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Requirements for automotive textiles – a car producer's view

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Abstract: The development of automotive textiles is a very complex and complicated process. Some parts are developed and purchased by Volvo, and some parts by the first tier supplier. The number of technical demands are huge. The number of applications also. The same textile can be applied on different surfaces in the car, resulting in different technical solutions for the applications, but still with the same visual appearance demands. The cooperation with the design department starts very early and remains very close during the whole development process.

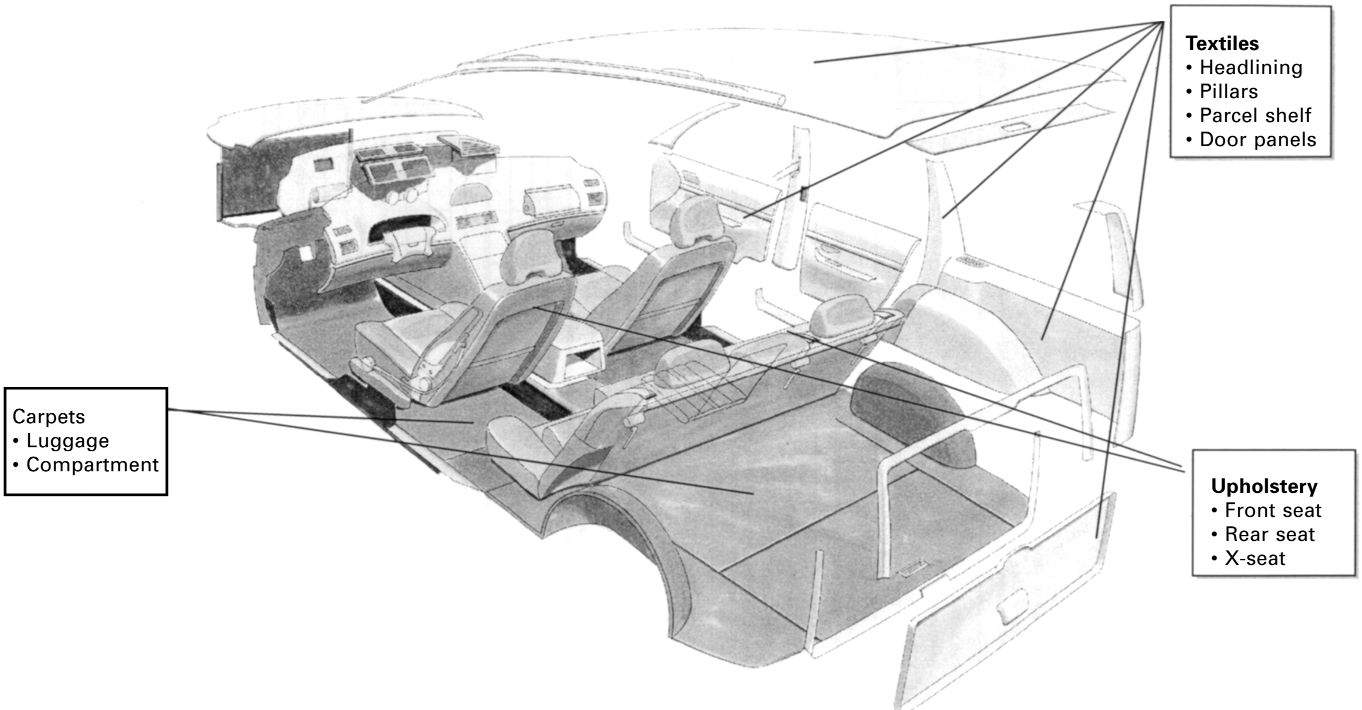
Key words: automotive textiles, master sample, photo book, flammability, light fastness, colour changes, fogging, metamerism.

