are relatively difficult to adapt for use with vehicles because they require large surface areas to be truly effective. On the other hand, many studies have been carried out on techniques that will make it possible to recover the energy released by vehicle movement.

9.3 Textile sensors

9.3.1 Conductive composite

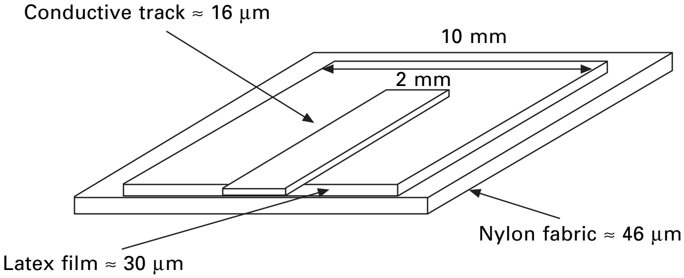
A sensor based on a thermoplastic elastomer (Evoprene)/carbon black nanoparticle composite has been developed during this study. This sensor displays general mechanical properties that are strongly compatible with any flexible and soft material such as a textile structure and offers great potential for use in car interiors.

To improve the precision and reliability of a sensor, it is important to know the influence of external parameters such as rate of strain deformation, temperature and humidity on the sensor's response and on its mechanical behaviour.

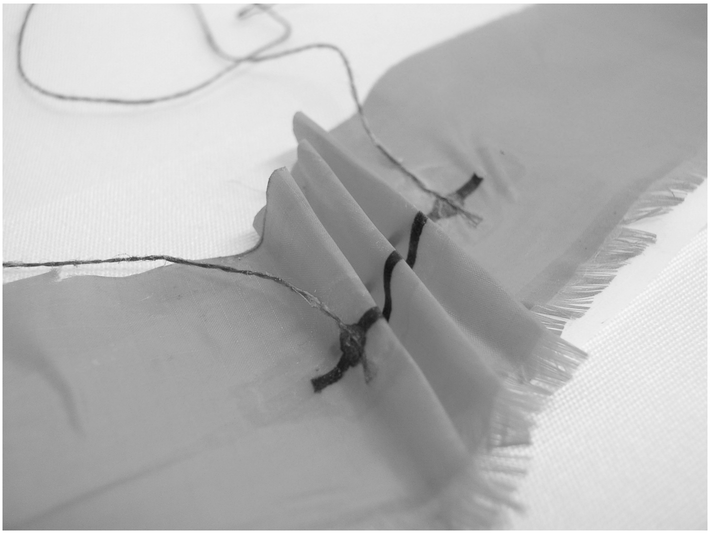
The design and calibration of the sensor on a nylon fabric have been demonstrated in previous papers.[6,7] This present study will describe more particularly the behaviour of the sensor in various climatic conditions of different temperatures and relative humidity, as well as some results on the sensor's response at different strain rates.

Full details of the sensor's fabrication and optimization can be found in our previous work.[7] The conductive polymer composite that the sensor material is made from is prepared via a solvent process. Carbon black particles (Printex L6, from Degussa) are dispersed with a thermoplastic elastomer (Evoprene 007 from Alpha Gary, which is a Styrene-Butadiene-Styrene (SBS) co-polymer) in chloroform (Aldrich). After mixing for the necessary time at 55°C, the blend obtained is applied as a coating on the textile substrate and left to dry at room temperature. The final concentration of carbon black filler particles in the Evoprene polymer matrix is 27.6 vol.%, after total evaporation of the chloroform solvent. This concentration is greater than the percolation threshold so that there is a good conducting network throughout the composite. Finally, a protective latex film is applied on the sensor. Figure 9.6 shows schematically the dimensions of the sensor on the fabric, which is a light nylon fabric with a mass per unit area of 42 g.m^2. The linear density of the weft and warp yarns is equal to 3.3 tex.

The complete sensor system (conductive polymer composite + latex film) has the following dimensions: 10 mm wide, 110 mm long and only 46 µm thick. The sensor track is parallel to the weft direction of the fabric (sample dimensions: 50 mm × 300 mm). Stainless steel yarns, used as electrical



9.6 Schematic representation of the structure and dimensions of the sensor integrated on the fabric.



9.7 Set-up of sensor on fabric, with electrical connections.

connections, are added at the ends of the sensor track in order to measure its electrical response (Fig. 9.7).

9.3.2 Experimental results

Tensile characterization

The sample was set up on a tensile testing machine (MTS 2/M), with the sensor track positioned parallel to the direction of fabric extension and at the centre of the test specimen (fabric test length = 200 mm). Different rates of extension, 16, 200 and 500 mm/min, were applied to different samples, and the electrical resistance of the sensor was recorded during elongation until the sample broke. Since the different sensor specimens will necessarily present slight variations in their intrinsic resistance values, a normalized relative electrical resistivity is defined to characterize the sensor's electrical property:

$$Rr = \frac{(R - R_i)}{R_i} \Delta R/R \qquad 9.1$$

where R_i is the initial resistance of the sensor measured before extension, and R the resistance at a certain length l of the sample. The sample was left at rest for about 1 minute before beginning the test, and R_i represents the mean value of resistance measured during this lapse of time. The electrical resistance was measured until the fabric broke up, which occurred at around

45% elongation. In general textile applications such as weaving, the elongation zone of interest is within the 0 to 10% range. An example of the electrical behaviour of the sensor in this zone is given in Fig. 9.8.

To be able to compare our gauge sensitivity to existing strain gauges, a first assumption of a linear variation was made. In this case, the gauge factor (K) is defined as follows:

$$K = (\Delta R/R)/\varepsilon \qquad 9.2$$

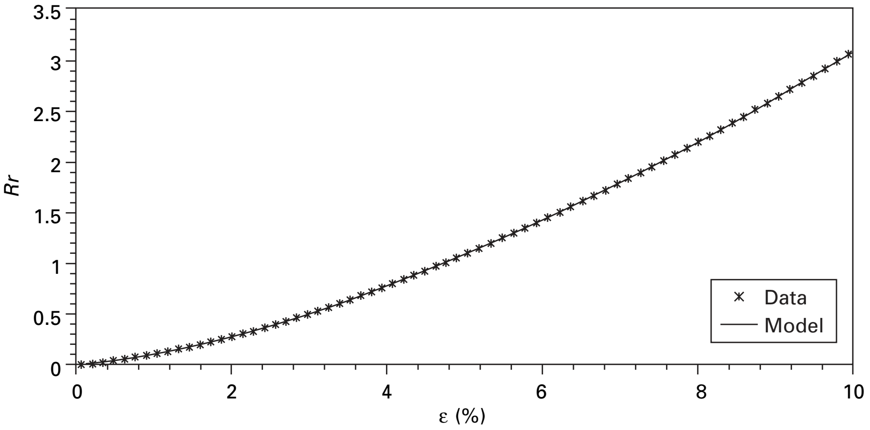
In the elongation range (0–10%), K is greater than 30. In comparison, the coefficient K of a classic metal gauge (copper-nickel) is 2.1. Moreover, a classic metal gauge has a range of elongation between 0.1 and 0.5%.[8]

The linear relationship (Eq. 9.2) applied to our sensor is, however, not very satisfying. In fact, the electro-mechanical behaviour of the sensor can be better modelled by the following equation:

$$\Delta R/R = a\varepsilon^b \qquad 9.3$$

where a represents the sensitivity of the sensor, while b relates to the deviation from the linear model, in which for the ideal case $b = 1$ and $a = K$.

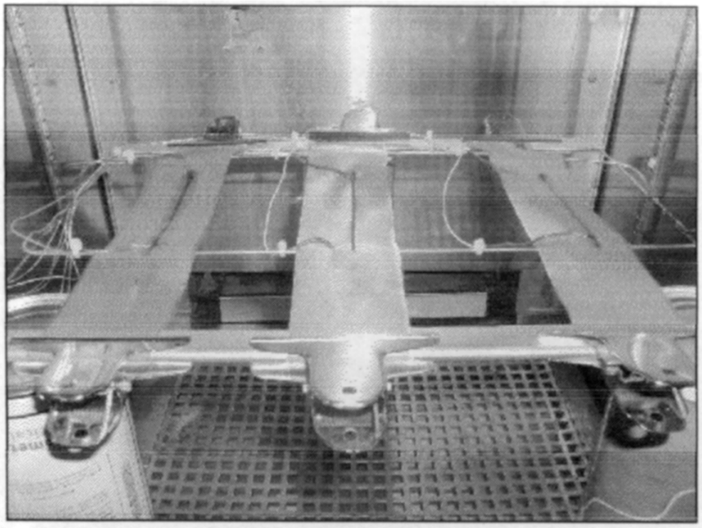
The good fitting of this model is illustrated on Fig. 9.8 by the solid line. In this case, $a = 99.9$ and $b = 1.51$. The two parameters depend not only on the intrinsic characteristics of the sensor (initial resistance, length to width ratio, composite quality, etc.), but also on the elongation rate. Table 9.1 gives the values of a and b obtained at other rates of deformation. In all cases, there is a good match between the experimental data and the model (Eq. 9.3).



9.8 Dependence of relative electrical resistivity of sensor on elongation ε, at an extension rate of 16 mm/min.

Table 9.1 Elongation rates

	Elongation rate (mm/min)		
	16	200	500
a	99.9	200.8	264.2
b	1.51	1.69	1.79



9.9 Set-up of samples in climatic chamber.

Influence of climatic conditions

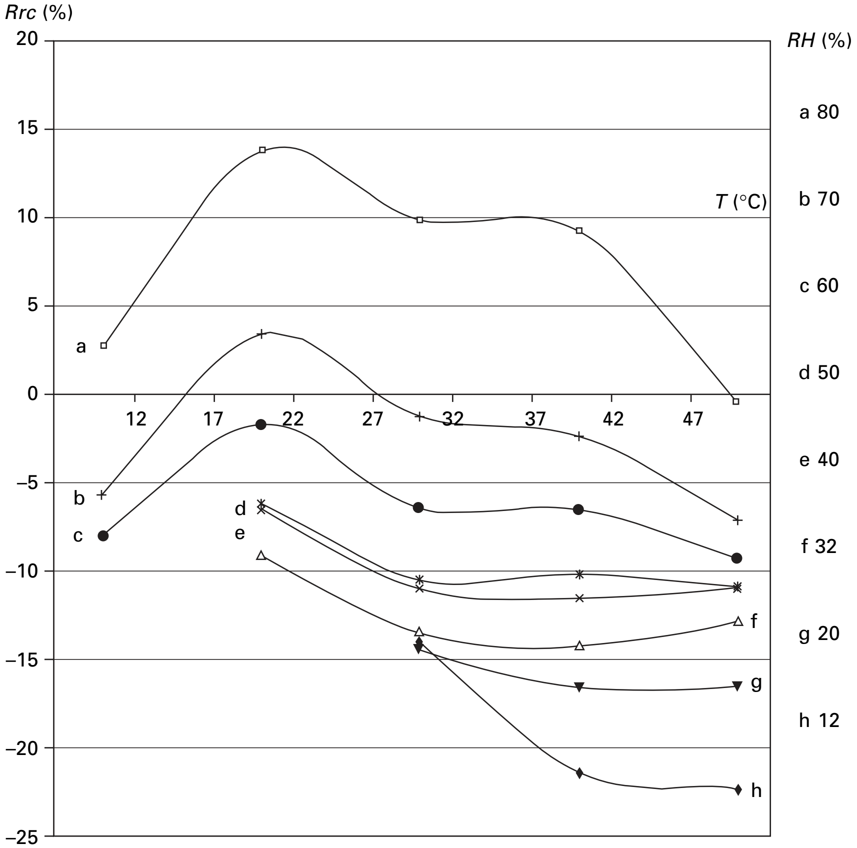
This investigation is carried out with a climatic chamber (Excal 2221-HA, Climats®). The samples, mounted on a metallic grid, are placed at the centre of the chamber (Fig. 9.9). The electrical resistance R of each sensor is recorded by an ohmmeter during the experiment.

With the aim of separately studying the two parameters, temperature T and relative humidity RH, two types of test are performed in which one of the parameters is kept constant while the other undergoes a cycle. In the iso-humidity cycle, RH is kept constant, and T is increased from 10 to 50°C and decreased back to 50°C, in successive 10°C steps. At each step, the temperature is kept constant for a period of 150 minutes, during which time the resistance of the sensor is recorded. In the isothermal cycles, T is kept constant while RH undergoes a cycle from 20 to 90% in incremental steps of 10%, again with a 150 min equilibrium time for each step. At the beginning of each cycle, a reference value of electrical resistance R_0 is measured at 20°C/40%RH. As in the electromechanical characterization (Eq. 9.1), the resistance is expressed as a normalized relative resistance Rrc:

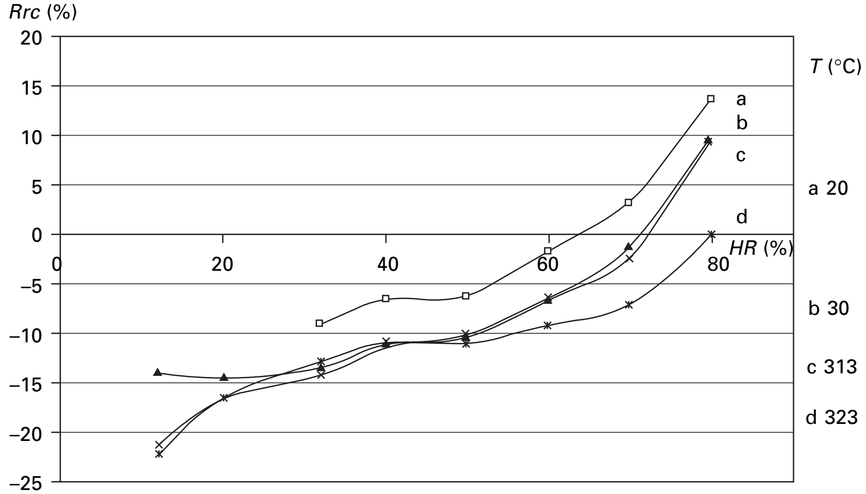
$$Rrc = \frac{(R - R_0)}{R_0} \qquad 9.4$$

For each cycle experiment, two values of *Rrc* are measured for each *T*/*RH* pair, one during the upward direction, and the second during the downward direction of the cycle. It was found that there was little difference between the two values, so to illustrate the results, a mean value was calculated. The results of the iso-humidity cycles are given in Fig. 9.10, and those of the isothermal cycles are given in Fig. 9.11.

In Fig. 9.10, the curves can be divided in two categories. For $RH < 60\%$, similar curves are obtained: relative resistance first decreases and reaches a constant value when *T* increases. For $RH = 60\%$, *Rrc* undergoes different variations when *T* increases. In all cases, for constant *RH*, the variations



9.10 Iso-humidity cycles for temperature varying between 10 and 50°C.



9.11 Isothermal cycles for RH varying between 20°C and 50°C.

nevertheless remain relatively low, since ΔRrc is at a maximum of 9% for the curve 80% *RH*.

It is remarkable and unusual that the electrical resistance decreases when *T* increases for this type of conductor, carbon black, which displays a metallic-like conduction.[9] However, although carbon behaves in a 'metallic' way when conducting electricity in the sensor, the carbon particles are surrounded by a polymer matrix, which is an insulator. *RH* and *T* probably have an impact on the molecular arrangement in the polymer, leading to a modification in the arrangement of the conductive carbon particles.

With regard to the isothermal curves (Fig 9.11), the same behaviour is obtained at all temperatures. *Rrc* increases with *RH*, with a somewhat sharper dependence for *RH* lower than 35% (sensitivity around 0.5%/%*RH*) and higher than 55% (sensitivity around 1.2%/%*RH*). In between these two values, the resistance does not vary much, and the sensor sensitivity amounts to only 0.2%/%*RH*. There are very few studies found in the literature on the influence of humidity on conductive polymer resistance. The only study is about sensors used to measure hygrometry and in that particular application, the electrical resistance varies linearly with *RH*.[10,11]

The increase in resistance with *RH* can be attributed to the absorption of water molecules by the carbon particles. These particles have a complex structure and generally are in an agglomerated form in the composite, hence presenting a porous network with numerous pores which are accessible to water molecules by capillarity. The absorption of these water molecules may lead to an 'un-percolation' of the conducting network of carbon particles, leading to a loss in conductivity of the system.

The sensitivity of carbon black particles to moisture is confirmed in Fig. 9.12.

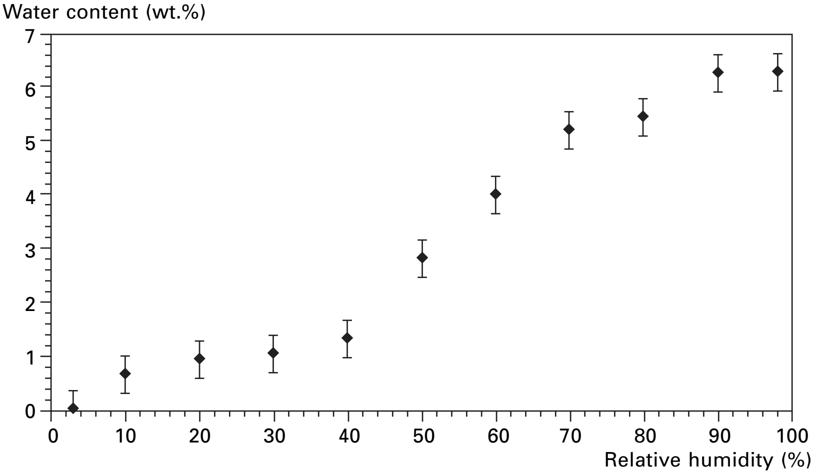
The study of water content in the particles at different *RH* shows the same behaviour as observed in Fig. 9.11: at about the same value of relative humidity (40–50%), there is a sharp increase in water absorption in carbon particles, and resistivity can be observed in the sensor.

9.3.3 Conclusion

The electrical conduction of insulating polymers charged with conductive particles inducing a metallic behaviour (see *I/V* curve) is due only to physical phenomena. If the number of conductive particles is significant (concentration above percolation threshold), the conductive network is continuous, guaranteeing electric conduction.

In order to create a sufficiently sensitive sensor, the conductive particle concentration has to be higher than the percolation rate. Indeed, when the composite undergoes a strain deformation, the number of electrical contacts between particles will decrease, and the number of contacts has to remain high so as not to affect the general electrical conductivity. A fall in the number of 'electrical contacts' or 'conductive paths' (and thus an increase in electrical resistance) can also result from temperature and/or moisture. This sensitivity to these parameters could possibly lead to the use of this material as a moisture and/or temperature sensor.

The results regarding electrical and mechanical characteristics are encouraging. Below a 10% strain, the sensitivity of the textile-based sensor is 14 times higher than that of traditional metal gauges. However, the sensor response is dependent on the strain rate, and thus it has to be calibrated



9.12 Water content in carbon black particles at different *RH* (*T* = 80°C).

according to the strain rate found in the envisaged application. The conductive composite is also rather sensitive to moisture and temperature. Calibration curves can be plotted to correct the data according to these two climatic parameters. More measurements and tests have to be carried out in order to optimize and improve our textile sensor's properties with regard to the function of their application.

9.4 Textile actuators

9.4.1 Heating fabrics for car interior

Heating textiles can find applications in numerous and varied fields such as sports and leisure, medical, or automotive.[12–14] Non-textile conventional sensors and actuators based on wire heating technologies exist that may be integrated into textile structures, but they are often not appropriate because of their rigidity and cost. The situation is even more complex with actuators because they need large power supplies that are rarely flexible and lightweight.

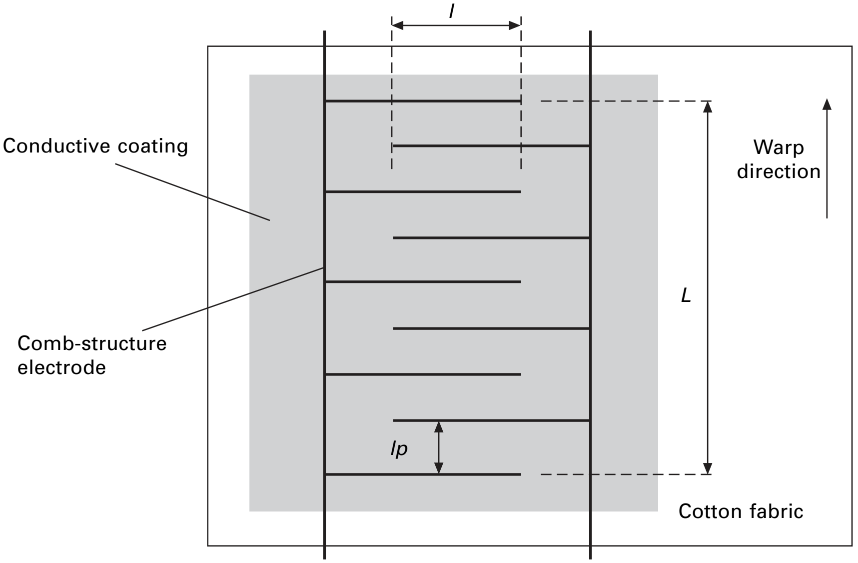
The heating element developed and presented in this work is designed specifically to be suitable for flexible structures. It comprises a plane woven textile element in which are integrated electrodes composed of metallic yarns, woven or stranded directly in the fabric in a comb architecture arrangement. These electrodes are connected to a power supply. In order to ensure a uniform heat distribution, a thin conductive coating is applied on the fabric surface and electrode arrangement. The coating is based on a conductive polymer composite consisting of synthetic rubber and conductive carbon black nano-particles. The heating element can thus be shaped in any desired pattern by choosing specific dimensions for the electrode structure and the area of the coating layer. Moreover, the whole assembly can be placed in selected areas, depending on the application.