1.1 Introduction

This chapter will describe the textile materials used in the interiors of Volvo cars. Volvo purchases some upholstery material, which includes the textiles used for seats, whereas other textiles for the interior are purchased by the system supplier but developed by Volvo. We use technical requirements specifications – design prerequisites, master samples, drawings, technical regulations, etc. – in which we also specify testing methods. There are some unique and extra tough requirements for the properties of textiles such as: light-fastness, ageing, fogging/emissions, and dirt resistance/cleanability, therefore the textile supplier needs to be involved at an early stage in our development work. The supplier must have a creative design/styling department of their own and a flexible production capacity, since the normal lead time for developing a new textile is 12–24 months. As Volvo has warranty periods of up to four years in some markets, the textile supplier will also be involved in regress issues, and therefore continuous improvement is a necessity.

1.2 Automotive textiles

Automotive textiles are applied on several surfaces of the car interior (see Fig. 1.1). An automotive textile is a complex and complicated product with a great many demands placed upon it. The fabrics used are:



1.1 Diagram of a car interior.

- Knitted, warp-knitted or woven fabric for upholstery and panel applications.
- Tufted or non-woven fabric for carpet applications.

An upholstery textile consists of the textile plus laminate and scrim (backing), which are normally bonded together by a flame-lamination process, but a process of glue-lamination has also been developed. Unlaminated textiles are specified for panel and insert applications, but for carpet applications, different laminations and backings are specified.

1.3 Volvo Car Corporation development process

It is a challenge for suppliers to work with the car industry, with its highly complex development process. Suppliers are involved from a very early stage and need to remain so over a long period since the normal lead time is 12–24 months. The first challenge is to be nominated, followed normally by taking part in Volvo's competitive selection process to become a development supplier. After that, the textile supplier starts to work with Volvo's engineering section either directly or via a system supplier. When the technology and initial appearance are approved, the development of the colour can begin. The normal procedure is that the supplier sends samples for design approval using a light cabinet at Volvo. When the design is approved, which can involve 1–3 loops, testing starts at Volvo and its suppliers. Once the relevant testing is acceptable, Volvo releases a master technical document.

Requirements are often contradictory, which means that not all of them can be fulfilled at the same time, in the same project and on the same product. Decisions on balancing the various demands are made during the development process. The work is normally performed by an assignment team, led by a Volvo-person, together with representatives from Purchasing, Purchase Engineering, Testing, Preparation Manufacturing, the System Supplier and the Material Supplier.

The following three major documents show the input from all the other parties involved:

- Job-split list
- Time schedule
- Interior colour matching process.

1.4 Technical demands

The automotive textile is specified using the following technical demands/ requirements documentation.

Primary documents

- Part drawings
- Technical regulations (TR)
- Master samples
- Standards
- Final Requirements Picture (photo book) and Natural Characteristics Standard (NC Std)

Complementary documents

- Design prerequisite (DPR)
- Colour matching basis
- A-master
- Property description (PD) (or EB in Swedish)
- Function requirement description (FRD) (or FKB in Swedish)

1.4.1 Master sample

What is a master sample?

- It is a physical sample distributed by Volvo.
- It is also a primary document specifying the design of the material.

There are three different masters that are used at different times:

- *A-master* is a master sample that shows only the initial idea of the material's appearance.
- *C/D-master* (Component Development) shows the approved appearance, i.e. colour, pattern, grain/structure, gloss and technology.
- *P-master* (Procurement) is the final master, which shows the approved appearance and the approved technical demands.

1.4.2 Material drawing

The material drawing specifies width, weight, thickness, etc. The drawing also specifies references to TR, Part no. Colour and Master no. Normally the textile is delivered on a roll.

For all other interior surface materials there are normally tolerances on colour and gloss, although an ongoing AE-job will introduce tolerances on textiles in a couple of years.

1.4.3 Design prerequisite

Purpose

The purpose of this document is to show what the design prerequisites are so that suppliers can fulfil Volvo Car Corporation (VCC)'s demands and VCC product design can select suitable surface materials.

The requirements in a design prerequisite (DPR) are valid for all processed materials but individual material requirements can be found in the specific TR. The DPR is a Volvo document and also contains details of what is required when testing methods are inadequate.

General demands

- The interior and the materials will exude quality and harmony.
- The interior should look the same as that of a new car even after three years' normal usage in the harshest market in which the car is sold.
- The interior must be easy to clean.
- The materials will age in a homogeneous way.
- The materials must not have an unpleasant smell.
- The surface materials will last for the four years of the guarantee without any problems.
- The materials will be as rattle- and squeak-free as possible.
- The upholstery materials should be positioned in a way that minimises squeak and rattle.

Material demands

- The aim should be to fulfil all requirements without the use of any chemical substances. The material may only be treated if no other solution can be found to solve a problem.
- The EPS (Environmental Priority Strategy) is to be used systematically in the engineering design and choice of concepts/materials in order to apply the environmental holistic approach that we stand for. EPS calculations will be part of the respective decision parameters in the project.
- All textile and leather materials will be certified according to OEKO TEX 100 in product class 4. Features to be used by children should be certified according to product class 2. A copy of each certificate will be submitted to the environmental co-ordinator at the Interior and Climate Engineering department.
- Materials and chemicals containing substances listed in the 'Restricted Substance Management Standard' STD WSS-M99P9999-A1 must not be used.

- The use of rare metals must be avoided. If they have to be used, they must be documented so that it will be possible to take the appropriate action for the metals at the end of the lifecycle of the car. In addition, EPS calculations must be done on the system and alternative solutions must be analysed.
- Surface coatings containing chromium may not be used.
- Cadmium may only occur as a trace element or contaminant and its content must fall well below the limits of legal regulations. In surface treatments, the content must not exceed 50 mg/kg.
- PVC should be avoided in interior applications. If there are no cost-effective alternatives, the PVC applications must not contain:
  - phthalate plasticisers other than linear C>10
  - lead and organotin stabilisers
  - antimony oxide (SbO_3) flame retardant.
- PUR (polyurethane) must be used with caution because isocyanates present a hazard during production and their uncontrolled incineration during the end-of-life phase can release unwanted gases.

1.5 Technical regulation

The technical regulation (TR) document contains a combination of requirements and well-defined testing methods. Testing is done both at Volvo and the supplier via a job-split list (defined in the DPR).

Most of the requirements are familiar to all textile suppliers, but there are some demands specifically developed by the car industry. The TR reflects in a sense ‘the soul of the company’ – the requirement, its importance and the testing method to be used is an empiric, long-term, experience-based result connected to the product – the car.

For the most typical automotive requirements, a description is given of both the background of the test and the testing method as follows.

Flammability

Background of test

The flammability test is an American legal requirement which must be performed successfully on all materials of the car interior. This test is carried out on every production batch.

Test method

To fulfil the legal requirements, the test must be carried out according to standard MVSS 302. This document specifies what parts and materials are to be tested, what equipment to use, testing procedure, etc.

The test piece is placed horizontally in a small cabinet and exposed to a flame. The burning rate of the material is calculated, measured in mm/min. The legal requirement is 102 mm/min, but some car manufacturers specify a lower value.

Light-fastness

Background of test

During the life of a car, the interior materials will be exposed to a large amount of sunlight, especially in areas like Australia or the southern USA. Fading and deterioration of the materials leads to a poor impression of the quality of the interior.

Test method

Testing is normally performed according to international test methods like ISO 105-B02 or ISO 105-B06, where the test pieces are exposed to a filtered Xenon arc lamp for a certain length of time. A maximum value for a change of colour is specified and usually the requirement is blue-scale rating class 7 or higher.

Ageing

Background of test

As cars are sold and used all over the world, they will be exposed to different temperatures and climates with temperatures ranging from –30°C in winter to +90°C in warmer climates, in dry or humid conditions, with a year-to-year variation. Cars are shipped by boat from Gothenburg to Singapore via the Suez Canal, therefore the cars are exposed to big differences in temperature and humidity during this three-week period; and during the summertime in places like Arizona and Saudi Arabia, areas such as the dashboard, head rests and parcel shelf can reach temperatures of 110°C or more.