The electrical resistance of the heating element (electrodes and conductive coating, Fig. 9.13) can be calculated. The two stainless steel yarns parallel to the warp direction are used to supply the power that is necessary to heat the fabric and also create – together with the stainless steel yarns on the weft direction – a comb structure. This comb structure electrode design is made to create a parallel resistance (decreases the resistance).

Taking into account that the element is composed of a number of parallel resistances, and the distance between the comb teeth is constant:

$$\text{Number of parallel resistances} = \frac{L}{lp}$$

with L: conductive coating width
lp: distance between two adjacent teeth



9.13 Pattern of heating element.

The total resistance is thus: $R_{\text{tot}} = \dfrac{R}{L/lp} = \dfrac{\rho \times lp/S}{L/lp} = \dfrac{\rho \times lp^2}{LS}$

where l: comb teeth superposition width
S: coating cross-section area= l/e, e is the coating thickness
ρ: coating resistivity

The coating resistivity depends on the amount of carbon black loading in the composite. It can be predicted by the following relation:

$$\rho = \rho 0\ (V - Cp) - t$$

where $\rho 0$: constant
V: vol.% of carbon black
t: critical index
Cp: concentration of carbon black (vol.%) at percolation threshold.

Experimental: design of textile heating element

The textile fabric was made on a hand weaving machine (ARM, electronic control Selectron). A plain weave was chosen, and the warp and weft were made of cotton yarns with warp and weft densities of 27 yarns/cm and 10 yarns/cm, respectively. For the electrodes, stainless steel 2-ply yarns (Créafibres, France) were used, each ply consisting of 275 filaments. The overall yarn count was 500 tex, with a resistivity of 14 ohms/m. The distance between the teeth of the comb (*lp*, Fig. 9.13) was 0.7 cm, while the distance between the two parallel steel yarns in the warp direction was around 7 cm. The steel yarns were introduced manually during the weaving process according to the pattern in Fig. 9.13.

The conductive carbon black coating composite was made with the following ingredients:

- a synthetic rubber latex solution, Kraton IR-401 (Kraton Polymers), an anionic dispersion of polyisoprene
- a dispersing agent, Disperbyk-2010 (from SPCI)
- carbon black (CB) particles, Printex L6, from Degussa (Table 9.2).

The preparation procedure was as follows: the dispersing agent was put into water and the CB particles were gradually added while mixing continuously. A paste was obtained and left to rest for some time. The polymer was finally added while mixing gently in order to avoid a too strong shearing.

The coating was then applied on the fabric using a magnetic coating table equipped with a magnetic bar as a scraper. The thickness of the coating was, however, hard to adjust with this technique. Moreover, the quantity of coating deposited depended on the viscosity of the solution, which itself depended on the amount of water in the coating solution. If the viscosity was different, even if the same thickness was deposited on the fabric, the final quantity of composite would differ, since the absorption of the coating would be different. Hence, the final resistance would also be different. After drying at room temperature, the resistance of the actuator was measured with an ohmmeter, and was found to be equal to 12 ohm. The fabric with the electrodes is shown in Fig. 9.14, before and after the application of conductive coating. The final coated surface is approximately 5 × 7 cm.

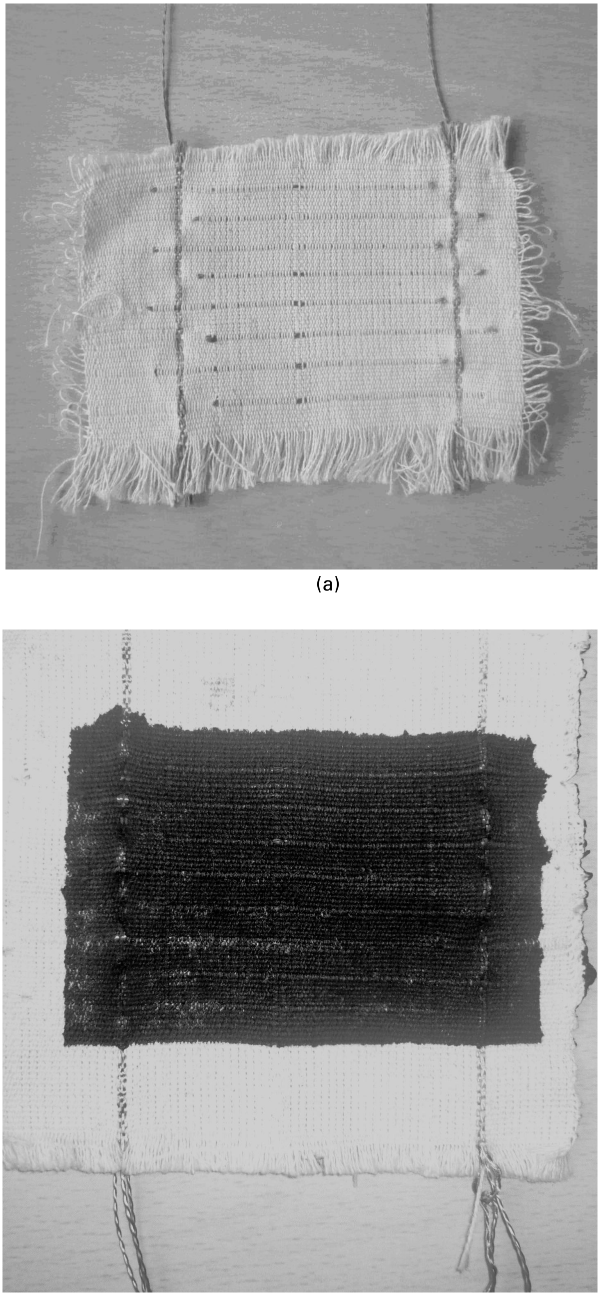
Characterization of textile heating element

The electrical and heating properties of the element were studied. The electrical resistance of 3 × 3 cm coated samples with various carbon black contents was measured (Fig. 9.15). It was found to depend, of course, on the CB loading level: the higher the amount of CB, the lower the resistance.

The optimum CB loading is thus around 35 to 45% in weight. A coating containing 37.5 wt.% was used for the heating property study.

Table 9.2 Characteristics of carbon black particles

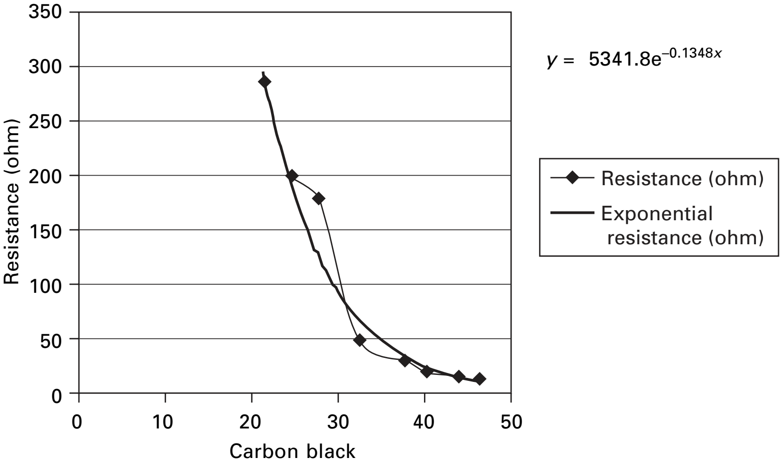
Particle average diameter (nm)	Structure (DBPA number)	Specific surface area (m^2/g)	Volatiles (%)
18	122	250	<1



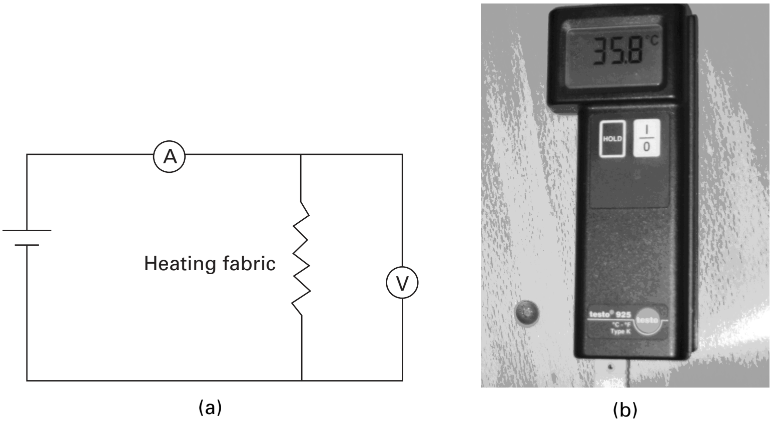
(a)

(b)

9.14 Fabric with heating element: before and after coating with conductive composite.

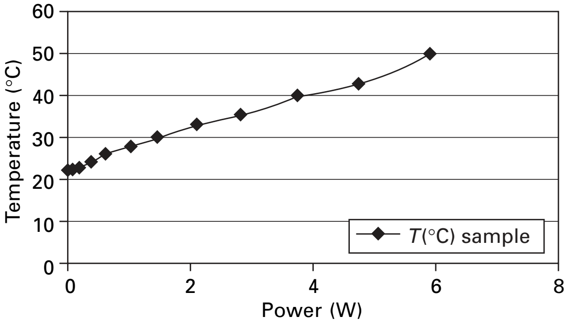


9.15 Variation of electrical resistance with carbon black content.



9.16 Power circuit with fabric heating element, and temperature sensor.

The coated fabric was connected to an ammeter and a power supply as shown in Fig. 9.16. It is important to note that the sample temperature may change as a function of time even when applying the same voltage. Because of this, the temperature of each sample was measured for 60–80 min for a given voltage. The temperature of the sample surface was recorded every five minutes with a temperature sensor (Testo® 925). The temperature was not the same for every point of the heating element, and the highest temperature was obtained at the centre of the sample, but the variation was not very important.



9.17 Temperature of heating fabric as a function of power supply.

The results are presented graphically in Fig. 9.17. The measurements were made at room temperature (22°C).

The increase in temperature was significant, about 30°C from an initial temperature of 22°C, for the highest power supply (6 W). The heating process was found to be quite rapid; the time taken to reach the highest temperature was about 10 minutes.

Conclusion

An increase in heating efficiency requires quite a large percentage of carbon black, more than 35 wt.%. It was found that the temperature was not homogeneous over the whole coated surface, the sample being hotter at the centre than at the corners. Therefore this characteristic has to be improved, maybe by modifying the pattern design of the electrodes. The heating was, moreover, limited to the coated area; it is possible that the use of intelligent design could result in the dissipation of the excess heat generated to other parts of the fabric.

After being coated with the CB solution, the woven samples became quite rigid. Other studies therefore need to be done to obtain a more flexible final structure, and our next work will be on knitted structures.[15] The steel yarns will be integrated inside the knitted fabric and, as this type of textile structure is intrinsically more deformable that woven structures, the final heating element will normally be more flexible.

9.4.2 Shape memory alloys for car seats

Introduction

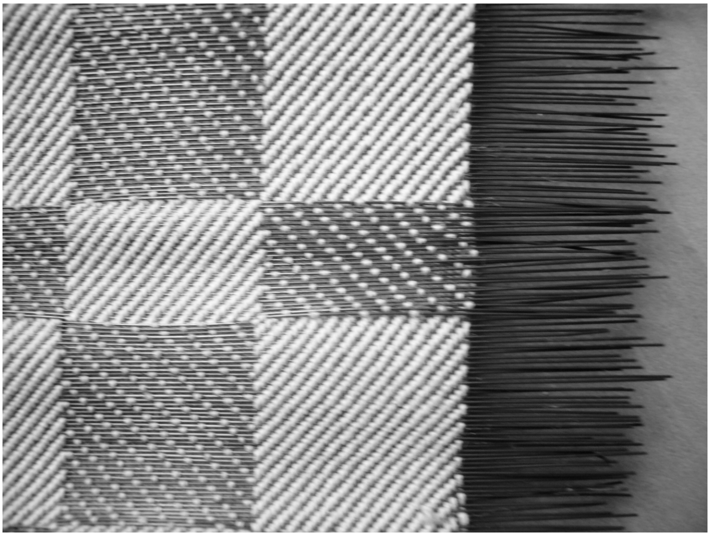
The existing solutions presented in Section 9.1 do not fit all the requirements and future functionalities that need to be integrated inside car seat fabric.

Therefore, a research team based in the GEMTEX laboratory has attempted to develop a new fabric which could combine attractive fabric patterns with properties such as: stab resistance, high buckling resistance[16] and smooth heating of the car seat. The proposed solution is a woven structure with Nitinol (made of nickel and titanium) yarns of 0.25 mm diameter included in the weft direction (Fig. 9.18). This particular yarn is a shape memory alloy wire which has the notable property of being super elastic which allows it to be subjected to greater buckling than a conventional alloy such as steel (Fig. 9.19).[17]

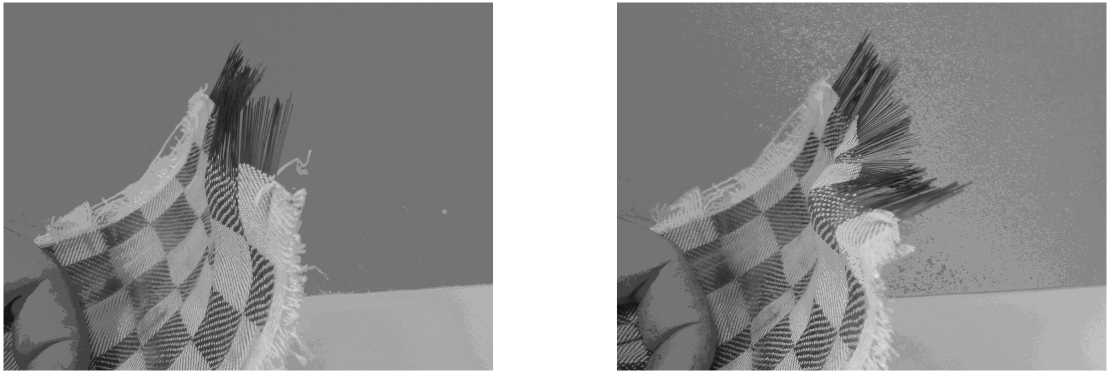
Experimental

The main advantage in the future of using SMA wires inside the fabric could be controlled buckling as its elastic property increases with a particular applied temperature when close to the human body but it becomes more rigid under a different temperature. To illustrate this change of fabric shape under different temperatures, the sample has been educated to be flat at ambient temperature and bent during heating.

An interesting possibility for this fabric could be the design of 'moving' parts to ensure a surface motion which could help to avoid the inclination to sleep while driving.

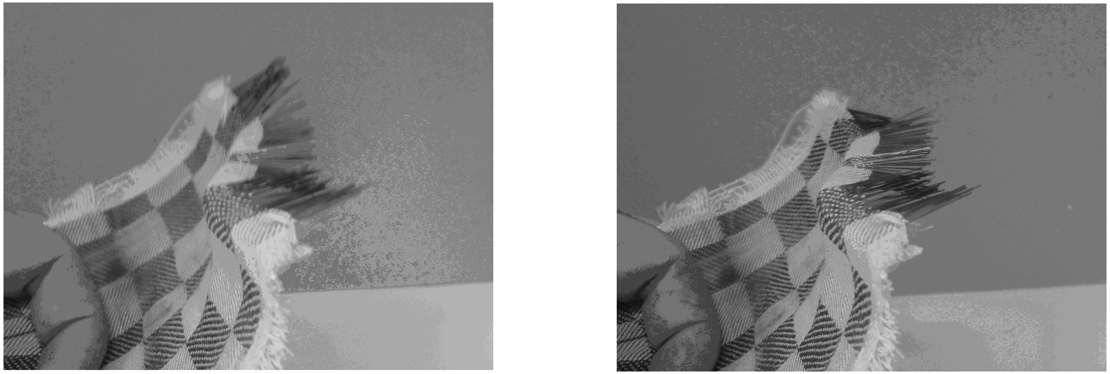


9.18 View of the fabric made of polyamide yarns in the warp direction and SMA Nitinol yarn in the weft direction.



SMA fabric at 20°C

SMA fabric at 30°C



SMA fabric at 40°C

SMA fabric at 50°C

9.19 Shape memory alloy behaviour.

9.5 Conclusions

Different building blocks (sensors and actuators) have been presented in order to show the development and integration possibilities of smart textile structures designed for car interiors. Sensors based on conductive composites may be used to detect fabric lengthening or passenger presence, or to evaluate seat belt ageing. They may also be used to control air bag deployment as shown in the patent of Mr Jayaraman. Alternatively, heating fabrics are suitable for car seats. The advantage of our solution is that it is low cost, and has a long lifetime and is particularly reliable. The other advantage is that the same actuator may be used as a sensor, helping with temperature control and regulation.

The potential use of shape memory alloys in car seats, so that they always have the same 'new' look, is also very interesting. Their price is currently the main problem. Nevertheless, they may be used in small quantities and mixed with traditional textile threads to achieve costs attractive for luxury cars.

9.6 References

1. 'Futurotextiles': an exhibition on innovating textiles, lille3000: international cultural event http://lille3000.ensait.fr, Lille, France, 14 October 2006 to 14 January 2007.
2. Habert Cédric, The 'Happy attitude' concept, *Decautex conference Texile and Plastics: Innovation for automotive interior decoration*, Faurecia Interior Systems, Mulhouse, 30 November–1 December 2006.
3. Kawashima Textile MFG, 39th Tokyo Motor Show 2005.
4. Jayaraman *et al.*, Method and apparatus for controlling air bag deployment, US Patent 6,254,130 B1, Jul. 3, 2001.
5. Swallow S., Thompson A.P., *Applications for woven electrical fabrics*, Part IV Applications, Chapter 25, Intelligent textiles and clothing, Woodhead Publishing, 2005.
6. Cochrane C., Koncar V., Lewandowski M., Dufour C., 'Design and development of a flexible strain sensor for textile structures based on a conductive polymer composite', *Sensors*, 2007 **7** 473–92.
7. Cochrane C., Koncar V., Dufour C., 'Création d'un capteur d'allongement souple, compatible textile', *Matériaux 2006 Conference*, November 13–17, Dijon, France, 2006.
8. Asch G., *Les capteurs en instrumentation industrielle*, 5th edition, Dunod, Paris, 2000.
9. Cochrane C., Koncar V., Dufour C., 'Nanocomposite material sensors for textiles', *AUTEX 2006 World Textile Conference*, June 11–14, Raleigh, NC, USA, 2006.
10. Barkauskas J., 'Investigation of conductometric humidity sensors', *Talanta*, 1997 **44** 1107–12.
11. Barkauskas J., Vinslovaite A., 'Investigation of electroconductive films composed of polyvinyl alcohol and graphitized carbon black', *Materials Research Bulletin*, 2003 **38** 1437–47.
12. Droval G., Glouannec P., Feller J.F., Salagnac P., 'Simulation of electrical and thermal

behaviour of conductive polymer composites heating elements', *Journal of thermophysics and heat transfer*, 2005 **19** (3) 375–81.

13. El-Trantawy F., Kamada K., Ohnabe H. 'In situ network structure, electrical and thermal properties of conductive epoxy resin-carbon black composites for electrical heater applications', *Materials Letters*, 2002 **56** 112–26.
14. Kirkpatrick S., 'Percolation and conduction', *Reviews of Modern Physics*, 1973 **45** (4) 574–88.
15. Lewandowski M., Koncar V., Cochrane C., Giraud S., 'Electro-conductive heating textile elements based on a carbon black conductive polymer composite', *Intelligent Textiles & Mass Customisation International Conference*, Casablanca, Morocco, Nov. 2007.
16. Boussu F., 'Shape memory alloys used in fabrics for car seats', *2nd NEST conference Smart and intelligent materials*, Gothenburg, Sweden, 22–23 February 2007.
17. Boussu F., *Development of Shape Memory Alloy Fabrics for Composite Structure*, Part II Shape memory materials, Chapter 8, Intelligent textiles and clothing, Woodhead Publishing, 2005.