Test method

Deterioration and changes of colour through ageing are evaluated by accelerating the ageing process in a climate chamber for a number of weeks. The climate chamber might be set at a fixed temperature and humidity level, or it might be set to change over a cycle of, normally, 24 h.

Fogging

Background of test

Materials release substances, especially when heated, and these substances, including additives, process enhancers and flame retardants, condense on the cold windscreen, creating a film on the inside called fogging. Not only is fogging difficult to remove, requiring solvents and therefore causing annoyance to the customer, but it also reduces vision and is a safety issue.

Test method

Fogging is tested for by putting a piece of the material in a glass beaker, which is placed into hot oil for several hours. The beaker opening is covered with a glass plate or aluminium foil, which is cooled by a cooling device placed above it. The purpose of the cooling device is to cause condensation of the fogging onto the glass plate or aluminium foil. The fogging is then determined by measuring the gloss of the glass plate before and after the test (reflectrometric fogging) or weighing the aluminium foil before and after the test (gravimetric fogging). A maximum level of fogging is specified as a percentage (reflectrometric) or in mg (gravimetric). Testing is usually done according to ISO 6452.

Soiling and cleanability

Background of test

People spend more and more time in their cars and it is not unusual for them to eat burgers and drink coke, therefore items such as cup-holders are featured in most vehicles. The surface materials are also exposed to dirty shoes and dust from the streets when people enter the car. In addition, people often have their coats and jackets on in a car, unlike when they are at home. As a result of customer demand and fashion trends, many car manufacturers, including Volvo, tend to offer lighter-coloured interiors, which makes them more sensitive to soiling and staining.

Test method

During testing, the materials are exposed to artificial standard soils and also to stains from coke, coffee, ketchup, etc. The appearance of the soiling or staining is evaluated, as is the possibility of cleaning the material using conventional cleaning methods.

Abrasion

Background of test

The materials in a car should last as long as the rest of the car, meaning at least 10–15 years, which requires them to be abrasion-resistant.

Test method

Abrasion is usually tested using well-known methods like Martindale (ISO 12947) or Taber (ISO 5470). The material can be subjected to up to 50 000 cycles in a Martindale tester.

Metamerism

Background of test

The light in a showroom differs from natural sunlight. When the light source is changed, the difference in wavelengths must not lead to a change in colour appearance.

Test method

Metamerism is not allowed. The procedure for obtaining design approval involves the use of a light cabinet.

Generally speaking, testing is done by both Volvo and the supplier. What is done and when is defined in the job-split list.

Volvo performs complete car tests at their test facilities. For example, cars are left for one year at the Arizona Proving Ground in Phoenix for long-term, real-time ageing. Another example is the TAXI-test for seats, which normally lasts for nine months, covering 100 000 km and involving 15 000 ingress/egress cycles.

1.5.1 Additional functional demands

The application of a textile can add some additional automotive demands that are hard to fulfil or cause design changes to be made to the textile because it is easier to change the textile than the form of the part or the function.

A panel textile is specified to be a *non-laminated* material. This means that the panel supplier is responsible for selecting and carrying out the lamination, and also means that the textile supplier must be competent enough to know how a laminate affects the textile and vice versa.

1.6 Design demands

Often a supplier's first contact with Volvo is with a designer during company visits, exhibitions and conferences, where the designer is looking for new trends, new ideas, new appearances, etc. However, there is a long development period before the start of production (SOP).

The design department selects a textile supplier on the basis of a textile's appearance, which must portray the following features of the Volvo brand:

- core values
- image
- long-term fashion and trends
- identity
- heritage
- the spirit of time
- type of car
- type of level.

This means that it is essential that the supplier understands design trends, fashion and the Volvo image.

The first critical 'key-hole' is to attract the attention of the design department. In the concept and pre-study phases, the prerequisites from the design department are normally shown as *life-style boards*. To be able to work with design, each textile supplier must have a design department of its own that is extremely creative. VCC often chooses textiles from the supplier's own collection, which means that the collection must already be developed up to an early production status and its feasibility must be satisfactory. The development of VCC colours and adaptation to VCC's demands remain important criteria.

1.7 Purchase demands

Volvo sources the following upholstery materials for application on both seats and doorpanels:

- textiles
- leather
- tricot-plastic.

All other surface materials including:

- carpets
- cloth on pillars, headlining, parcel shelf

are sourced by the system supplier but developed by VCC.

1.7.1 Volvo's general purchasing conditions

- The supplier must be third party (an outside-accredited institute) certified according to Automotive Industry Quality Standards, e.g. QS9000/ TS16949, EAQF or VDA 6.1.
- For environmental requirements, the supplier must be certified as conforming to environmental management systems, e.g. EMAS or ISO 14001.
- The supplier must fulfil requirements as detailed in the PQP – 'Purchasing Quality Procedures' manual.
- Demonstrable capability in the production process.
- 4-year normal warranty.
- 15-year post-sales service.
- Flexibility in development.
- Flexibility in technologies.
- Flexibility in production.
- Testing facilities.

1.7.2 Supplier evaluation model

The supplier evaluation model (SEM) enables Volvo to make a formal decision to accept the supplier (see Fig. 1.2).

1.7.3 Cost

A typical price for a material is 5–15 Euro per square metre, depending on its application and quality level. Normally, annual cost reduction figures are included in the business agreement and during the last decade the square metre price has dropped by approximately 20%. Table 1.1 shows some normal coverage figures.

When it comes to warranty issues there are two main sources.

Customer surveys

'JDP' and 'GQRS' represent customer surveys which gather customer opinions with reference to different systems in the car. One result is often a request for product changes.

Warranty cost

With regard to regress issues with the supplier, in most markets there is a four-year warranty, but in the US market there are two additional circumstances:

VOLVO
Evaluation matrix

Supplier Evaluation

		Evaluation						
		0 pts	1 pt	2 pts	3 pts	4 pts	Res.	Max
1	**Company profile**						0	8
	1.1 ownership							
	1.2 global ability							
2	**Management**						0	12
	2.1 management							
	2.2 customer satisfaction							
	2.3 TQM work procedure							
3	**Environment**						0	8
	3.1 environmental management system							
	3.2 company-level assessment							
4	**Quality**						0	12
	4.1 quality system							
	4.2 quality performance, deliveries							
	4.3 reliability							
5	**Logistics**						0	8
	5.1 logistic system							
	5.2 delivery precision							
6	**After Market**						0	4
	6.1 co-operation and support							
7	**Competence**						0	12
	7.1 product and ind technology							
	7.2 industrial engineering							
	7.3 customer support, comm.							
8	**Product development**						0	12
	8.1 prod developement process & proj. support							
	8.2 engineering experience & technology							
	8.3 support (prototypes, design changes)							
9	**Finance**						0	4
	9.1 finance evaluation D&B							
10	**Productivity**						0	12
	10.1 internal cost reduction							
	10.2 investments							
	10.3 cost targets							
11	**Sourcing**						0	8
	11.1 sourcing process							
	11.2 sub-contractor performance							

stopping parameter

Res	Max
0	100

Suppl no	Supplier name

Date	Examinator

Grading:

A	World class	>=90
B	Excellent	>=75
C	Good	>=60

1.2 Volvo supplier evaluation model (SEM).

Table 1.1 Normal coverage figures (in square metres) for a car with textile upholstery and textile-covered panels

• Upholstery	10 m^2
• Door panels	2 m^2
• Pillars	2 m^2
• Carpet	4 m^2
• Parcel shelf	1 m^2
• Headlining	4–6 m^2 (4D–5D)
• Luggage compartment	4–5 m^2 (4D–5D)
• Seat belts	0.5 m^2
• Airbags	3.5 m^2
TOTAL	31–34 m^2

1. Product liability legislation; 2. Lemon Law, which can, in addition to customer complaints, lead to market campaigns, the recall of cars, product liability issues, ill will and the repurchase of cars.