10

Reducing noise in automotive interiors

J Y CHEN, Louisiana State University Agricultural
Center, USA

Abstract: Noise reduction is a big issue involved in the design and production of vehicle interior parts. This chapter focuses on the principles of noise control and engineering approaches for vehicle noise reduction using acoustic textile materials. Noise sources and noise paths in vehicles are first discussed. Mechanisms of textile materials for noise absorption and noise insulation in vehicle interiors are analyzed. Various noise control methods using different types of acoustic textile materials are illustrated by exhibiting some typical application cases. Finally, future trends in the new surface vehicle design and production are addressed, including new material requirements, novelty interior structures, and highly integrated acoustical interior systems.

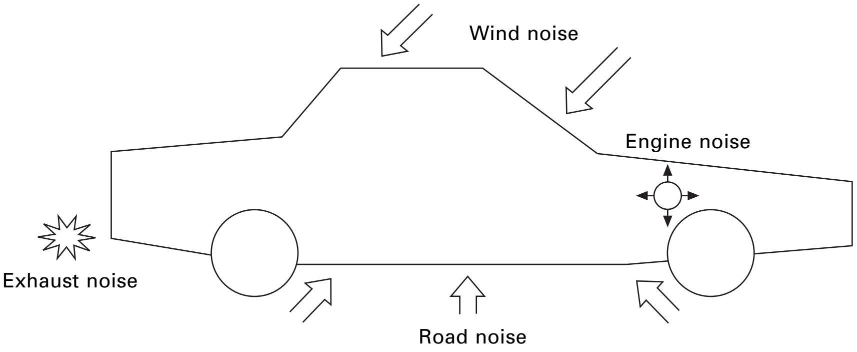
Key words: automotive interior, acoustical material, textile material, nonwoven composite, vehicle noise, noise absorption, noise insulation, transmission loss, normal incidence noise wave, sound impedance tube, reverberant rooms.

10.1 Causes of noise generation in moving vehicles

10.1.1 Noise sources

The generation of vehicle interior noise comes from many sources (Fig. 10.1). These sources can be categorized into three types: vehicle noise sources such as engine noise, intake noise, exhaust noise, and brake noise; road and wind (aerodynamic) noise sources; and miscellaneous noise sources such as the noises of squeak, rattle, and tizz from interior components and ancillaries that are usually difficult to predict in many cases. These noise sources are briefly described below (Harrison, 2004).

Engine noise is a combination of combustion noise and mechanical noise. Combustion noise derives from fuel ignition in the cylinders that produce gas forces to move pistons. As a result, engine structure vibrates and radiates noise. For diesel engines, the combustion noise dominates the engine noise. During the conversion of gas forces into mechanical forces by a crank system composed of pistons, conrods, crankshaft, and bearings, the engine structure reacts to the crank movement and generates mechanical noise. For gasoline engines, the mechanical noise is the most significant contributor to the engine noise. When an engine runs, oxygen is supplied and combusted fuel is emitted



10.1 Vehicle noise sources.

during each piston stroke in a cylinder. Intake noise and exhaust noise occur in association with the vibration of the sucked air flow and exhausted gas flow. In addition, the engine timing drive, valve train, and fuel injection device also produce some levels of mechanical noise.

Brake noise is generated by the friction between pads and rotor disks. The type of brake noise depends on vehicle speed. At high speeds, brake squeal occurs within a noise frequency range well above 1000 Hz. All brake components (the disk, pads, and calliper assembly) contribute to this noise radiation. At moderate speeds, brake moan occurs with a noise frequency level around 100 Hz. Brake creep-groan happens at speeds less than walking pace and the noise frequency is also around 100 Hz. The brake noise with a frequency around 10 Hz is called brake judder. It also occurs when the vehicle speed is below walking pace. During the start-stop transition of a moving vehicle, the vehicle itself vibrates as a resonant system to develop those low-frequency brake noise sources.

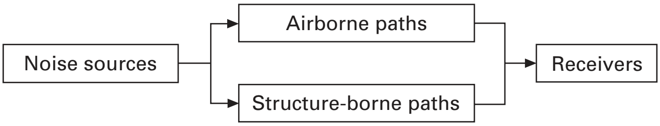
The contact and friction between the tires and road generates road noise. The road noise becomes interior noise when it is transmitted to the interior by an interaction with vehicle structure. Auto interior acoustics must control this part of road noise. The road noise also produces noise impact on passing-by vehicles. This part of the road noise is often called tire noise. Tire manufacturers are interested in this noise source because all tire products need to pass the drive-pass noise test. As vehicles are driven at high speeds, wind noise becomes a significant source of interior noise. The wind noise paths that transmit sound waves into the interior can be observed through the following aspects. Airflow excites the vibration of the wind shield glass and roof panel thus causing the structure to radiate the noise inside a vehicle. Airflow passes over the underside of a vehicle and causes a noise leak into the vehicle (mainly through the wheel-arch areas). Wind noise is leaked into the interior through door and window seals or is radiated through door and window vibration. Airflow blowing in the vehicle through partially-open windows or sunroofs causes intensive low-frequency noise and buffeting.

The miscellaneous noises such as squeaks, rattles, and tizzes usually have a random and chaotic nature and in many cases they are easy to detect but hard to locate. When there is a relative motion between interior material pairs, squeaks may occur. These material pairs can be hidden deep inside the composite structure of an interior part such as a dashboard assembly. As the paired materials possess different values of static and dynamic coefficients of friction, the relative motion develops the stick-slip process between the materials and causes the squeak noise. Material types, surface properties, frequency and amplitude of excitation, normal loads, interference levels, temperature, and humidity are all factors that help provoke squeaks. Rattle noises often result from hard and loose-fitting interior trims. Analysis of this noise is not easy because objective measures are not very consistent with human responses to this noise. In contrast, tizz noises are often caused by high-frequency contact vibration among interior parts and are relatively easy to find and eliminate.

10.1.2 Noise propagation and noise control approaches

As described in acoustics, sound waves traveling in space take the forms of reflection, refraction, diffraction, and diffusion. In reality, there are multiple sound sources existing in the same space and at the same time. Complicated acoustic phenomena, such as room reverberation and resonance, sound concentrations, and sound standing points, can be observed. Considering a passenger car, its space is usually divided into three parts: engine compartment; passenger compartment; and trunk compartment. The vehicle interior noise we are discussing here means that all noise waves the driver and passengers receive are inside the passenger compartment. Among the noise sources described in the previous section, only squeaks, rattles, and tizzes are directly from inside the passenger compartment, all other noise sources occur outside and transmit into the passenger compartment by certain ways of interaction with the vehicle structure.

According to the automotive acoustics, there are two types of interacting mechanism between the noise sources and vehicle structure. One type is called airborne noise path that means outside noise waves directly leak or transmit into the passenger compartment to cause interior noise. The other type is called structure-borne noise path. From this path, outside noise waves excite the vibration of vehicle structure and cause interior part surfaces to radiate noise inside the passenger compartment. Figure 10.2 illustrates a typical system for vehicle interior noise control in which a noise source, a noise path, and a noise receiver are three components. Therefore, the principle



10.2 Vehicle noise paths.

of controlling the vehicle interior noise is to interrupt the airborne or structure-borne paths for noise propagation.

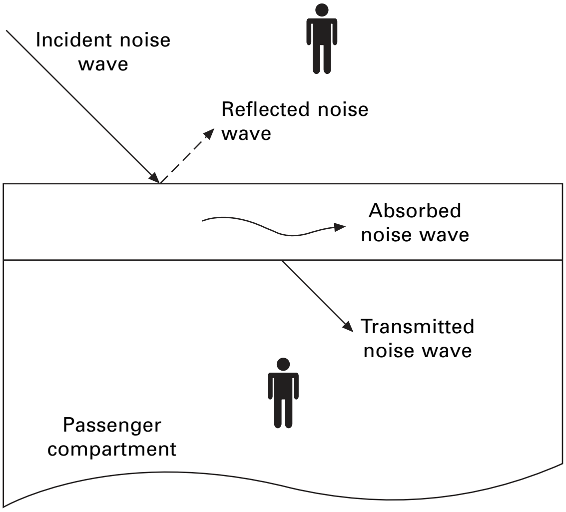
The major engineering approaches for the interruption of airborne paths include effective sealing of the passenger compartment to avoid direct noise leaking; high performance insulation of noise sources, such as the encapsulation of engine noise using panels or the encapsulation of road noise using heavy floor padding materials, which helps block noise waves transmitted from outside to inside; and efficient noise absorption to reduce reflected noise level inside the passenger compartment. For the interruption of structure-borne paths, isolating and damping the vibration of vehicle structure are two main methods. These methods are usually effective for the control of low-frequency noise, because the structure-borne noise is within the range of low noise frequency. In the range of high noise frequency, it is the noise received through airborne noise paths that usually dominates the interior noise levels.

10.2 Theory of noise-minimizing properties of textiles

To insure vehicles' acoustical performance, auto designers and manufacturers need to select and use different acoustical materials for maximum reduction of interior noise. Some materials are able to reduce airborne noise, while others help control structure-borne noise. Each material selected must possess a specific property that can contribute to at least one of these acoustical functions: noise absorption, noise insulation, vibration isolation, and vibration damping. The following sections discuss some primary theoretical issues regarding the effectiveness of textile materials on noise absorption and noise insulation, because the absorption and insulation materials account for a large percentage in the consumption of auto acoustical materials.

10.3 Textile materials for noise absorption

As a noise wave reaches the surface of an auto interior part during its propagation by an airborne path, it will become three different components: reflected part, transmitted part, and absorbed part (Fig. 10.3). A receiver on the same side as the sound source can receive both the incident and reflected sound waves. Absorbing the incident noise wave by an acoustic material is



10.3 Airborne noise transmission.

an effective way to lower the reflected noise level in the interior noise control engineering. A common question is what types of material can be used as excellent noise absorption materials. These materials must function like air, being able to prevent noise reflection from incidence surface, and like an energy disperser capable of dissipating the noise energy entering the material.

Porous materials such as textiles and foams are ideal noise absorption materials. The feature of numerous tiny air pockets inside the material allows the materials to perform two important absorption functions described above. Textiles materials in the form of wovens, knits, and nonwovens are widely used as auto interior materials ranging from decor fabrics to substrates and composites. These different applications provide different levels of noise absorption in the vehicle passenger compartment. The principle of noise absorption by these textile materials is generally described by these mechanisms: (1) heat conduction converted from the sound energy encapsulated in porous areas in the material; (2) viscous losses because of the oscillating air flow entering the porous areas inside the material; and (3) material vibration mainly caused by the noise waves encapsulated in closed porous areas.

It is difficult to use theoretical methods for describing the relationship between material structures and noise absorption performance, because of diverse textile fiber materials and complex fabric geometric structures. In practice, the material physical properties, in terms of flow resistance, porosity, and structure factor, are often used to characterize the material performance for noise absorption.

10.3.1 Flow resistance

Assuming that a noise wave enters a porous material, there exists a steady air flow flux passing through the material. The flow resistance of the porous material, denoted as r, is defined as (Harrison, 2004):

$$\frac{\partial p}{\partial x} = - r u_{\mathrm{m}}, \qquad 10.1$$

where u_{m} is air volume velocity per unit cross-sectional area of the material (m/s); p is air pressure, and x is displacement of air flow in the material. The standard ISO 9053-1991 provides a protocol of instrumentally evaluating the flow resisitance of porous materials. To address this issue, an instrumental method of measuring the material flow resistance was proposed (Bies and Hansen, 1996). This method measures the pressure difference across a material specimen in a tube with a steady air flow to determine the flow resistance r. The equation for calculating r is expressed below:

$$r = \frac{\rho A \cdot \Delta p}{v_{\mathrm{m}} l}, \qquad 10.2$$

where ρ = gas density (kg/m^3); Δp = pressure drop (N/m^2); A = material cross-sectional area (m^2); v_{m} = air mass flow rate (kg/s); and l = material specimen thickness (m). It should be noted that the above equation is based on the assumption that the material performs the same resistance to both oscillatory acoustic flow and steady air flow. Overall, this equation is only suitable for measuring low speed internal flows (Fahy and Walker, 1998).

Another instrumental method was proposed to directly measure an oscillatory acoustic flow passing through a porous material installed in an impedance tube (Ingard and Dear, 1985). This device is composed of a tube, a noise source, two pressure sensors, and a specimen installed in the tube with a distance equivalent to an odd number of $\frac{1}{4}$ wavelengths from the closed end of the tube. The following equation is used for the calculation of flow resistance:

$$\frac{r}{\rho_0 c_0} \approx \left| \frac{p_1}{p_2} \right|, \qquad 10.3$$

where ρ_0 is air density and c_0 is sound speed in air. In the case of measuring fiber porous materials, the above equation is modified to include more specific parameters (Bies and Hansen, 1996). The new format becomes:

$$\frac{rd}{\rho c} = 27.3 \left(\frac{\rho_{\mathrm{m}}}{\rho_{\mathrm{f}}} \right)^{1.53} \left(\frac{\mu}{d \rho c} \right) \left(\frac{d}{b} \right), \qquad 10.4$$

where

ρ = gas density (kg/m^3);

ρ_m = porous material (fabric) density (kg/m^3);
ρ_f = fiber density (kg/m^3);
μ = gas viscosity (Ns/m);
b = fiber diameter (m);
c = sound speed in gas (m/s);
d = sample thickness (m).

A standard method for the determination of airflow resistance of acoustical materials is ASTM C 522. Acoustical materials suitable for this test include boards, mats, felts, fabrics, papers, and screens. Similarly, a specific test method for evaluating the textile porous property related to flow resistance is the air permeability test described in the standards ASTM D 461, ASTM D 737, and BS 5636. The air permeability of textile materials is determined by the volume of air passed through a fixed area of sample at a pressure difference in a time period. The Frazier Air Permeability Tester is an instrument commonly used in the industry.

10.3.2 Porosity

Material porosity is used to describe the fraction of porous space in a material. It is defined as:

$$\delta = \frac{V_0}{V}, \tag{10.5}$$

where V_0 is the volume of porous space of the material and V is the total volume of the material including the porous space (Harrison, 2004). The value of δ is between 0 and 1. For noise absorption materials, δ is usually high (above 0.90). In the discussion of a sound wave propagating in a tube with a fixed cross-sectional area, a linear equation of mass conservation in free air is obtained (Fahy and Walker, 1998), expressed as:

$$\frac{\partial u}{\partial x} = -\frac{1}{\rho_0}\frac{\partial \rho}{\partial t}, \tag{10.6}$$

where u is air flow (particle) velocity. Because the air bulk modulus is defined as:

$$k_0 = \rho_0 c_0^2 = \rho_0\left(\frac{\partial p}{\partial \rho}\right), \tag{10.7}$$

Equation 10.6 can be rewritten as:

$$\frac{\partial u}{\partial x} = -\frac{1}{k_0}\frac{\partial p}{\partial t}. \tag{10.8}$$

Now considering the situation that a sound wave passes through a porous material, the material bulk modulus k (defined as k_0/δ) and air volume flow rate u_{m} are used. Therefore, the above equation becomes:

$$\frac{\partial u_{\mathrm{m}}}{\partial x} = -\frac{1}{k}\frac{\partial p}{\partial t}. \qquad 10.9$$

For textile materials, the formation of porous space is complicated because of diverse structures. In woven and knitted fabrics, the porous space consists of structural pores formed by yarns and yarn pores formed by fibers. If specialty fibers (such as hollow fiber or activated carbon fiber) are used for weaving and knitting, micropores inside the fiber will also be included. In nonwoven fabrics, the porous space is directly formed by randomly laid fiber. The nested fiber web structure makes nonwoven fabrics much bulkier than woven and knitted fabrics.

From Equation 10.5, the volume of porous space V_0 needs to be known in order to determine the porosity of textile materials. Some commercial instruments are available for characterizing pore volume, pore size, pore volume distribution, and other porous properties. The PMI porometers (Porous Materials, Inc.), the ASAP™ porosimetry system (Micromeritics Instrument Corporation), and the SA 3100 Surface Area and Pore Size Analyzer (Beckman Coulter Inc.) are among those instruments widely accepted for different industrial applications.

10.3.3 Structural factors

It is not enough to use porosity alone for describing materials' porous properties, because even if two porous materials indicate the same porosity, their noise absorption performance can still be totally different. Some other structural factors also must be taken into consideration. A theoretical fundamental used for analyzing material structural influence is the linear inviscid Euler equation (Kinsler *et al.*, 1982). This equation is expressed as:

$$\frac{\partial p}{\partial x} = -\rho_0\frac{\partial u}{\partial t} \quad \text{or} \quad u(x,t) = -\frac{1}{\rho_0}\int \frac{\partial p}{\partial x}\,dt. \qquad 10.10$$

In the case that there is an orientation of pore space in the material measured with an angle θ to the surface of the material, Harrison (2004) gives the following description:

$$\frac{\partial p}{\partial x}\cos\theta = -\rho_0\frac{\delta u_{\mathrm{m}}}{\partial t}\frac{1}{\delta\cos\theta} \qquad 10.11$$

$$\frac{\partial p}{\partial x} = -\frac{s\rho_0}{\delta}\frac{\partial u_m}{\partial t} \quad \text{where} \quad s \propto \frac{\alpha}{\cos^2\theta}. \qquad 10.12$$

In Equation 10.12, s is called structure factor and α is an attenuation constant of the material. Overall, a random orientation of pores may help increase the flow density. In a more specific case of a plane wave propagating in a tube with a termination impedance, the linear inviscid Euler equation is modified as:

$$\frac{\partial p}{\partial x} = -\frac{s\rho_0}{\delta}\frac{\partial u_m}{\partial t} - ru_m. \tag{10.13}$$

For a simple harmonic motion with frequency ω, the above equation takes the following specific format:

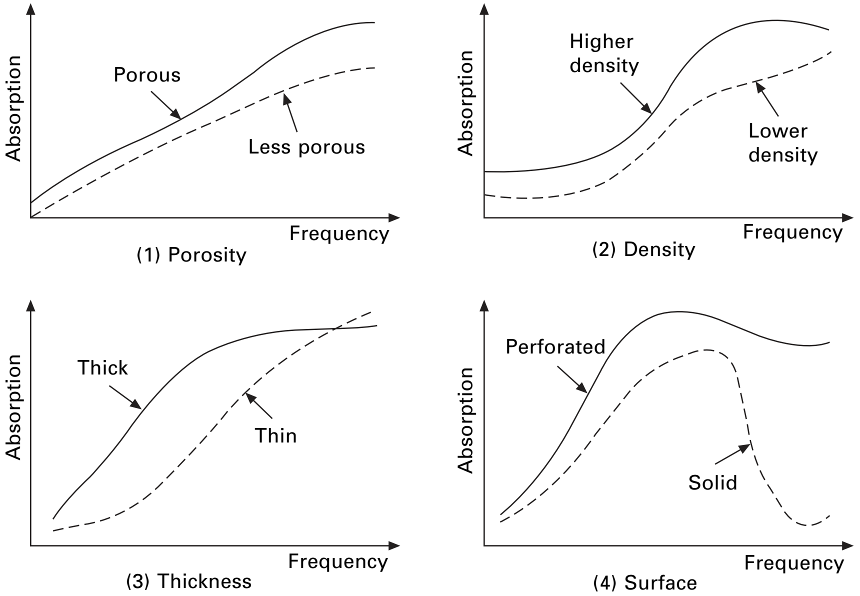
$$\frac{\partial p}{\partial x} = -\left[\frac{s\rho_0}{\delta} + \frac{r}{i\omega}\right]\frac{\partial u_m}{\partial t} = -\rho_m\frac{\partial u_m}{\partial t}. \tag{10.14}$$

The parameter ρ_m, because of including several structural effects, is used to represent the effective bulk density of porous materials. Ultimately, the introduction of ρ_m helps determine the characteristic acoustic impedance of air inside a porous material, defined as:

$$Z_c = \sqrt{k\rho_m}. \tag{10.15}$$

It should be noted that besides those important material factors discussed above, there are some other structural components to which some attention must be paid in engineering practice. Irregularity of pore size and uniformity of pore space distribution inside the material body affects a steady flow volume speed inside the material. Side pockets outside a flow stream in the material tend to cause a reduced acoustic pressure along a given strain gradient in the pore. These structural features are also called the tortuosity of acoustical materials. This property indicates the effectiveness of preventing direct flow through the acoustical material. In contrast, porosity indicates the ease of noise waves entering the material. They both contribute to the flow resistance of acoustical materials.

Regarding the textile materials applied for the noise absorption, fabric structures, yarn structures, and finish methods may influence the acoustic property of absorption. Fiber orientation in fabric materials, particularly in nonwovens, is a special parameter closely related to the pore orientation. In addition, fabric weight (mass per unit area), fabric thickness, fabric yarn count, fiber type, fiber linear density, fiber cross-sectional shape, and fiber surface property are all influential components that may play a role in the determination of the material capacity for noise absorption. In general, textile materials with the use of finer fibers and with smaller pore sizes tend to produce higher viscous losses and to increase the material flow resistance. Figure 10.4 gives a brief summary of the discussion in this section (Wyerman, 2003).



10.4 Effect of material properties on noise absorption.

10.4 Textile materials for noise insulation

10.4.1 Introduction

A passenger sitting inside a sealed passenger compartment of a vehicle can still receive external noise waves (Fig. 10.1). But these noise waves are transmitted noise waves with a certain level of noise intensity reduction, because of the insulation material existing between the noise source and receiver. The acoustical materials used for blocking the transmission of noise from one side to the other side of the material are called barriers. In vehicle engineering, acoustic barriers are important interior materials to reduce airborne noise. For best acoustic performance, a barrier material should have these features: a smooth and high density surface to maximally reflect noise waves, a non-porous structure to effectively encapsulate incident noise waves, and a certain material stiffness to minimize excited vibration. In a wide range of textile materials, natural fiber and synthetic fiber nonwovens (felts) with sufficient fabric weight and thickness are suitable for the noise insulation application in auto manufacturing. They are usually incorporated together with decor fabrics (such as wovens, knits, and genuine or artificial leather), interlinings (foams, films, etc.), and substrates into interior parts as a composite backbone after a hot-pressing process.

The insulation performance of a barrier material is assessed by sound transmission loss (TL). This parameter is determined by the ratio of incident noise intensities (w/m^2) to transmitted noise intensities, as defined below (Harrison, 2004):

$$\mathrm{TL} = 10\log_{10}\left[\frac{I_i}{I_t}\right]. \tag{10.16}$$

The unit of TL is dB and its value varies corresponding to the noise frequency. The TL mass law indicates that the sound transmission loss increases as the mass or frequency increases.

10.4.2 Noise transmission through thin panels

Most nonwoven felts for interior noise insulation form a thin panel after hot-pressing. In the range of audible sound frequencies, thin panels are often excited by noise to radiate bending waves that cause a panel deflection in the plane perpendicular to the panel surface. This deflection involves the deformations of extension, compression, and shear. Thus, the mechanical properties and dimensional parameters of the panel are used in the determination of the propagation speed of bending waves. The phase velocity of bending waves, denoted by C_B, is given by:

$$C_B = \left(\frac{B}{\rho S}\,\omega^2\right)^{\frac{1}{4}}, \tag{10.17}$$

where B is bending rigidity (N·m); ρ is panel density, S is panel area; and ω is radial frequency ($=2\pi f$). For a thin plate with thickness d, the above equation becomes:

$$C_B = \sqrt{1.8c_L d f} \tag{10.18}$$

$$c_L = \sqrt{\frac{E}{\rho(1-\nu)}}, \tag{10.19}$$

where E is the Young's modulus (N/m^2), ν is the Poisson's ratio, and f is frequency (Hz).

When the bending wavelength from the panel is equal to the noise wavelength in the air, a strong coupling between the panel bending waves and noise waves occurs. This means that the noise impinging on the panel from any angle of incidence will induce a strong responding bending wave in the panel. This phenomenon is called coincidence. The frequency needed to make this coincidence happen is called the critical frequency. For the isotropic panel, this critical frequency is determined by (Harrison, 2004):

$$f_c = \frac{c_0^2}{2\pi}\left(\frac{m}{B'}\right)^{\frac{1}{2}}, \tag{10.20}$$

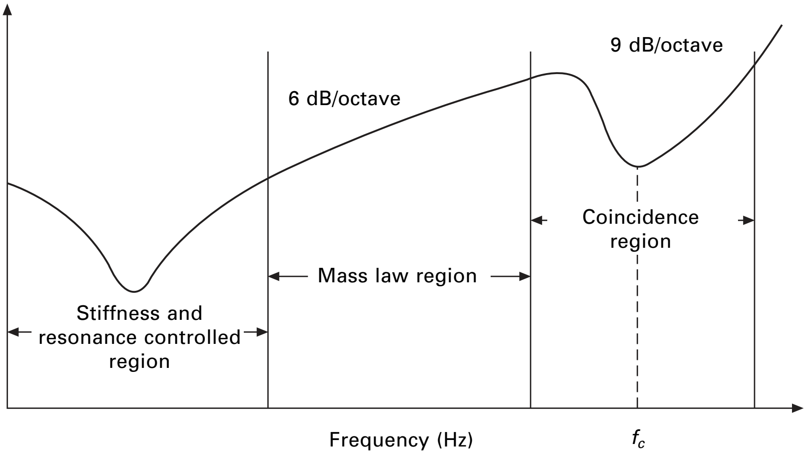
where m is the panel surface density (kg/m^2) and B' is the modified bending rigidity expressed as:

$$B' = \frac{d^3}{12} \cdot \frac{E}{1 - \nu^2}. \qquad 10.21$$

The TL-frequency curve given in Fig. 10.5 illustrates the sound transmission property of an isotropic thin panel responding to the increase of sound frequency (Bies and Hansen, 1996; Wyerman, 2003). This curve exhibits three transmission property regions. In the range of low frequencies, the TL values are controlled by panel stiffness and resonance. At the frequency where the first panel resonance occurs, the sudden decrease of TL is partially controlled by the system damping. The medium frequency range is mass law region. In this region, TL complies with the mass law relationship determined by Green (2005):

$$\text{TL} = 20\log_{10}(mf) - 47.2. \qquad 10.22$$

The high frequency range is called coincidence region, because this range is around the critical frequency. At the frequencies below the critical frequency, the wavelength in air is longer than the wavelength in the panel. As a result, the panel is coupled poorly to the airborne noise wave. This poor coupling makes the panel have good TL performance. In contrast, at the frequencies above the critical frequency, the panel is coupled well to the airborne noise wave with a certain incident angle. The good coupling causes a poor TL property. Therefore, the panel TL depends on damping control and can be increased at a rate of 9 dB per octave.



10.5 Noise insulation property of thin panel.

10.5 Testing methods for acoustical properties of textile materials

Vehicle acoustic performance has become an important invisible factor to improve passenger comfort, in contrast to visible factors (esthetic attributes) for vehicle interiors, such as color and style. From an engineering point of view, acoustic performance of a vehicle can be evaluated at three levels: material level, component level, and system level (Khambete, 2003). At the material level, a major task is to evalute the noise absorption and noise insulation of flat (2D) materials subject to strikes of any incident noise waves. At the component level, the effectiveness of 3D interior parts on noise attenuation in a reverberation room is of interest to investigate. This method is also called buck testing. At the system level, focus is on the dynamic overall acoustic performance of vehicles on roadside driving. Considering the focus of this book, the scope of present discussion is limited to the material level evaluation of noise absorption and noise insulation for textile materials.

10.5.1 Measurement of noise absorption

There are two instrumental approaches for assessing the material ability to absorb noise: one is the test of normal incidence noise absorption and the other is the test of random incidence noise absorption. The standard test methods are listed in Table 10.1.

ASTM C 384/ISO 10534-1. These methods use a standing wave impedance tube to allow a plane wave traveling in the tube. After hitting the test sample, the plane wave is reflected to produce a standing wave. Maximum pressure (P_{max}) and minimum pressure (P_{min}) in the tube are measured by a movable microphone, so that the absorption coefficient of normal incident noise can be determined:

$$\alpha_n = \frac{4P_{max}P_{min}}{(P_{max} + P_{min})^2}. \qquad 10.23$$

The standing wave method is not only a good educational model but also a good practical instrumental approach for testing absorption coefficient, reflection coefficient, impedance, and admittance of the normal incidence noise. One disadvantage of this method is its slow test procedure.

ASTM E 1050/ISO 10534-2. These methods use a two-microphone impedance tube to determine the ability of acoustical materials for absorbing normal incidence noise waves. The Brüel and Kjær instrument of impedance tube system is commonly used for these standard test methods within the frequency range 0–6400 Hz. This instrument system includes Type 4206 Impedance Tube, PULSE Analyzer Type 3560, and Type 7758 Material Test

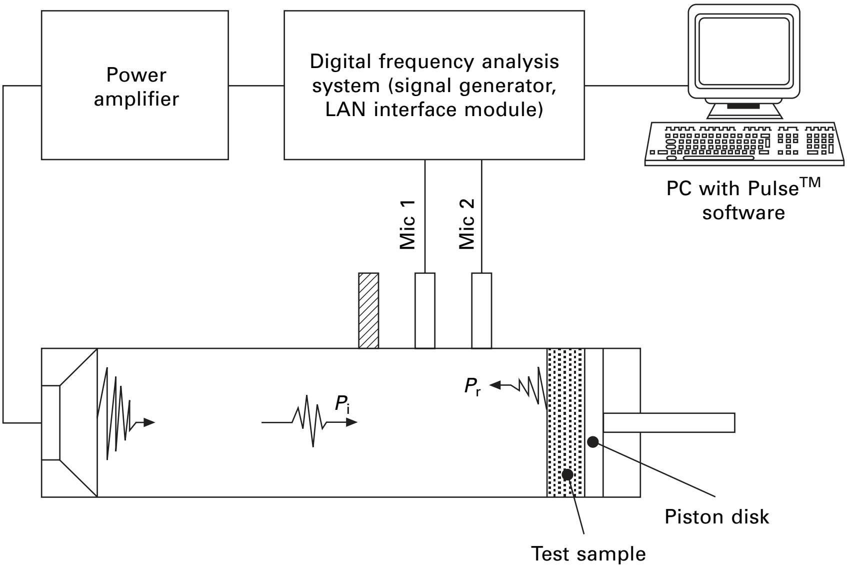
Table 10.1 Standard test methods for sound absorption

Noise source	Standard	Title
Normal incidence	ASTM E 384-98	Standard Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method
	ISO 10534-1: 1996	Acoustics – Determination of sound absorption coefficient and impedance in impedance tubes – Part 1: Method using standing wave ratio
	ASTM E 1050-98	Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System
	ISO 10534-2: 1998	Acoustics – Determination of sound absorption coefficient and impedance in impedance tubes – Part 2: Transfer-function method
Random incidence	ASTM C 423-99a	Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method
	ISO 354: 1985	Acoustics – Measurement of sound absorption in a reverberation room. Amendment (1998)

Software. The testing principle of this system is illustrated in Fig. 10.6. A sound source is mounted at one end of the impedance tube and the material sample is placed at the other end. The loudspeaker generates broadband, stationary random sound waves. These incident sound signals propagate as plane waves in the tube and hit the sample surface. The reflected wave signals are picked up and compared to the incident sound wave. The frequency range to be tested depends on the diameter of the tube. A large tube (100 mm diameter) is set up for measuring the nonwoven sound absorption in the low frequency range from 50 Hz to 1600 Hz. A small tube (29 mm diameter) is set up for testing the material sound absorption in the high frequency range of 500–6400 Hz.

The major parameters to be measured are corrected transfer function H fallen into the real part H_r and imaginary part H_i, complex reflection coefficient R determined by the real part R_r and imaginary part R_i, and normal incidence sound absorption coefficient α (taking values between 0 and 1). These parameters are described below:

$$H = \frac{\overline{H}}{\overline{H}_c} = H_r + jH_i \qquad 10.24$$



10.6 Measuring system configuration.

$$R = \frac{H - e^{-jks}}{e^{jks} - H} e^{j2k(l+s)} = R_r + jR_i \qquad 10.25$$

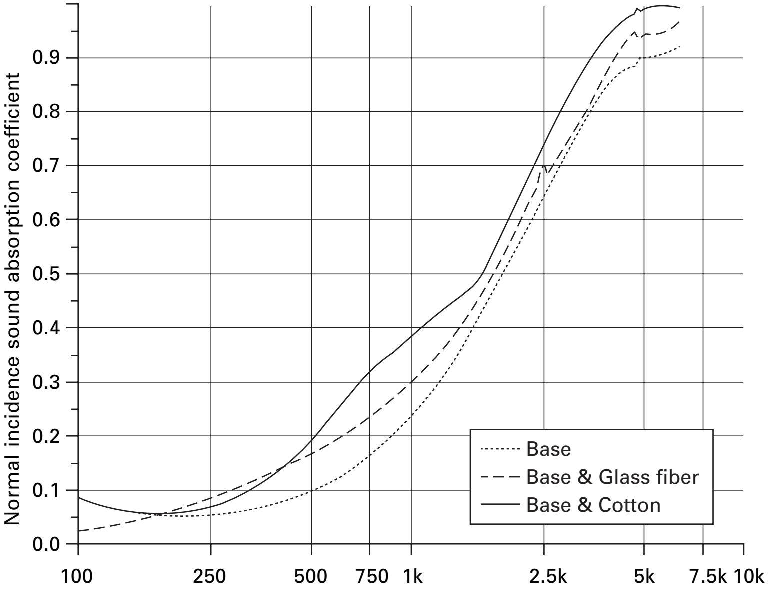
$$\alpha = 1 - |R|^2 = 1 - R_r^2 - r_i^2 \qquad 10.26$$

$$\frac{z}{\rho c} = \frac{1 + R}{1 - R} = \frac{r}{\rho c} + j\frac{x}{\rho c}, \qquad 10.27$$

where

$\overline{H}$ = measured transfer function;
$\overline{H}_c$ = microphone calibrated factor;
$j = \sqrt{-1}$, indicating an imaginary unit in the equation;
c = speed of sound (m/s);
ρ = density of air (kg/m^3);
f = sound frequency (Hz);
$k = 2\pi f/c$ (m^{-1});
l = distance from the test specimen to the center of the nearest microphone (m);
s = center-to-center spacing between the two microphones (m);
$r/\rho c = \alpha/[2(1 - R_r) - \alpha]$, acoustic resistance ratio;
$x/\rho c = 2R_i[2(1 - R_r) - \alpha]$, acoustic reactance ratio;
$z/\rho c$ = acoustic impedance ratio.

Figure 10.7 exhibits a tested result of the normal incidence sound absorption coefficients (α) as a function of the sound frequency (f) for the cotton/cotton



10.7 Noise absorption of cotton nonwoven composites.

and cotton/fiberglass nonwoven composites, using the above instrument. The curves combine the low frequency data and the high frequency data together to indicate a whole bandwidth of the 1/3 octave band frequency. The x-axis uses a log scale. The two-microphone method is a very fast and accurate method with a broad band of normal incidence noise frequencies. It only needs small sample sizes for testing.

ASTM C 423/ISO 354. These standard methods use a reverberation room to test materials for random incidence noise absorption. A major procedure is to measure decay rate ($\Delta dB/\Delta t$) that can be determined by turning off a steady noise source and measuring sound pressure decrease over time elapse. The sound absorption of the reverberation room, denoted as A in m^2 or Sab, is determined by the Sabine formula:

$$A = 0.9210 \frac{Vd}{c}, \qquad 10.28$$

where

V = volume of reverberation room (m^3);
c = sound speed (m/s);
d = decay rate (dB/s).

For testing an absorption material, the noise absorption coefficient of the measured sample is calculated by the following equation:

$$\alpha = \frac{A_2 - A_1}{S} + \alpha_1, \qquad 10.29$$

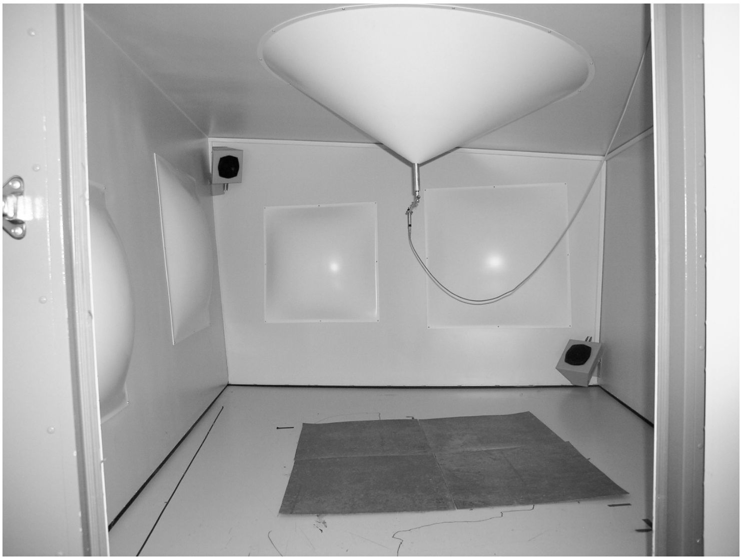
where

α = absorption coefficient of test specimen (dimensionless);
A_1 = absorption of the empty reverberation room (m^2);
A_2 = absorption of the room with the installed test specimen (m^2);
S = area of test specimen (m^2);
α_1 = absorption coefficient of the surface covered by the specimen.

Alpha Cabin Method is another reverberation method commonly used in the auto industry (Müller and Krobjilowski, 2003). Compared to the above standard method, Alpha Cabin uses a small reverberation room with a sound diffuse environment, because of the presence of a sound diffuse area inside the room. Figure 10.8 shows the structure of an Alpha Cabin, composed of three sound sources, a sound diffusing area, and a microphone. The band of random noise is within 0.4–10 kHz. Specimen size used in tests is between 0.6 and 2.4 m^2. The standard size is 1.2 m^2. The measurement is taken at five different positions in the cabin and reverberation time will be determined after integrating decay curves. The following equation is used for the computation of measurement:

$$\overline{\alpha} = 0.805\left(\frac{1}{t} - \frac{1}{t'}\right) \tag{10.30}$$

$$\overline{\alpha}_E = S \cdot \overline{\alpha}, \tag{10.31}$$



10.8 Alpha Cabin in the BIK Research Laboratory at Univeristy of Bremen, Germany.

where, $\overline{\alpha}$ is absorption coefficient when standard-size specimen is used; t is time of reverberation without specimen; t' is time of reverberation with specimen; $\overline{\alpha}_E$ is equivalent absorption when non-standard size specimen is used (m^2); and S is surface area of specimen (m^2).

In summary, the reverberation room methods allow the use of large samples for the measurement of materials exposed to random incident noise waves, and therefore are suitable for testing inhomogeneous materials. The material acoustical properties of reflection coefficient, impedance, and admittance cannot be determined through these room methods. Also, the value of noise absorption coefficent can be larger than one, meaning that the numerical numbers of this absorption coefficient are not comparable with those obtained from the impedance tube methods. Because a dedicated test room is needed, the implemention of the reverberation room methods is overall costly and inconvenient.

10.5.2 Measurement of noise transmission loss

The evaluation of material ability for noise insulation also has two instrumental approaches: the reverberation suite method dealing with random incidence noise and the impedance tube method coping with normal incidence noise. These measurement approaches are described in different test standards. It is essential to understand test scopes and physical definitions for each standard method, so that measured data resulting from different standards can be interpreted properly. The measuring methods discussed below are three most important standard methods widely adopted by vehicle OEMs.

ISO 140-1 and 140-3 / ASTM E 90. These test standards are designed for laboratory measurement of airborne noise transmission loss through a building partition or partition element. The measurement method uses two reverberant rooms (as a suite), one for noise source room and the other for noise receiver room. A test panel specimen is mounted between these two rooms (Fig. 10.9). The noise transmission loss for the test panel is determined by the ratio of noise power incident on the panel (W_i) to the noise power transmitted through the panel (W_t), expressed as:

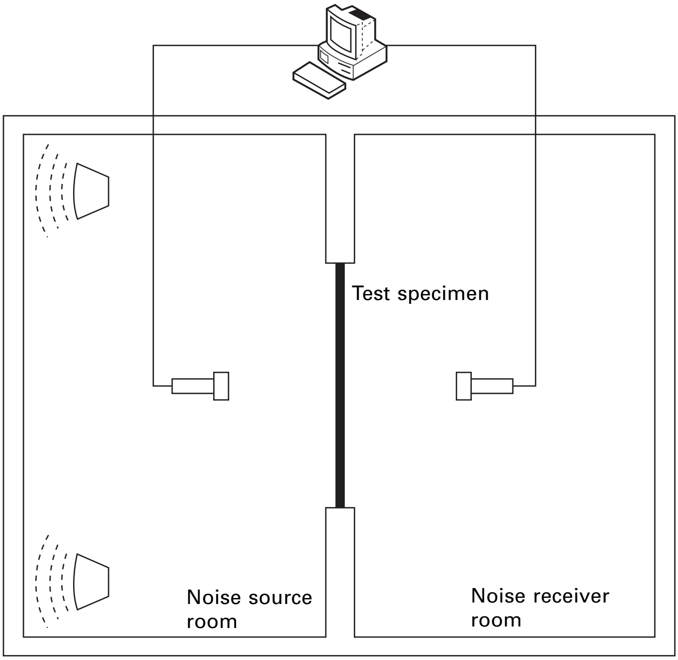
$$\mathrm{TL} = 10\log_{10}\frac{W_i}{W_t}. \qquad 10.32$$

The noise power impinged on the panel is calculated by:

$$W_i = I_i S, \qquad 10.33$$

where S is panel area. The noise power transmitted through and absorbed by the receiver room is determined by:

$$W_t = I_t A, \qquad 10.34$$



10.9 Reverberant room method for measurement of noise transmission loss.

where A is noise absorption of the receiver room. Rewriting Equation 10.32 obtains:

$$\mathrm{TL} = 10\log_{10}\left(\frac{I_i S}{I_t A}\right) = 10\log_{10}\left(\frac{I_i}{I_t}\right) + 10\log_{10}\left(\frac{S}{A}\right). \qquad 10.35$$

Because the measured noise pressure and energy in a diffuse room are comparable, the term $10\log_{10}(I_i/I_t)$ is the noise reduction (NR) indicating the difference of the noise pressure levels between the two reverberant rooms ($SPL_i - SPL_t$). Therefore,

$$\mathrm{TL} = \mathrm{NR} + 10\log_{10}\left(\frac{S}{A}\right) = SPL_i - SPL_t + 10\log_{10}\left(\frac{S}{A}\right). \qquad 10.36$$

SAE J1400. This standard test method, entitled 'Laboratory Measurement of the Airborne Sound Barrier Performance of Automotive Materials and Assemblies,' is established by the Society of Automobile Engineers (SAE) with the purpose of providing a test procedure that can determine the airborne noise barrier performance of materials and composite assemblies widely used for making vehicle interior products. The measurement set-up includes a reverberant source room, a hemianechoic receiver room, and a signal analyzer.