1.8 Purchase engineering demands

For initial samples see Reference STD 5036.1, PQP – 'Purchasing Quality Procedures' manual and QADF – 'Quality Assurance Document File'.

1.8.1 QADF – Quality Assurance Document File

All products and processes used for projects must be quality assured according to the QADF.

This is a large document which is used from the moment the supplier is nominated. The following three items are noteworthy:

1. *Trial production run* This is done so that the supplier can show and verify its production capacity and capability.
2. *ISA – Initial Sample Approval* This is used to show that the supplier has produced approved parts for delivery to Volvo. Any specifications that are not fulfilled can lead to either 'Temporary Deviation Approval' with an action plan or 'Product Approval' so that ISA can be given without all demands being fulfilled.
3. *Appearance of item* Visible parts in a car have an additional requirement, which means that the supplier has to control colour, gloss and texture via measuring protocols, not only for ISA but also on a regular basis (see Fig. 1.3).

1.3 Sample of textile for automotive interior.

2
Mapping the automotive textile supply chain

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Abstract: Information visibility is an essential element to improved supply chain performance. Without adequate sharing of information, firms are required to supplement the available information with other costly alternatives. This chapter follows the development of a convertible fabric material in the supply chain for a large automotive assembler, beginning with a large textile manufacturer in fabric formation to final assembly of the convertible top. The current level of information sharing in the supply chain is assessed and the effects of inefficient information flows between the various tiers of suppliers are determined.

Keywords: supply chain, automotive textiles, information visibility, sourcing in the value system, case study.

2.1 Introduction

The sourcing of textile products for vehicles is typical of the complex supplier network for the large-scale global automotive industry. Nieuwenhuis and Wells describe the complex automotive market as characterized by the conflict between the production capabilities and the market demand (2003). The auto industry is considered the epitome of the mass production system, affecting the global balance in trade and commerce, environmental issues, safety, employment, manufacturing and assembly methods, technology, and style (Cagan and Vogel, 2002). As Cagan and Vogel describe the automotive industry, 'No other market develops products in an atmosphere where competition is as fierce, the product is as complex, and the challenge of constant refinement and innovation is as great' (2002, p. 254).

The Society of Automotive Engineers lists more than 10,000 companies in their 2007/2008 supplier directory (2007). Materials and components are estimated to contribute up to 80% of the value of a finished vehicle. Global Insight (2007) estimated the occupant restraint equipment business alone to be worth US$17 billion in 2005 and it is expected to grow (p. 13).

The demand for rapid prototyping, cost effectiveness and streamlining of supply systems is critical in all component parts, but particularly in automotive textile materials. In the tiered structure of the automotive supply chain the original equipment manufacturer (OEM), such as General Motors, is responsible for initial overall design, assembly and marketing of the complete vehicle and brand through dealerships to the consumer. A complete system component such as an interior compartment would be supplied directly to the OEM by a Tier One supplier, such as Johnson Controls. A Tier Two company would supply subassemblies to the interior system. The individual parts of these subassemblies would be sourced to a Tier Three supplier, and the materials would be provided by a Tier Four company. Some companies function in roles across tier levels. A textile company may be considered a supplier at the third or fourth tier.