A test sample is mounted between the two rooms. This test also needs a reference sample (usually a homogeneous limp material like lead) for the characterization of test condition. Random incidence noise is generated in the verberant source room. The sound pressure levels in both the source room and receiver room are measured. The TL of test samples is calculated according to the TL mass law. For the reference specimen, the measured transmission loss is expressed as:

$$\mathrm{TL}_0 = 20 \log_{10} (mf) - 47.2. \qquad 10.37$$

For the test specimen, the TL is calculated by:

$$\mathrm{TL} = \mathrm{NR} - \mathrm{CF}, \qquad 10.38$$

where NR is noise reduction measured by the test specimen and CF is called correlation factor determined by:

$$\mathrm{CF} = \mathrm{NR}_0 - \mathrm{TL}_0, \qquad 10.39$$

in which NR_0 is noise reduction measured by the reference specimen (Hoult, 2003).

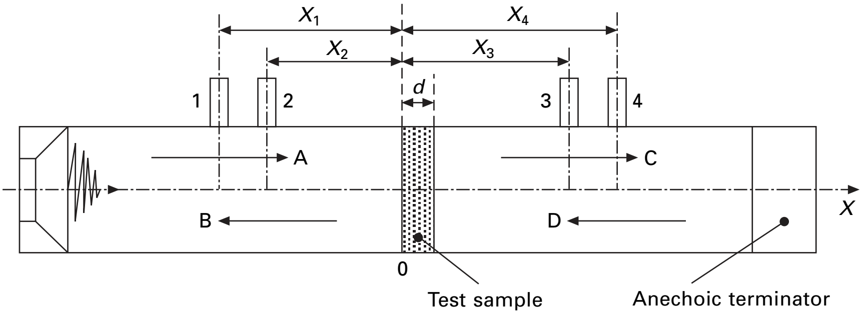
ASTM Work Item 5285. This test method, entitled ‘Measurement of normal incidence sound transmission of acoustical materials based on the transfer function method,’ has been proposed as Draft 050415 by an ASTM technical committee, and will be designated as ASTM E xxxx-04. This in-progress standard method describes the use of an impedance tube, four microphones, and a digital frequency analyzer for measuring material transmission loss. The sound source to impinge test materials is normal incidence noise wave. The Brüel and Kjær transmission loss tube Type 4206T is designed for the TL measurement. This tube set is actually an extension of the Brüel and Kjær impedance tube Type 4206, including an additional pair of microphones and two extended tubes, a large tube (diameter 100 mm) for measuring sound frequencies within 50–1600 Hz and a small tube (diameter 29 mm) for measuring sound frequencies within 500–6400 Hz.

The measuring principle is illustrated in Fig. 10.10, in which A, B, C, D are coefficients that represent complex amplitudes of the sound waves in the field of normal incidence sound wave tube. These coefficients are determined by the following equations (Song and Bolton, 2000):

$$\mathrm{A} = \frac{j(P_1 e^{jkx_2} - P_2 e^{jkx_1})}{2 \sin k(x_1 - x_2)}, \qquad 10.40$$

$$\mathrm{B} = \frac{j(P_2 e^{-jkx_1} - P_1 e^{-jkx_2})}{2 \sin k(x_1 - x_2)}, \qquad 10.41$$

$$\mathrm{C} = \frac{j(P_3 e^{jkx_4} - P_4 e^{jkx_3})}{2 \sin k(x_3 - x_4)}, \qquad 10.42$$



10.10 Impedance tube method for transmission loss test.

$$D = \frac{j(P_4 e^{-jkx_3} - P_3 e^{-jkx_4})}{2 \sin k(x_3 - x_4)}, \qquad 10.43$$

where P_1, P_2, P_3, and P_4 are transfer functions measured by four microphones located at 1, 2, 3, and 4; k is wave number in the ambient fluid. The transmission loss is defined as:

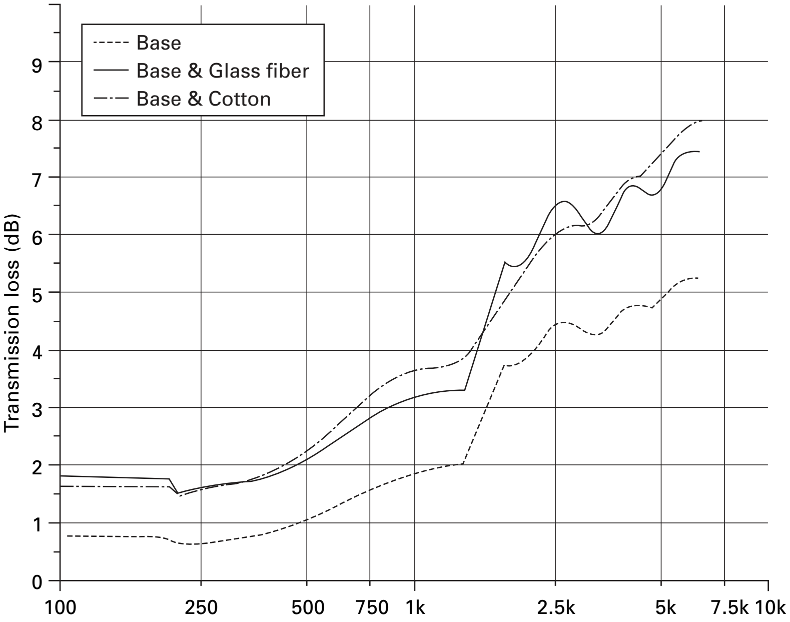
$$\text{TL (dB)} = 20 \log_{10} \left| \frac{C}{A} \right|. \qquad 10.44$$

Figure 10.11 exhibits a test result of three acoustic nonwovens using the Brüel and Kjær TL tube: cotton nonwoven (Base) with weight 62 g/m^2 and thickness 35 mm; glass fiber-surfaced cotton nonwoven composite (Base & Glass fiber) with weight 189 g/m^2 and thickness 38 mm; and cotton-surfaced cotton nonwoven composite (Base & Cotton) with weight 336 g/m^2 and thickness 38 mm.

10.6 Engineering of acoustic textiles for noise control in vehicles

10.6.1 Type and function of auto interior materials

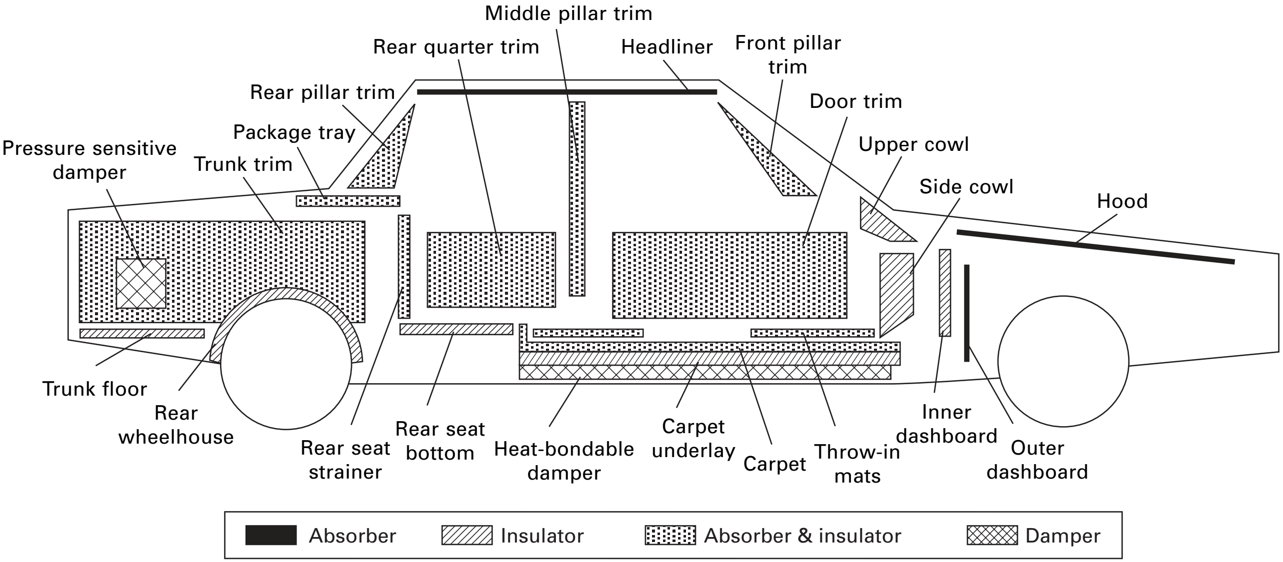
To achieve the best acoustic performance for a vehicle, four different types of acoustical materials are needed for use in vehicle interiors. Noise absorbers and barriers are mainly for the control of airborne noise. Vibration isolators and dampers are primarily for the control of structure-borne noise. These materials are integrated into interior parts (composite assemblies). Each material may become an important component in these composite assemblies, such as soft-touch skin or rigid 3D structure. Figure 10.12 illustrates all interior applications of these acoustical materials (Wyerman, 2003). It can be seen that the barrier materials are heavily used to insulate engine noise, road noise, and exhaust noise. Effective noise barrier materials should feature



10.11 Transmission loss curves of cotton nonwoven composites.

non-porosity, high surface density, flexibility, and double-wall panel structure. Inside the passenger compartment, headliner, floor carpet, door trims, pillar trims, and seats become major absorbing and insulating components for reducing interior noise. 'Absorber everywhere' is a good interior design philosophy that helps achieve the excellent acoustical performance in vehicle manufacture. Ideal noise absorption materials should have unique porosity and tortuosity in structure and high flow resistance in the interaction with noise waves.

It is estimated that the consumption of textile materials in each car is about 20 kg. This includes interior trims, tires, seat belts, airbags, and composites (World Textile Publications Ltd, 1999). Major textile and foam materials used in vehicle acoustical applications are listed in Table 10.2. Woven, knitted, and nonwoven fabrics are commonly used as stylish decor layers of interior parts. Fibers selected for these fabrics are man-made fibers like PET, PA, and PP. The polypropylene-blended natural fiber nonwovens have become a core layer in the interior composites. They can be either bulky format or rigid format (panel) depending on whether they are required for acoustic absorption or for acoustic insulation. Foam materials are prominently used in two interior structures: surface components for soft touch and noise absorption and padding components for noise insulation. These foams can be made from PUR, PP, PE, or PVC.



10.12 Acoustical materials in vehicle interior.

Table 10.2 Major textile and foam acoustical materials in auto interiors

Area	Interior part	Component	Material
Engine	Hood absorber Outer dash absorber	Single layer	Foams: polyurethane, melamin Felts: cotton/phenolic resin, glass/thermoset resin
Passenger	Floor carpet	Decor	Needlepunched PET nonwovens; PA or PET tufts
		Insulator	Foams, thermoplastic-bonded felts
		Heavy layer	
	Inner dash insulator	Single layer	Foams, thermoplastic-bonded felts
		Heavy layer	
	Headliner	Decor	Nonwovens, warp knitted fabrics
		Insulator	Phenolic resin bonded felts, natural fiber/PP, PUR foam and glassmat sandwich, polyester felts
		Retainer	Spunbond nonwovens
	Door panel Door trim	Decor	Wovens, warp and weft knits, nonwovens, PVC skins, leathers
	Door insert	Soft touch	Foams
		Substrate	Thermoset resins, natural fiber/PP
		Retainer	Spunbond nonwovens
	Instrument panel	Decor	PVC skins, leathers
		Soft touch	Foams
	Seat	Cover	Wovens, warp and weft knits, PVC skins, leathers
		Pad	Foams
Trunk	Side trim	Decor	Nonwovens
		Insulator	Natural fiber/PP, trilaminate
	Liner (floor cover)	Decor	Nonwovens
		Insulator	Recycled fiber felts
	Load floor	Single wall	Natural fiber/PP, wood/resin, baypreg sandwich
		Double wall	Twinwall (glass/PP, natural fiber/PP)
	Package tray/ parcel shelf	Decor	Nonwovens
		Rigid layer	Natural fiber/PP, wood/resin, baypreg sandwich

10.6.2 Interior noise control through different acoustical materials

There are two engineering routes for reducing interior noise levels in vehicles. One route is to eliminate noise sources or to interrupt any noise path that allows noise waves to enter the vehicle interior. The other route is to use acoustical absorption materials to absorb noise waves already transmitted into the passenger compartment. The first route is essential and is closely related to the vehicle quality rendered by design and installation. Also, some noise sources such as wind noise or road noise are simply unavoidable. The second route is very practical in engineering. But under certain circumstances, the noise reduction efficiency may not be high enough because the selection and application of acoustical materials are influenced by other factors such as cost, weight, and recyclability. To address the question of how to use high performance acoustical materials for leveraging efficient interior noise reduction, some typical application cases are selected and analyzed below.

Material approaches for controlling noise absorption

Issue of surface material influence. Use of interior surface materials is choosy and highly dynamic, because of customers' need for new vehicle design and for more choices of vehicle models. Interior noise levels may vary with the difference of surface materials or with the change of surface material area (e.g., with or without riders). It is considered that the passenger compartment is neither like a truly reverberant room nor an anechoic room. In the study of this semi-diffuse acoustic environment, a parameter called room constant R is defined (Harrison, 2004):

$$R = \frac{S\bar{a}}{1 - \bar{a}}, \qquad 10.45$$

where S is total room area (m^2) and $\bar{a}$ is average Sabine absorption in the room. Accordingly, the sound pressure difference in the reverberant field is determined by:

$$\Delta SPL = 10\log_{10}\left(\frac{4}{R}\right). \qquad 10.46$$

Table 10.3 provides the sound absorption data in terms of fabric seats and leather seats in a typical European passenger wagon (Harrison, 2004). Using the data from this table, the calculated R is 14.98 for fabric seats and 11.53 for leather seats. Applying Equation 10.46, the difference of noise reduction between the use of fabric seat cover and the use of leather seat cover can be calculated by:

$$\mathrm{NR} = 10\log_{10}\left(\frac{14.98}{11.53}\right) = 1.1\ (\mathrm{dB}). \qquad 10.47$$

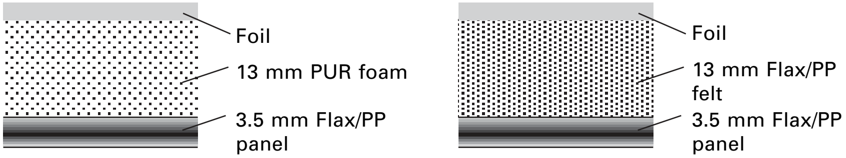
This is a comparative value, indicating that the fabric seat surface may result in a slightly greater effect on the noise reduction (here 1.1 dB extra) compared to the leather seat surface.

Biobased nonwoven sandwich composites for enhancing noise absorption. Biobased nonwovens using natural fibers (cotton, ramie, flax, hemp, kenaf, etc.) and polypropylene fiber as binder have been increasingly used for making auto interior parts. These biobased nonwovens feature lightweight,

Table 10.3 Interior surface area and noise absorption of a typical European wagon

Interior	Surface area S (m^2)	Fabric seat		Leather seat	
		$\bar{a}$	$S\bar{a}$	$\bar{a}$	$S\bar{a}$
Headliner	3.50	0.60	2.10	0.60	2.10
Carpet	1.47	0.42	0.62	0.42	0.62
Footwell	1.05	0.42	0.44	0.42	0.44
Trunk	1.12	0.42	0.47	0.42	0.47
Front screen	1.05	0.03	0.03	0.03	0.03
Rear screen	1.05	0.03	0.03	0.03	0.04
Seat squabs	1.96	0.89	1.74	0.61	1.20
Seat backs	2.80	0.89	2.49	0.61	1.71
Side glass	3.00	0.03	0.09	0.03	0.09
Side trim	3.00	0.18*	0.54	0.18*	0.54
Dash	0.84	0.18*	0.15	0.18*	0.15
Rear trim	0.84	0.18*	0.15	0.18*	0.15
Total	21.68		8.86		7.53

*Estimated.

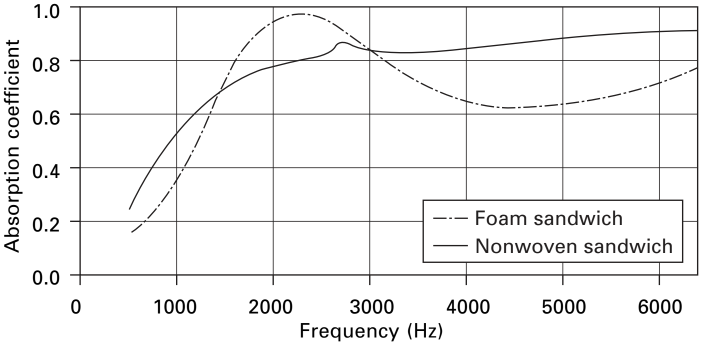


10.13 Two nonwoven sandwich acoustical composites.

enhanced acoustical performance, and high capacity of impact energy absorption. A typical engineering use of these nonwovens in the vehicle interior applications is a sandwich structure nonwoven composite in place of foam insulators. The research at the University of Bremen (Müller and Nick, 2005) has conducted a comparative study on a nonwoven sandwich composite and a foam sandwich composite (Fig. 10.13). The sound absorption property of these composites in response to normal incident noise was measured using the Brüel and Kjær impedance tubes (Fig. 10.14). The result indicates that in the tested freuquency range, the nonwoven sandwich has a higher average value of absorption coefficient than the foam sandwich. When using the nonwoven sandwich to replace the foam sandwich, the material weight is reduced and the ability to absorb noise is enhanced, particularly in the frequency range above 3000 Hz.

Material approaches for controlling noise insulation

At the range of low frequencies, the TL performance of noise barrier materials is usually low, mainly because the barrier materials tend to vibrate and



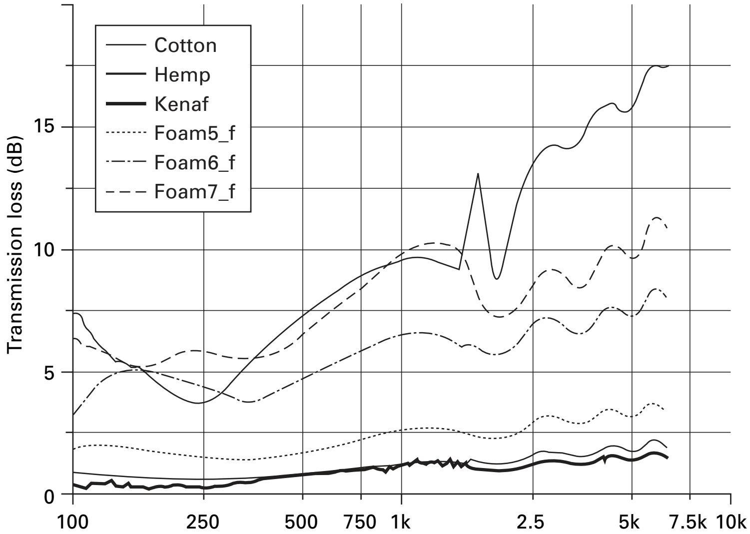
10.14 Comparison of noise absorption: nonwoven sandwich vs. foam sandwich.

Table 10.4 Sample specifications of biobased nonwovens and foams

Sample	Description	Thickness (mm)	Weight (g/m^2)	Density (kg/m^3)
Cotton	Blended with 30% PP	11	1024	93.1
Kenaf	Blended with 30% PP	11	997	90.6
Hemp	Blended with 30% PP	11	940	85.5
Foam #5	Recycled foam with scrim surface	12.7 (1/2″)	1265	99.6
Foam #6	Recycled foam with coated surface	9.5 (3/8″)	1777	187.0
Foam #7	Recycled foam with foil surface	9.5 (3/8″)	1590	167.4

resonate more than at the high frequency range. The improvement of the interior material property for low frequency noise insulation becomes an important technical issue. This issue can be seen in the design of car flooring systems, particularly the flooring system for diesel engines. Heavy padding layers (foams) are often required for enhancing the barrier performance to block the engine and road noise transmitting into the passenger compartment. However, a pay-off of this design is an increase of total vehicle interior weight and production cost. The other concern of using heavy foam materials for floor insulation is the disposal issue of ELV interior materials.

As an alternative, natural fiber or synthetic fiber nonwoven felts can be used as carpet underlayers for improving the efficiency of noise insulation. A recent study reported the TL evaluation of three natural fiber nonwoven felts in comparison with three commercial foam materials (Chen *et al.*, 2006). The material specifications are listed in Table 10.4. The TL property was measured using the Brüel and Kjær impedance tube. As shown in Fig. 10.15, the cotton/PP felt has superior TL performance, compared to the commercial



10.15 TL comparison: biobased nonwovens vs. foams.

foam products and the kenaf/PP and hemp/PP felts. It can aslo be seen that the type of foam surface influences the TL significantly. Here, Foam #7 (foil surface) is better than Foam #6 (coating surface) and Foam #5 (scrim surface).

10.7 Future trends

Future vehicle visions are energy efficiency, intelligent interior functions, and ecological performance. Because today's automotive industry is growing globally, the competition for auto interior design and production is fiercer than ever before (Weiser, 2005). Although the rivalry theme is still winning customers, vehicle OEMs are increasingly using merging technologies in all stages of manufacture, in order to keep their products safer, quieter, and more cost-effective. Consequently, vehicle interior producers (Tier 1 and Tier 2 suppliers) are facing these challenges: strong price competition, increasing raw material price, and shorter development time period. Vehicle acoustics will be a leverage for the consumer automobile estates. Future trends in the development of innovative interior materials are envisaged below.

In the material aspect, use of lightweight interior materials that contribute to the reduction of overall vehicle weight is a priority in responding to OEMs' urgent need for improving vehicle energy efficiency. Natural fiber-based nonwoven composites will become a major type of lightweight auto interior material because of their performance in noise reduction, impact energy absorption, and renewability. A typical application case is twin wall (or twin sheet) panels for trunk interiors, e.g. 50/50 fiberglass/PP such as ‘Sommold’ from Faurecia (Nick and Duval, 2005), or 50/50 natural-fiber/PP such as ‘KENBOARD air™’ from R+S Technik GmbH (Fischer, 2005). Other new textile materials particularly innovated by nanotechnologies will also gain attention in the interior acoustical applications. For example, micro- and nano-fiber fabrics can provide a highly porous surface for noise absorption. Nano finishing technologies can be used to modify fabric surface micro texture for an improvement of noise reduction efficiency. New technologies for the acoustic material development also include tunable noise absorbers and barriers, hybrid lightweight materials with balanced noise absorption and transmission loss, and active noise and vibration reduction systems (Wyerman, 2003).

In terms of the material design aspect, ‘features designed in’ and ‘design for disassembly’ have become a new design approach for today’s sound package and vehicle integration (He 2005; NASA, 2003). New vehicle interior features are required to design in, rather than to add on, right at the beginning stage of the product development. This will allow interior parts to be defined and refined earlier so that a balanced solution for whole interior system can be made. The concept of design for disassembly reflects an OEM’s focus on vehicle recyclability. The EU has issued an ELV regulation that 95% of a vehicle by weight has to be recyclable by 2015 (Kemper and Hobi, 2003). Under this guideline, European vehicle designers have to insure the recyclability of all newly produced interior parts to be accountable. Recycling automotive interior parts is very difficult because most of them are petrobased polymer materials with mixed composite structures. Current disposal methods for these auto interior parts are either garbage dumps or burning. A possible solution for this problem is to make interior parts either using one single polymer or using biodegradable materials. The EU-funded project Controlled Close Loop Recycling (CONCLORE), headed by the University of Bremen in Germany, is focusing on a concept car with all PET interiors. The most significant impact of this research is the establishment of an industrial ally that brings the university research lab, automaker, interior manufacturer, PET producer, nonwoven producer, and RFID technology provider to work together for implementing the EU ELV regulation.

Regarding the design tools for interior acoustical materials, poro-elastic modeling (PEM) is a major simulation method for single and multilayer 2D panel materials (Dinsmore, 2005). A typical frequency range for this method is 0.1–10 kHz. This method can provide a quick solution with minimal computational needs; enabling simulation of different material combinations; and allowing inverse computation to determine material parameters. Finite element analysis (FEA) and statistical energy analysis (SEA) are commonly used for simulating interior parts, interior systems, and complete vehicles (Manning, 2003). FEA is powerful at low frequencies (below 200 Hz) but has difficulty modeling damping and absorption. SEA is suitable for analyzing high frequency response. The establishment of the FEA and SEA models enables the performance of vehicle sound packages to be predicted without costly vehicle testing. Many CAD software tools for simulating interior sound packages or for sound mapping are commercially available, such as FEWaves, VNoise, AutoSEA, SEA-XP, and Comsol Multiphysics™.

10.8 References

Bies, D. A. and Hansen, C. H. (1996), *Engineering noise control – theory and practice*, Second edn, E&FN Spon.

Chen, Y., Negulescu, I., Sun, L., Jiang, N., Zhang, X. and Parikh, D. V. (2006), 'Acoustical and Flame Retardant Performance of Biobased Nonwovens as Auto Interior Materials', in *Techtextil Symposium North America*, Messe Frankfurt, Atlanta, GA.

Dinsmore, M. (2005), Design tools for acoustical materials, http://www.sae.org/events/nvc/dinsmore_final.pdf.

Fahy, F. and Walker, J. (1998), *Fundamental of Noise and Vibration*, E&FN Spon.

Fischer, D. (2005), 'IMG vs. "One-Shot" Process ThermoGrain,' in *IQPC Workshop – Interior Surfaces and Materials*, International Quality and Productivity Center, Frankfurt, Germany.

Green, E. R. (2005), The principles of acoustical attenuation, http://www.sae.org/events/nvc/green_final.pdf.

Harrison, M. (2004), *Vehicle refinement: controlling noise and vibration in road vehicles*, SAE International, Warrendale, PA.

He, H. (2005), Sound package and vehicle integration, http://www.sae.org/events/nvc/he_final.pdf.

Hoult, P. (2003), Test methods for determining performance of acoustical materials, http://www.sae.org/events/nvc/ws-mon-presentation.pdf.

Ingard, K. U. and Dear, T. A. (1985), 'Measurement of Acoustic Flow Resistance', *Journal of Sound and Vibration*, 103 (4), pp. 567–572.

Kemper, P. and Hobi, G. (2003), 'Hot Melt Adhesives Combine with Nonwoven Fabrics', *Adhesives and Sealants Industry*, pp. 22–24.

Khambete, S. (2003), 'Acoustic Influence of Nonwoven Fiber Products in Automotive', in *2003 Auto Interior Show/Conference*, The Auto Interior Show, Detroit, MI.

Kinsler, L. E., Frey, A. R., Coppens, A. B. and Sanders, J. V. (1982), *Fundamentals of acoustics*, Third edn, John Wiley & Sons Inc., New York.

Manning, J. E. (2003), Predicting the performance of acoustical materials, http://www.sae.org/events/nvc/ws-mon-presentation.pdf.

Müller, D. H. and Krobjilowski, A. (2003), 'Processing, Applications and New Developments of Natural Fiber', in *Beltwide Cotton conferences*, National Cotton Council of America, Memphis, TN, pp. 2406–2420.

Müller, D. H. and Nick, A. (2005), 'Noise, Vibration, Harshness, Lightweight, Costs, Recycling: Too Many Requirements?', in *IQPC Workshop – Interior Surfaces and Materials*, International Quality and Productivity Center, Frankfurt, Germany.

NASA (2003), 'Designing for Disassembly', *NASA Tech Briefs*, pp. 22–24.

Nick, A. and Duval, A. (2005), 'Twinwall sommold innovative mechanical and acoustical felt material', in *13th International Techtextil Symposium for Technical Textiles, Nonwovens and Textile-Reinforced Materials*, Messe Frankfurt, Frankfurt, Germany.

Song, B. H. and Bolton, J. S. (2000), 'A transfer-matrix approach for estimating the characteristic impedance and wave numbers of limp and rigid porous materials', *Journal of the Acoustical Society of America*, 107 (3), pp. 1131–1152.

Weiser, T. (2005), 'Requirements and potentials of innovative interior trim materials', in *IQPC Workshop – Interior Surfaces and Materials*, International Quality and Productivity Center, Frankfurt, Germany.

World Textile Publications Ltd. (1999), 'Changing landscape: notable developments in the automotive sector', *Nonwovens Report International*, July 1999, (340), pp. 34–37.

Wyerman, B. R. (2003), Basics of acoustical materials, http://www.sae.org/events/nvc/ws-mon-presentation.pdf.

11

Leather and coated textiles in automotive interiors

M MEYER, H SCHULZ and M STOLL, Research Institute of Leather and Plastic Sheeting (FILK), Germany

Abstract: Besides textiles, leather and leather substitutes are important upholstery materials in the automotive industry. Compared to textiles they are easier to clean and more durable which causes the use of synthetic leathers in the public transport sector and the use of leather in private automobiles.

The selection of the different leather types such as aniline leather, semi-aniline leather and leathers which are pigmented and finished depends on their intended use and the required quality. Nevertheless, all these leathers are manufactured by a sequence of processing steps. The first steps from raw hide to crust include wet operations performed in drums complemented by mechanical operations mainly to purify the material and to adjust the thickness. The final operations comprise drying and finishing by several lacquer coatings to improve fastness.

With the beginning of the series production of automobiles the need for leather substitutes became obvious as the demand for interior material grew very fast. There was a need for heavy-duty, easy to process and cost-efficient material with leather-like properties. This chapter deals with the development and evolution of polymer coated textiles, commonly summarised under artificial leather, in the automotive industry. It will give an overview of the state of the art regarding textile substrates, coating mediums, coating technologies, material properties and application areas of the various materials.

In the automotive industry the requirements for materials are specified in great detail. This results in extensive testing standards. The EN and ISO standards available today are summarised at the end of this chapter.

Key words: leather, synthetic leather, polymer-coated textiles, automotive interior, producing technologies, physical testing methods, chemical testing methods.

11.1 Introduction

Leather and its substitutes are used in the automotive industry as upholstery material for seats and headrests, as covering material for dashboards, back shelves, door linings, centre consoles, gear shifts, steering wheels and ceilings, and also for accessories. Compared to textile materials, leather and synthetic leather are easier to clean and more durable. Synthetic leather, therefore, is used in the public transport sector (in taxicabs, ship cabins, buses and trams). Leather, however, is more expensive than synthetic materials. It represents exclusivity and comfort. It is used in private cars according to the rule that the more expensive the car, the more leather it will contain.

Leather has been used as an interior material for cars since the invention of automobiles. In the early years of car manufacturing, automobiles were luxury goods finished with luxury material, i.e. leather. From the 1920s–1940s, manufacturers used heavyweight vegetable-tanned and pigmented leathers, finished with an acrylic base coat and nitrocellulose. The 1960s saw the introduction of chromium-tanned nappa leathers, which were at first finished using polyurethane coatings, and therefore showed better fastness properties. Chromium-free leathers with improved dry heat behaviour have now been on the market for 15 years, for use as dashboard coverings, for instance. They are combination-tanned with glutaraldehyde and synthetic tannins.

Today, most modern automotive leathers used in upholstery are chromium-tanned nappa leathers with polyurethane/acrylate finishing. They have a matt-finished appearance and cannot be polished (Wachsmann, 2005). In recent years, however, chromium-free tanned leathers have become increasingly important. Automotive leathers are high-end products with properties adjusted for special use in car interiors, reflected in the standardised requirements described in Section 11.5.

However, the beginning of mass car production in the 1930s required cheaper substitutes. The first leather substitute used in cars was based on nitrocellulose-coated textiles. Then, at the beginning of the 1950s, the first PVC-coated textiles came onto the market. PVC had already been invented a hundred years earlier, but technological difficulties had delayed its technical use (Lueger *et al.*, 1931). In parallel to leather finishing, polyurethane-based substitutes were invented as upholstery materials in the 1960s. These PVC and polyurethane-based substitutes with optimised polymeric systems are still in use today.

The next section will describe the technologies for making leather and leather substitutes, their special qualities and the necessary requirements when they are used as automotive interior materials. A short section will also deal with leather board, a leather waste-based substitute.

A compendium describing the use of leather in the automotive industry has been compiled by Buirski *et al.* (1999).

11.2 Technologies for producing leather for automobiles

Leather is made from the naturally grown collagen fibre network of hides and skins by suitable chemical and physical processes (Reich and Taeger, 2007). The properties of automotive leathers are usually similar to those of upholstery leathers for furniture, with some improved features relating to better abrasive behaviour, improved fastness parameters and minimised gaseous emissions.

The types of leather used in the automotive industry are:

- Aniline leather: full grain leather which is fully penetrated and aniline-dyed; it has no pigmented finish, but is oil and water resistant. Because of its natural appearance, this type of leather shows poorer light fastness and abrasive properties than finished leathers.
- Semi-aniline leather: full grain leather, with a light pigmented finish allowed.
- Pigmented and finished leathers: full grain or light/medium corrected grain, with slight or heavy buffing; with a pigmented finish consisting of several coating layers, embossed with a brand-typical grain or fancy pattern, and showing improved light fastness.
- Coated split leathers: flesh splits with a pigmented finish of several layers, embossed with brand-typical grain structures or pattern.
- Nubuck: leather with heavily buffed grain.

Many automotive manufacturers insist upon full grain leathers, especially in the case of more expensive leather qualities. Buffing is not allowed during the manufacture of these leathers, although they are finished with pigmented lacquers.

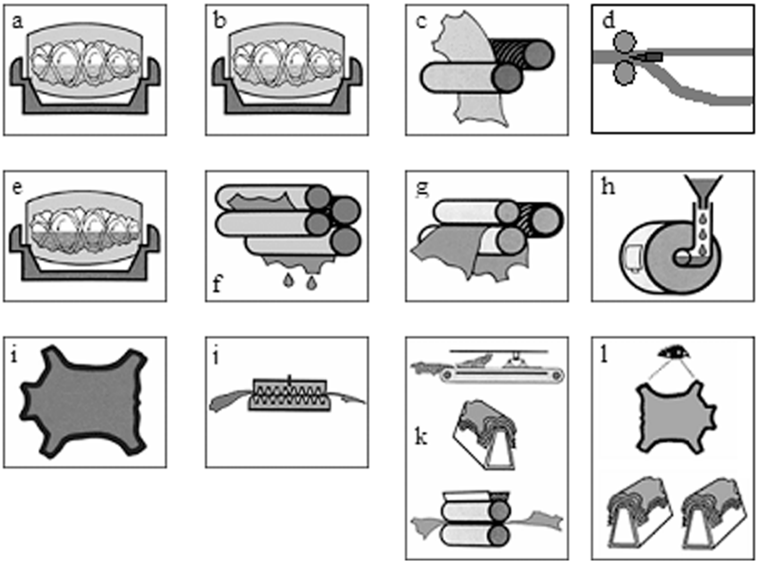
As shown in Fig. 11.1, tanning of hides for the manufacture of leather is a complex procedure consisting of a dozen technological steps. These steps can be divided into a sequence of four technological sections: beamhouse, tanning, retanning/wet end, and finishing. Each of these sections comprises both chemical and mechanical operations. The chemical operations of the first three stages are performed in rotating drums or mixers. The volumetric capacity of these drums ranges from 100 kg up to several tons, to contain raw material and float. Water is used as the transport medium for chemicals, and as float and solvent. After working in the raw materials, the hides are not dried until the finishing stage. Therefore, an efficient work system and suitable preservation of the material and floats are necessary.

Amongst others, the most important difference between making leather and processing textiles is the handling of pieces, and the fact that leather is a naturally grown raw material with all its visible defects.

The principles of the various tanning technologies have been described in detail elsewhere (see references in Section 11.6).

11.2.1 Raw material

Leather is made from animal hides. For automotive leathers, bovine hides are used almost exclusively. Trading companies buy hides from abattoirs,



11.1 The process steps of leather manufacturing are soaking (a), liming (b), fleshing (c), splitting (d), deliming – bating – pickling – tanning (e), sammying (f), shaving (g), wet end (retanning, dying, fat liquoring) (h), drying (i), milling – staking (j), finishing (k), final sorting (l) (with permission of German Leather Association VDL).

preserve them by salting or cooling, and trade them worldwide. The quality of the raw material strongly affects the final leather quality, and therefore the final price.

On the one hand, the quality of the hides depends on the slaughtering itself and also the preservation after slaughtering. On the other hand, the livestock husbandry conditions are responsible for the final quality of the leather. Parasites and insect bites, physical injuries inflicted by the farmer, by barbed wire or other animals lead to individual defects of the grain, which reduce the leather's quality. The tanners are unable to notice or control many properties of the raw hides because of the pelage – and the tanner may buy a pig in a poke.

11.2.2 Beamhouse

The aim of the beamhouse operations is the unhairing, purification, bleaching and opening up of the structure of the hides. The beamhouse processes begin with soaking and washing the hides several times in order to remove dung and non-collagenous proteins, and to rehydrate the salted hides. During soaking and washing, chemicals such as surfactants, enzymes and soaking auxiliaries are added to improve and speed up rehydration and cleaning.

The purpose of the subsequent liming step at pH ~12.8 is to remove the epidermis and hair (keratin) and open up the collagen fibre structure. To do this, the hides are soaked overnight in solutions of sodium and calcium hydroxide, sharpened by the addition of sodium sulfide. The addition of sulfide is necessary to reduce the disulfide bridges of the keratin, making it susceptible to alkaline deterioration. After washing again, the now hairless pelts are neutralised by deliming, using organic acids in combination with ammonium sulfate. For the manufacture of soft leathers, the pelts are bated in an enzyme bath to further open up the structure.

11.2.3 Tanning

Before tanning, the pelts have to be adjusted to acidic pH. However, pure collagen swells in acid at pH < 5 with a maximum swelling at pH 2.8. Swelling, therefore, has to be prevented during leather manufacture and the pelts are acidified in the presence of high amounts of sodium chloride (5–10%) (pickling), which strongly suppresses the swelling in order to prepare the collagen structure for tannage.

Today, around 80–90% of leathers in the world are tanned with chromium-III salts, in combination with synthetic tannins as retanning agents. Only small amounts of leather are tanned with combinations of aldehydes, synthetic and vegetable tannins (free of chromium leather, FOC).

The resulting wet products are sammied, that is, pressed mechanically to obtain the slightly wet semi-finished wet-blue (Cr-III salts) and wet-white (aldehyde-synthetic), respectively. The semi-finished products are traded worldwide.

11.2.4 Wet end: retanning, dying, fat liquoring

Tanneries which do not cover the complete technology buy semi-finished leather (wet-blue, wet-white) on the worldwide market place for further processing – comprising wet end and finishing. Wet-end technologies include retanning, e.g. by synthetic tannins and/or vegetable tanning agents, followed by dying and fat liquoring. In special cases, the resulting crust leathers are subject to after-treatment with special hydrophobic and fire protective agents. All these steps are again performed in rotating drums. Finally, the crust leathers are dried, either on a toggle drier, by vacuum drying or hang drying.

11.2.5 Finishing

Finishing is the final coating of the leather's surface. Today, finishing is one of the most important steps in leather manufacturing, especially for the automotive sector. The finish strongly affects many properties of the leather, such as fastness to light, sweat, water and oil, improved abrasive and soiling behaviour, and these properties facilitate application in automobiles. The finish is the face of the leather, printable with artificial brand grain structures. An overview of the techniques and systems used can be found in Reich (2006). Requirements differ between the US, European and Asian markets. In the US, there is a demand for higher abrasion properties, whereas in Europe higher flex performance is needed. The Japanese market tends to require the combination of both of these properties (Tomkin, 2005).

With regard to finishing techniques, leather is a complicated substrate because of its flexibility, softness, rigidity, high porosity, hydrophilicity, and above all its thermal sensitivity. Many coating techniques used for other materials, such as foils of synthetic polymers, textiles or paper, are also suitable for leather finishing. In principle, the finish is composed of different layers: prefinish, impregnation, base coat and top coat. The layers increase in hardness from prefinish to top coat. Finishing recipes consist of polymer components (polyacrylates, polybutadienes, polyurethanes), colouring pigments, softeners, hardeners/cross-linkers, UV protective agents, and further additives. Spraying is the most common application technology, though to an increasing degree reverse roller-coating, and on a limited scale, brush-coating, casting and screen process, are also in use. Between these coating operations, mechanical operations such as staking and milling are suitable to increase softness. Over the last twenty years, finishing systems have changed from solvent-based to water-based systems (Reich, 2006).

In Europe, finishes are built up by a larger numbers of lighter coatings, whereas in the US a minimum number of heavier coats is applied. Finishing lines in the US are long multi-stage plants designed to obtain high throughput. European tanneries, in contrast, often combine different techniques, which gives more flexibility when changing colours or products. American leathers may show higher pigment-to-resin ratio than leathers produced in Europe, thus interfering with the flex properties (Tomkin, 2005).

11.2.6 Mechanical operations

Chemical operations in leather manufacture are also accompanied by a set of mechanical operations. In contrast to textile or synthetics technologies, the tanner has to handle the pieces, and so all mechanical operations are oriented towards this requirement. The limed hides are fleshed by fleshing machines. Fleshing is usually combined in one production line, in which a splitting machine splits the pelts with a sharp band knife, mostly into two parts – grain split and flesh split. The tanned hides are shaved to unify the thickness, then sammied before storage. These semi-finished wet-blues or wet-whites are traded around the world. Tanneries operating wet-end technologies often have to shave their wet semi-finishes again. At the end of the wet processes, the leathers are dried either on a toggle dryer, by vacuum drying or hang drying. During the finishing operations, the leathers are adjusted and unified in softness by milling and staking. If corrected grain is allowed, the surfaces of the crust leather are buffed, and the finished leathers are often embossed to produce a unified brand-typical appearance.

11.2.7 Sorting

Each leather is unique as each animal was an individual – with visible defects. The price to be obtained for leather depends dramatically on its visual appearance and so leathers are sorted several times during the manufacturing process. The first sorting step is usually carried out at the semi-finished stage, but sometimes the pelts have already been sorted before this. Furthermore, crust leathers are sorted at the end of the wet-end process as well as at the finished stage, and especially in the automotive sector, the cut pieces are sorted before the coverings are sewn. Sorting is always performed by trained employees. Complete automation of sorting has so far only been realised at a rudimentary level.

11.2.8 Further treatment of the leather

The subsequent processing steps comprise a multitude of further stages, which in rare cases are performed at the car manufacturing plant itself, although more often at independent factories, such as punching, sewing and upholstery factories and component suppliers. The tannery usually receives a release note for a leather batch from the car manufacturer. Leather for certain purposes is frequently developed specifically by the car manufacturers and tanneries. This development comprises, e.g., colour, design, grain, thickness, firmness, climate properties, odour, and even the permitted visual characteristics. Reference samples of these specially developed leathers are produced and deposited at the car manufacturer's and the tannery. The car manufacturer then buys batches of this leather and has it punched and sewn, partly by the tannery itself, partly by affiliated factories. Thereafter, it is further processed by component suppliers, and the components themselves are delivered at the necessary time to the car manufacturer's production lines.

Punching is one of the most important steps where money is made or lost, because the yield of punched area in relation to the required area per lot is determined as a result of negotiation between supplier and customer before the leathers are produced. Nearly all leathers show certain visible defects which are often of natural origin – such as scars, insect bites, coarse patches – and only in some cases may derive from technological sources. However, most of these characteristics are not accepted by customers. During punching, therefore, attention must be paid to circumvent these patches or hide them in non-visible areas. Furthermore, leather for automotive applications is divided into different regions (ABC), depending on its intended use. For seat upholstery, only the core region of the butt is allowed to be used, whereas coverings of gear shifts or door linings can also be made from the belly. Cutting skill determines profit or loss.

11.2.9 Technological trends

Technological trends are heading in two directions, one relating to the whole leather industry and the second pertaining especially to automotive leather. There is generally a tendency to eliminate (aqua)toxic, mutagenic and teratogenic chemicals from the whole process. Furthermore, automotive leather is being optimised with regard to its utilisation properties, such as haptics, abrasion and soiling behaviour, fastness and water vapour permeability.

With regard to beamhouse processing, the most important aim is to reduce, or completely eliminate, sulfide application for unhairing. Oxidative techniques and enzymatic processes are alternatives discussed nowadays (Heidemann, 1993; Trommer, 2002; Bronco *et al.*, 2005; Brady *et al.*, 1990; Alexander, 1988). However, neither of these techniques could completely displace the established technologies.

The use and handling of chromium salts are not risk-free, and therefore many attempts have been made to substitute broadly used chromium tannage. Glutaraldehyde tannage was introduced in the 1980s. Nevertheless, technologically and economically, chromium tannage is still more advantageous than wet-white tannage, which moreover did not produce the expected ecological benefits (Trommer and Kellert, 1999; Wilford, 1999).

The manufacture of chromium-free leather leads to the blocking of the cationic side chains of collagen as a result of aldehyde tannage. However, established auxiliary systems are optimised for chromium tanned leathers, where amino groups are still available for further reactions. Therefore, new and more flexible wet-end auxiliary systems are needed for the retanning, dying and fat liquoring of FOC leathers (Günther, 2002).

During retanning, leather can be further upgraded by the addition of microspheres. Their distribution is based on diffusion, and they become deposited predominantly in loose areas and voids. After drying, the microspheres are activated by exposure to pressureless steam, which does not wet the leather but softens the shell of the microspheres. The heat allows them to expand to form micro-cells. This results in a permanent filling effect, without making the leather heavy and hard (Tegtmeyer *et al.*, 2007).

As already described, the leather finish plays a very important role, especially in the automotive sector. Foam finish is currently in use to achieve softer surfaces. The technologically difficult technique of foaming has been completed by the addition of microspheres to the finishing layers. Using microspheres as a component of established finishing systems influences several parameters in a positive way, such as the masking of defects, better matting behaviour and the prevention of noise, soiling and hydrolysis (Simpson *et al.*, 2005).

The use of cool pigments is another very new technology in the finishing process, especially to prevent black and dark leathers from heating up in the sun. In one system, the pigments are transparent to IR radiation, but the leather surface reflects IR (Fennen *et al.*, 2006). The other system uses pigments which appear black in the visible spectrum, but reflect IR radiation (de Volder *et al.*, 2007). Compared to dark leathers without cool pigments, the resulting differences in surface temperature can reach 20°C.

In addition, the technique of ink jet printing is already used to individualise leather goods. Printing inks which are curable by UV radiation have now been developed, leading to printing with a high level of fastness (Rudolph, 2006).

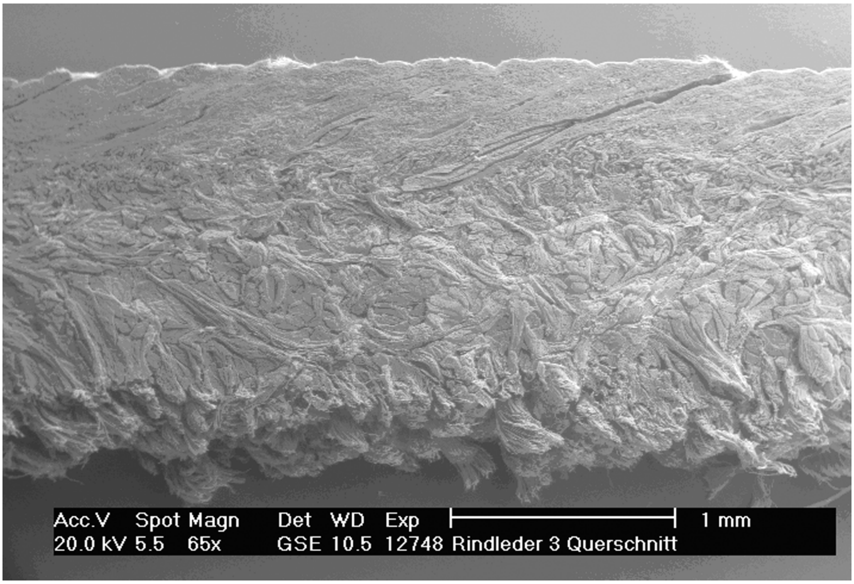
Powder coating to avoid solvents, and radiation-curing lacquer systems to eliminate chemical hardening of the binders are among new technological trends summarised by Günther (2002) and Reich (2006). However, both principles are still under investigation.

11.3 Technologies for the production of coated textiles and artificial leather for the automotive industry

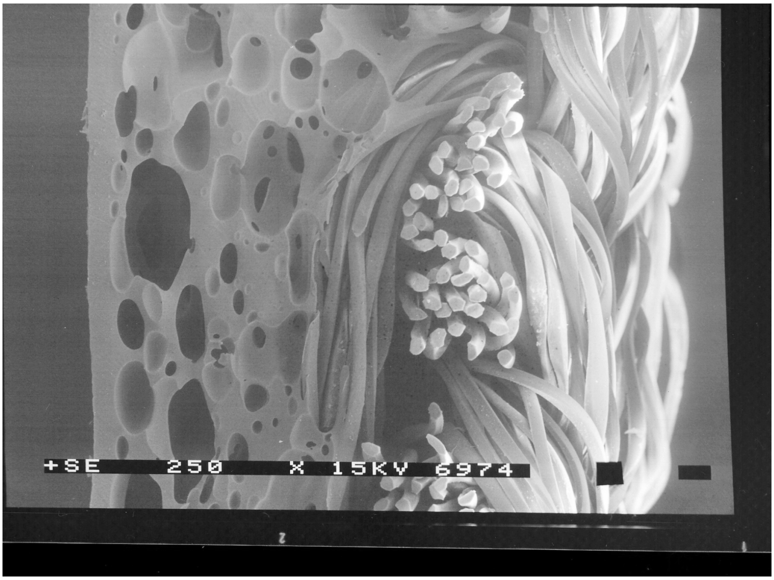
Coated textile substrates – summarised under the name artificial leather – compete with ‘real leather’ in the different fields of application, including of course for upholstery fabrics, although the structure of conventional artificial leathers differs basically from that of leather.

As described, leather consists of a meshwork of collagen fibres, which becomes continuously denser towards the grain side (Fig. 11.2). Artificial leathers are compound materials made of textile substrates, consisting mostly of several polymeric layers (Fig. 11.3).

Leather was the preferred material for the first motor-powered vehicles. The limited numbers of individual models, each produced laboriously by hand, were upholstered by the saddler using traditional technology. Supplying the demand for upholstery leather was not yet a problem, and in relation to the price of the automobile, costs played a subordinate role. This situation changed with the conversion of the automobile from a luxury car into a basic commodity, and when mass production started. To produce larger quantities, it was necessary to find alternative upholstery and covering materials to the expensive leather, which was also harder to process. There was a call for a high-quality substitute for leather.



11.2 SEM of a cross-section of a bovine leather.



11.3 SEM of an artificial leather with a foamed interface layer.

The demand was for a material which looked nearly as expensive and aesthetically-pleasing as leather, which had a similar smooth surface feel (haptics) and similar useful properties. However, the processing needed to be less laborious than for leather, and much cheaper.

The first leather substitutes, used in automobiles since the turn of the century (1900), were nitrocellulose (NC) artificial leathers known since about 1880. They were first used as upholstery fabrics in series production in 1927 by Citroen, Fiat and Ford. These nitrocellulose artificial leathers remained in use until about 1940 in many areas, e.g. as upholstery fabrics for automobile seats. But a general breakthrough in the use of synthetic-based upholstery fabrics could not be achieved. The properties of NC artificial leathers were too different from those of natural leather.

Although the discovery of polyvinyl chloride (PVC) goes back as far as 1835 (Regnault), it was about 100 years before the first industrial production started (Lueger, 1894; Münzinger 1940).

Once the difficulties of controlling even polymerisation, stabilising and processing had mostly been resolved, PVC became one of the most important types of thermoplastics. Its variety and simplicity of processing, excellent technical properties and low price opened up a wide field of applications.

The production of plastified PVC pastes and their application in textile coatings was first described in DE 685 839 of the Kötitzer Ledertuch- und Wachstuchwerke AG (1937) and in 1938 in the patent of BASF. In automobiles, foils made of plastified PVC were first used on paperboard for textile coverings in 1943. The war period, along with the economic restrictions imposed by post-war occupying powers, led to a short interruption of this development, but in the following decades it was more dynamic. From 1949 onwards, when PVC artificial leathers were first used for mass production in automobiles, the different types of PVC-based artificial leather became the predominant cover fabrics for upholstery and covering and lining materials in motor vehicles. Both car manufacturers and customers considered them as cheap substitutes, and this view was held over a long period of time, which was disadvantageous for all kinds of plastics. Today, however, vehicle interiors would be unthinkable without plastics.

Despite, or maybe due to, the constant rise in the quantities of both leather and artificial leather processed for use as vehicle interior covering materials, the properties required of the material have continued to increase – and are still doing so. This is true for strength and elongation properties, and especially for visible and haptic appearance and comfort behaviour, particularly temperature and humidity management.

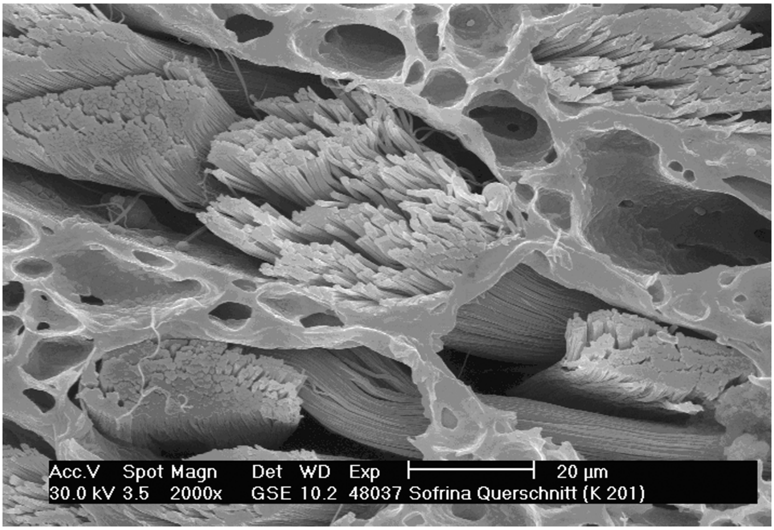
The impregnation, coating or other finishing of textile substances normally produces impermeable, compact materials with unfavourable properties, which cannot substitute for leather. Only more functional system solutions, both in the development of the substrates (microfibres) and the formation of a porous polymer coating, provide better comfort. In addition to elongation and strength properties, which are particularly found in textiles, the so-called breathability of the polymer compounds plays a large role. Thus, the permeability, absorption and humidity releasing capabilities are influenced. For synthetic materials this is achieved by microporosity and/or hydrophilicity, and it is described by the water vapour permeability (WVP) or the absorption of vapour capability (AVC) (Träubel, 1999).

11.3.1 Textile substrates

The textile substrate used influences how the goods will turn out with regard to the chosen fabrics (woven fabrics, knitted fabrics, non-woven material), and also with regard to the chosen fibres (natural or synthetic fibres, fibre yarn count), for properties such as visual appearance, grip, comfort, and in particular the mechanical properties of the compound material.

Processing non-woven material using micro-fibril fibres achieved a considerable improvement in the material's qualities (Anon., 1988). That is why these products are called leather materials (Nagoshi, 1987). Products such as Alcantara, Clarino, Sofrina and Lorica have become well known. These micro fibres with a fibre diameter <1 µm are generated by forming matrix fibril fibres. Due to this matrix fibril structure, these fibres can also be processed in conventional plants for non-woven material production. To create excellent material properties (strength, stress-strain behaviour, softness), flexibility of the micro fibre fibrils is necessary, which is implemented by the extraction of the matrix (Fig. 11.4) However, this process step is both time- and energy-consuming and results in high prices for the leather material.

Based on their high requirement profiles, especially with regard to strength, substrates consist mainly of a high proportion of synthetic fibres (mostly



11.4 SEM of a micro fibre bundle (Sofrina).

polyesters). These substrates thus do not meet, or do not meet satisfactorily, the requirements for compound materials based on natural raw materials with high comfort levels.

The use of natural fibres for the production of coating substrates is restricted. Non-woven materials can be made from viscose fibres by needle-punching, and also by water-jet interlooping, but this shows particularly low wet strength, and therefore certain coating techniques, such as coagulation procedures, are not possible.

Some fibre manufacturers have modified viscose fibres. The so-called Lyocell procedure produces fibres which show an increased wet strength and can thus be used to process non-woven materials, which are coated with the help of the coagulation procedure (Mädler, 1998).

The fundamental idea behind the use of non-woven materials in textile compound structures is based on the symbiosis of the properties and the advantages of the non-woven material in including functional fibres (such as super absorbent fibres), or in combining with other area-measured material, such as woven fabrics, knitted fabrics, clutch, foils, etc., to meet the often very heterogenic requirements made of the textile backing material (Schäfer, 1992) (Fig. 11.5)

11.5 SEM of a fabric-needleflet composite.

11.3.2 Porous polymer layers

The known chemical and physical foaming procedures lead mainly to closed-cell structures with pore sizes between 20 and 200 μm and above (Schürer, 1993; Günter, 1993). Chemical foaming agents such as azodicarbonamide are used for foaming PVC pastes or plastic melts. The physical foaming procedures are based on the use of combustible hydrocarbons, such as pentane and isobutene, as well as so-called microspheres (micro-hollow balls made of plastics with enclosed gases) or the mechanical integration of air in liquid plastics or melts.

Like compact coatings, closed-cell structures only have low permeability and are thus not suitable as leather substitutes. The formed cell walls can be partly destroyed by subsequent mechanical destruction or thermally-initiated expansion of the micro-hollow balls, and the foam can be made permeable.

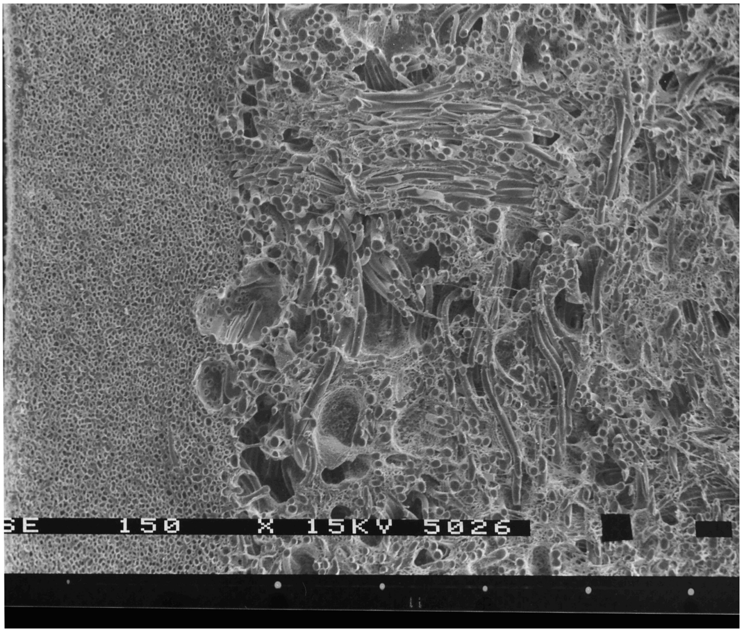
A polymer layer of pores communicating with each other can only generally be achieved by the precipitation of a polymer solution. The advantage of a layer generated in that way is that the sorption capability is allowed for, independent of the thickness of the formed layer, and thus layer thicknesses of over 100 μm can be achieved. Depending on the conditions, micro and/or macro pores (0.1 μm to 50 μm in size, in exceptional cases 100 μm) can be produced.

In 1958, a process for producing microporous coatings from polyurethane solutions by pre-coagulation and subsequent coagulation had already been published. In this process, a film applied to a polyurethane sheet material was pre-coagulated in the organic solvent under climate control (humidity of air >90%) and coagulated in a precipitation bath consisting of a solvent/non-solvent mixture (dimethylformamide/water) (Fig. 11.6). The remaining solvent was subsequently washed out (Wittke, 1983).

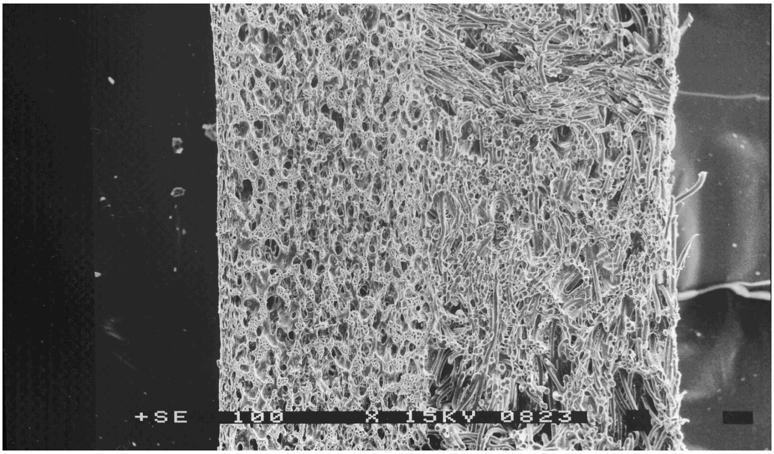
With constant further development, the quality of this process was improved and production technologies rationalised (such as the elimination of the laborious pre-coagulation phase) (Träubel, 1999; Merkle and Tackenberg, 1984; Freitag, 1983).

At the end of the 1970s/beginning of the 1980s, the range of poromeric materials was extended with impregnated woven materials (so-called immersed coagulates) for light upper materials and garments (Lomax, 1984).

A procedure was developed at the then Forschungsinstitut für Leder- und Kunststofftechnologie (Research Institute for Leather and Plastics Technology) to use a mechanically foamed polyurethane solution in dimethylformamide for the coagulation procedure (Stoll, 1994). By forming a so-called double structure, as seen in Fig. 11.7, the production of a solid porous layer with high water vapour permeability was successfully achieved. The technology described requires special systems engineering, consisting of a coat application unit, precipitation and washing baths, and a dryer.



11.6 SEM of an artificial leather on the base of a non-woven with a coagulated top coat.



11.7 SEM of a porous artificial leather on the base of a non-woven with a microporous foamed coat.

Especially designed polyurethanes, dissolved in low-boiling solvents and capable of absorbing a large amount of water, can be applied to suitable substrates in conventional coating machinery plants. In graded temperature zones, the solvent vaporises first so that the polyurethane in the non-solvent gradually coagulates, followed by the evaporation of the water. In this way, very uniform pores can be achieved, up to a maximum of 3 to 7 μm, which allow the water vapour molecules to pass unobstructed. However, only layers with a thickness of < 100 μm can be formed by this so-called vaporisation coagulation (Loogk *et al.*, 1983; UCB–Firmenschrift, 1995; Träubel *et al.*, 1994).

An alternative way of forming permeable layers is with hydrophilic coatings. By integrating hydrophilic components into the polymeric chains (polyurethanes or polyesters), the transport of water molecules is possible without the existence of pores. The hydrophilic groups are able to absorb the water molecules and transmit them to an adjacent group. By using a different water vapour partial pressure at each side of the coating, water molecules are absorbed on the wet side and transmitted via the hydrophilic groups to the dry side. There they will be released into the environment. The polyurethane or polyetherester membranes used (such as Sympatex) are very thin (10–25 μm), as the WVP strongly reduces with thickness (Träubel, 1999; Hürten and Spijkers, 1997)

Over the past years, an improved procedure for forming a polymer layer with a porous capillary structure has been developed at the Research Institute of Leather and Plastic Sheeting, in cooperation with the Institute for Applied Polymers (IAP) in Golm. The procedural principle applied is based on the precipitation of a polyurethane (PUR)–solution in dimethylformamide (DMF), using the controlled release of a means of precipitation from a thermally-sensitive hydrogel, which is added to the solution before application.

When a certain specific temperature for this material has been reached, water will be released from the hydrogel. This additional water exceeds the stability limit of the ternary system DMF/PUR/water and by nucleation starts the precipitation process.

The hydrogels suitable for the new procedure are based on the development of a linear poly-n-isopropylacrylamid (PNIPAM) copolymer with a reproducible phase transformation at about 50°C, a so-called LCST (lower critical solution temperature) procedure. In order to avoid spontaneous coagulation when adding the hydrogel to the PUR solution, a casing of the gel particles based on styrene/divinylbenzene (DVB) is necessary (Mädler, 2005; Bohrisch *et al.*, 2007).

The feasibility of the new coagulation procedure has been proven and three main advantages were achieved compared to the conventional procedure:

(a) a 2- to 3-fold increase of process speed,
(b) variable possibilities of texturing/capillary structure and
(c) improved sorption properties of the polymer layers generated.

11.4 A special case: leather board

Leather board is made up of an irregularly laid mixture of fibres, with different leather fibres as the skeleton substance. This fabric is bonded using mainly natural binders to obtain a firm board-like material.

Leather board is produced in accordance with paper technologies. Shavings which accrue during thickness-machining and waste from leather-cutting are milled to fine fibres and powder. These natural fibres are pulped with water, mixed with natural rubber or other synthetic-based lattices, emulgators and further additives, and poured out onto a sieving belt. The wet film is pressed continuously between roller presses to remove the water mechanically and is then dried in a heating channel.

Leather board is based mainly on natural materials; it smells like leather, feels board-like, can be imprinted with many structures and finished with lacquers. It is used in the shoe industry as insole material and for stiffeners, as well as to manufacture, for example, bags and belts.

Leather board has also been tested for use as automotive interior material (Richter, 2005). With regard to mechanical parameters such as tensile strength, elongation or tear strength, the leather board has poorer properties than leather. Its use for specific applications, such as injection-moulded door interiors or back shelf covering, seems possible. However, light fastness, and especially emission behaviour, proved to be problematic parameters (Richter and Schulz, 2006). Lubricants were identified as one reason for the high gaseous emissions. Both the fat liquors used in the leather board manufacturing process and those brought into the process through the raw materials, e.g. the cutting waste, seem to be a problem. Leather board can, therefore, be manufactured for automotive interior materials. However, it is important to select pure raw materials to keep within the specification limits.

11.5 Testing of leather and coated textiles for automotives: physical and chemical requirements

The specifications for automotive leather and coated textiles contain many different requirements depending on their use in the car interior. Over the last ten years, the various activities of different CEN and ISO working groups have resulted in many new ISO and EN methods. For many standard parameters, EN and ISO standards are now available (ISO = International Organisation for Standardisation; CEN = European Committee for Standadisation; EN = European Standard).

The most important specified parameters and their corresponding test methods are summarised in Tables 11.1 and 11.2.

Table 11.1 Important specified parameters for automotive leather and harmonised test methods used

Property	Test method
Sampling and conditioning	ISO 2418, ISO 2419
Apparent density, mass per unit area	ISO 2420
Thickness	ISO 2589
Surface coating thickness	ISO 17186, VDA 230-204
Tensile strength, percentage elongation, elongation at break	ISO 3376
Tear load	ISO 3377-1
Permanent elongation	DIN 53360
Adhesion of finish	ISO 11644
Stitch tear resistance	ISO 23910
Seam fatigue	Different internal tests, no harmonised method
Stiffness in bending	VDA 230-209
Flex resistance	ISO 5402
Abrasion	ISO 17076, VDA 230–210, many different test methods are used
Scratch resistance	Different internal tests, no harmonised method
Cold flexibility	ISO 5402 at low temperatures
Cold impact	Different internal tests, no harmonised method
Heat storage, climate change test	ISO 17288 and many different internal tests, evaluation of colour change (ISO 105-A02 or -A05), appearance and shrinkage
Hydrolic ageing	VDA 230-208, ISO 17288
Light fastness and hot light ageing	ISO 105-B06, VDA 75202, SAE J 1885
Colour fastness to and for rubbing	ISO 11640
Colour fastness to perspiration	ISO 11641
Colour fastness to migration	ISO 15701
Resistance to chemicals, cleaning agents, sun lotions, insect repellents and more	Many different internal test methods
Fogging	DIN 75201, ISO 14288
	VDA 277
Emission behaviour (VOC and SVOC)	VDA 278
	VDA 270
Smell	VDA 275
Formaldehyde emission	ISO 17074, FMVSS 302, DIN 75200
Burning behaviour	ISO 14268
Water vapour permeability	VDA 230-206 part 1 and 2
Stick-slip behaviour	ISO 5398 part 1, 2, 3, 4
Total chromium content	ISO 17075
Chromium-VI content	ISO 4048
Fat, matter soluble in dichloromethane	ISO 17070
PCP	ISO 4684
Water content, volatile matter	ISO 4045
pH value	

German car manufacturers are very committed to harmonising methods for testing automotive leather, textiles and coated textiles. Representatives of all German car manufacturers are working in different groups of the Association of the German Automotive Industry, VDA, creating new test methods as required and adjusting common methods for application in the automotive industry. The aim of this work is to enhance the quality of leather and coated textiles and reduce testing costs. Examples of newly developed testing methods are those for stick-slip behaviour, determination of loose grain effect of leather and determination of stiffness in bending.

Many other activities are still in progress to develop objective and realistic test methods, e.g. to describe the soiling behaviour of material surfaces, evaluate surface feel or measure the cooling effects of leathers treated with special colours and pigments.

11.6 Sources of further information and advice

Over the last century, hundreds of books about leather chemistry and technology have been published. The chemical and technological background has been described in detail, e.g. in Stather, *Gerbereichemie und Gerbereitechnologie* (1957), in Herfeld, *Bibliothek des Leders*, published in several volumes (1990), in Heidemann's *The Fundamentals of Leather Manufacturing* (1993) and the anthology of Reich (2003). The most recent work was published with Reich as the main author on behalf of Taeger (2007). This book gives an excellent overview, especially of the chemical background to leather manufacture.

The most popular scientific journals in this field are the *Journal of the American Leather Chemists Association* (JALCA, USA), the *Journal of the Society of Leather Technologists & Chemists* (JSLTC, UK) and *World Leather*, in which market trends are discussed. The International Union of Leather Technologists and Chemists Societies (IULTCS; www.iultcs.org) is the umbrella organisation for the various national leather chemistry and technology societies. This organisation is responsible for the biennial congresses, which are the most important scientific events in this sector.

The materials and technologies for manufacturing compact and microporous leather substitutes are described in detail by Träubel in his book *New Materials Permeable to Water Vapor* (1999). The manufacturing and material details of poromerics are described in the books of Albrecht *et al.* (2000) and in Günter (1993). PVC-coated fabrics are described in Felger (1986). The machinery, equipment and technologies for manufacturing coated fabrics are described in Hufnagl *et al.* (1981) and Giessmann (2003).

In addition, short reviews describing leather-like materials are published in the following encyclopedia entries: 'Leather Imitates', Ullmanns *Encyclopedia of Industrial Chemistry* and 'Man-made leather', Kirk-Othmer,

Table 11.2 Important specified parameters for automotive coated textiles and harmonised test methods used

Property	Test method
Sampling and conditioning	DIN 16909, ISO 2231-B
Total mass per unit area	ISO 2286-2
Thickness	ISO 2286-3
Tensile strength, percentage elongation, elongation at break	ISO 1421-1
Tear resistance	ISO 4674-1
Permanent elongation	DIN 53360
Coating adhesion	ISO 2411
Stitch tear resistance	DIN 54301
Seam fatigue	Different internal tests, no harmonised method
Stiffness in bending	VDA 230-209
Flex resistance	DIN 53351, DIN 53359
Abrasion resistance	ISO 5470 part 1 and 2, VDA 230–210, many different test methods are used
Scratch resistance	Different internal tests, no harmonised method
Cold flexibility	DIN 53351 and DIN 53359 at low temperatures
Cold impact	VDA 237-101, EN 1876 part 1 and 2, ISO 4646, ISO 4675, different internal tests, no harmonised method
Scratch resistance	Different internal tests, no harmonised method
Heat ageing, climate change tests	EN 12280-1 and many different internal tests, evaluation of colour change (ISO 105-A02 or -A05), appearance and shrinkage
Hydrolic ageing	VDA 230-208
Light fastness and hot light ageing	ISO 105-B06, VDA 75202, SAE J 1885
Colour fastness to rubbing	ISO 105-X12
Resistance to amines	Some internal test methods, VDA method in preparation
Resistance to chemicals, cleaning agents, sun lotions, insect repellents, etc.	Many different internal test methods
Burning behaviour	FMVSS 302, DIN 75200
Stick-slip behaviour	VDA 230-206 part 1 and 3
Coefficient of friction	ISO 8295
Fogging	DIN 75201, ISO 6452
Emission behaviour (VOC and SVOC)	VDA 277 VDA 278
Smell	VDA 270
Formaldehyde emission	VDA 275

Encyclopedia of Chemical Technology. The most important journals in this field are the *Journal of Coated Fabrics,* the *Journal of Industrial Textiles*, and *Coating*.

11.7 References

Albrecht, W.; Fuchs, H.; Kittelmann, W.: *Vliesstoffe*; Wiley-VCH, Weinheim, (2000) – ISBN-10: 3-527-29535-6.

Alexander, K. T. W.: The 1988 John Artur Wilson Memorial Lecture: Enzymes in the Tannery – Catalysts for Progress. In: *JALCA* 83 (1988) 9, pp. 287–316.

Anon.: What is a Microfibre? In: *Textile Horizons* (1988) 4, pp. 49–50.

Bohrisch, J.; Hahn, M.; Mädler, A.; Stoll, M.: Synthesis and properties of new thermosensitive polymer systems. In: *Journal of Applied Polymer Science* 104 (2007) 4, pp. 2122–2129.

Brady, D.; Duncan, J. R.; Russell, A. E.: Model for Proteolytic Depilation of Skins. In: *JALCA* 85 (1990) 9, pp. 334–343.

Bronco, S.; Castiello, D.; D'Elia, G.; Salvadori, M.; Seggiani, M.; Vitolo, S.: Oxidative Unhairing with Hydrogen Peroxide: Development of an Industrial Scale Process for High-Quality Upper Leather. In: *JALCA* 100 (2005) 2, pp. 45–53.

Buirski, D.; Wachsmann, H.; Daniels, R.; Landmann, W. (eds.): *Sitting comfortability, A world leather publication*, Worlds Trades Publishing, Liverpool (1999).

de Volder, N.; Hallmanns, M.; Levy, J.: Annoying Energy II. Solar Heating of Dark Leather, XXIX. Congress of the IULTCS and the 103rd Annual Convention of the ALCA, Washington DC, USA, 20–24 June 2007.

Felger H. K.: *Kunststoff Handbuch 2/2 Polyvinylchlorid*, 2. Auflage, (1986) – ISBN-10: 3-446-14161-8.

Fennen, J.; Döppert, F.; Hess, M.: Solar Reflective Leather; IULTCS II. Eurocongress Istanbul, 24–27 May 2006.

Freitag, H.: Über die Herstellung von synthetischem Leder – Vlieskunstleder. In: *Coating* 16 (1983) 8, pp. 210–214.

Giessmann, A.: *Substrat- und Textilbeschichtung*, Springer Verlag, Berlin (2003) – ISBN-10: 3-540-43426-7.

Günter, O. (Ed.): Kunststoff-Handbuch, Vol. 7 Polyurethane, Ch. 10, 3rd edn. München, Wien: Carl Hanser Verlag (1993) ISBN 3–446–16263–1.

Günther, E.: Innovationen und Trends bei der Oberflächenveredlung von Automobilleder. In: *Leder und Häutemarkt* (2002) pp. 25–30.

Heidemann, E.: *The Fundamentals of Leather Manufacturing*. Darmstadt: Eduard Roether KG und Verlag (1993). – ISBN 3–7929–0206–0.

Herfeld, H.: *Bibliothek des Leders*. 2. Aufl. Frankfurt a. M.: Umschau Verlag (1990).

Hufnagl, W. *et al.*: *Kunstledertechnik*, 1. Aufl. Hothing Fachbuchverlag, Heidelberg, (1981).

Hürten, J.; Spijkers, J.: Laminierung von Sympatex Membranen. Teil 1 Laminierung von Sympatex Membranen. Teil 2 Adhäsion – *Kleben & Dichten* 41 (1997) 1–2, pp. 34–36; Adhäsion – *Kleben & Dichten* 41 (1997) 3, pp. 34–37.

Lomax, R.: Recent Developments in Coated Apparel. In: *Journal of Coated Fabrics* 14 Oct (1984), pp. 91–99.

Loogk, M.; Döring, E.; Reich, G.: Vergleichende Untersuchungen zur Beurteilung der

Abrieb und Scheuerbeständigkeit von Leder und Kunstleder Leder Schuhe. *Lederwaren* 18 (1983) 6, pp. 277–279.

Lueger O.: *Otto Luegers Lexikon der gesamten Technik und ihrer Hilfswissenschaften.* Stuttgart: Deutsche Verlags-Anstalt, 1894–1899 (1894).

Lueger, O. *et al.*: *Otto Luegers Lexikon der gesamten Technik*, DVA, Stuttgart, 3. Auflage, (1931).

Mädler A.: *Schlussbericht PUR-Beschichtung von Lyocellträgern*, FILK GmbH Freiberg (1998).

Mädler, A.: *Ausbildung und Charakterisierung von, permeablen Werkstoffverbunden durch Fällung von Polymerstrukturen*/FILK GmbH. Freiberg (2005). Forschungsbericht.

Merkle, R.; Tackenberg, W.: Alternatives to Leather: Laif Poromerics. In: *Journal of Coated Fabrics* 13 Apr (1984) 4, pp. 228–238.

Münziger, Walter M.: *Kunstleder-Handbuch*. Berlin-Wilmersdorf: Pansegrau (1940).

Nagoshi K.: Leatherlike Materials. In: *European Polymer Journal* (1987) 8, pp. 677–697.

Reich, G.: *Vom Kollagen zum Leder – Gesammelte Abhandlungen*, Verein für Gerberei-Chemie und Technik e.V., Reutlingen (2003).

Reich, G.: Der Finish macht. In: *Leder & Häute Markt* (2006) 01/02, pp. 32–40.

Reich, G.; Taeger, T.: *From collagen to leather – the theoretical background*. Ludwigshafen: BASF AG (2007).

Richter, R.: Lefa für Sohlen, Böden & Autos – Entwicklung und Einsatzmöglichkeiten von lederfasergefüllten Kunststoffen. In: *Leder & Häute Markt* (2005) 10, pp. 20–22.

Richter, R.; Schulz, H.: Kniffelig: LEFA im Fahrzeug – Emissionsarmes und alterungs beständiges LEFA für den Automobilinnenraum. In: *Leder & Häute Markt* (2006) 03/04, pp. 30–34.

Rudolph, H.: Individuelles Design auf Leder. In: *Leder & Häute Markt* (2006) 11, pp. 16–18.

Schäfer, W.: Vliesverbundprodukte für Anwendungen in der Elektrotechnik. In: *Melliand Textilberichte* 73 (1992) 11, pp. 866–869.

Schürer, M.: Vortrag zum 1. *Freiberger Polymertag* (1993), FILK GmbH Freiberg.

Simpson, P.; Hörner, K. D.; Dreissigacker, G.; Salgado, J.: Innovations for the upgrading of automotive leathers. In: *World Leather* 18 (2005) 5, pp. 31–35.

Stather, F.: *Gerbereichemie und Gerbereitechnologie*. Berlin: Akadamie-Verlag, (1957).

Stoll, M.: Verfahren zur Herstellung poröser Polymerschichten nach dem Koagulations verfahren. In: *Coating* 27 (1994) 1, pp. 9–11.

Tegtmeyer, D.; Voerlaender, O.; Zeyen, W.; Silberkuhl, F.; Tysoe, C.: New Micro-sphere Application in the Leather Industry, XXIX. Congress of the IULTCS and the 103rd Annual Convention of the ALCA, Washington DC, USA, 20–24 June 2007.

Tomkin, M.: Technical Differences Between US and European Automotive Leathers. In: *JALCA* 100 (2005) 4, pp.133–136.

Träubel H.: *New Materials Permeable to Water Vapor*. Berlin: Springer (1999) – ISBN 3-540-64946-8.

Träubel, H.; Schütze, D. I.; Pedain, J.: Bessere Tragehygiene durch wasserdampfdurchlässige Materialien. In: *Textilveredlung* 29 (1994) 6, pp. 171–177.

Trommer, B.: Ein neuer katalytisch-enzymatischer Oxidativäscher. In: *Leder & Häute Markt* (2002) 1, pp. 28–35.

Trommer, B.; Kellert, J.: Ökologischer Vergleich verschiedener Gerbarten. In: *Leder & Häute Markt* (1999) 6, pp. 25–36.

UCB–Firmenschrift *Breathable coatings* (1995).

Wachsmann, H. M.: Autopolsterleder im Wandel der Zeit. In: *Leder & Häute Markt* (2005) 08/09, pp. 12–13.

Wilford, A.: Waste in the shoe industry – consequences for the leather industry. In: *Leather* (1999) 201, pp. 37–40.

Wittke, W.: Die Herstellung von Polyurethan-Kunstleder (PUR-Kunstleder) nach dem Koalugationsverfahren. In: *Coating* 16 (1983) 5, pp. 128–132.