In order to improve performance in the automotive supply chain and create a truly integrated value system, a number of tactical and strategic changes will be required throughout the automotive textile supply chain. Without the buy-in of supply chain members, asking them to react faster in response to real-time ordering systems is an exercise in futility. A supplier who receives an order via the Internet, prints it out and puts it on a stack on their desk is not contributing to supply chain value. Instead, when information is shared via the supply chain and made available to all parties, such that demand requirements, capacity limitations, inventory positioning, and collaboration between partners is established through *a priori* agreements, then the power of the Internet can begin to be fully exploited. This means providing an Internet-accessible, real time forum where buyers and their suppliers can communicate and share inventory and forecasting information, and allow for the effective dissemination of engineering change orders (ECOs) throughout the supply chain. Nowhere is this more important than in the automotive supply chain, where textile manufacturers are often several tiers removed from the final OEM assembler, and often subject to the vagaries of poor forecasts and lack of information. Visibility of information within the supply chain is a critical starting point in considering supply chain management in the automotive industry. An automotive textile case study tracks the development of a convertible top material (fabric) in the supply chain for an automotive components manufacturer for a large Big Three automotive beginning with a large textile manufacturer in fabric formation to final assembly assembler. The current level of information sharing in the supply chain is assessed and the effects of inefficient information flows between the various tiers of suppliers are determined. A discussion of the approach used to map the supply chain follows, and then summary observations conclude the chapter.

2.2 The importance of information in supply chains

The need to share accurate information across the supply chain is of paramount importance. In fact, lack of information or distorted information passed from one end of a supply chain to the other, can create significant problems, including, but not limited to, excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and missed production schedules. Distorted information throughout the supply chain is a common result of what logistics executives have termed the *bullwhip effect.* This phenomenon is characterized by a series of particularly erratic shifts in ordering up and down the supply chain, often with more demand variability at the distributors' and suppliers' linkages than at the retail level (Lee *et al.*, 1997). Four causes of this phenomenon were identified:

1. Demand forecast updating
2. Order batching
3. Price fluctuations
4. Rationing within the supply chain.

Automotive firms such as Ford and Toyota have experienced a similar phenomenon. Even a slight to moderate demand uncertainty and variability becomes magnified when viewed through the eyes of managers at each link in the supply chain. If each manager makes ordering and inventory decisions with an eye to the firm's own interest above those of the change, stockpiling may be simultaneously occurring at as many as seven or eight places across the supply chain, leading in some cases to as many as 100 days of inventory – waiting (Lee *et al.*, 1997).

2.3 Supply chain organizational dynamics

Two major interorganizational dynamics come into play when addressing information sharing across the supply chain: risk and power. All enterprises participating in a supply chain accept a specific role to perform. They also share a common belief that they and all the other supply chain participants will be better off because of their collaborative efforts. Each member specializes in the function or area that best aligns with its competencies. Risk occurs in that each firm must now rely on other supply chain members as well as its own efforts to determine the success of the supply chain. Those members most dependent on the supply chain with the most at stake may take more active roles and assume greater responsibility for fostering cooperation, including the information-sharing efforts, throughout the supply chain.

Power within the supply chain is a central issue, one that in today's marketplace centers on information sharing. Although not universal to all industries, there has been a general shift of power from manufacturers to retailers over the last two decades, which has resulted from a combination of factors. One is the trend toward consolidation at the retail level within the supply chain. Gone are the days of locally owned, independent dealerships in each town. In the interest of capitalizing on the benefits of economies of scale, giant retail conglomerates operate as part of nationwide supply chains.

In fact, relatively few of the thousands of retailers operating in the United States control the majority of dollars in this industry. Clearly, this consolidation impacts the entire supply chain. Although there were reportedly (Plunkett, 2007) 22,495–26,700 (Global Insight 2007) dealerships in the US in 2006, the 100 largest groups sold 17.7% of all new vehicles. Fewer and fewer firms control access to consumer trading areas. The number one public group AutoNation reportedly has 257 dealerships. Many larger organizations are looking outside their own domestic regions to expand their retail business globally (Global Insight, 2007).

Perhaps more importantly, retailers sit in a very important position in terms of information access for the supply chain. For several reasons, major retailers have risen to this position of prominence through sheer size and sales volume, and most importantly, their position within the supply chain right next to the final consumer. Providing current information on consumers' preferences and purchasing behaviors to OEMs can improve products and services. Retailers can capitalize on this position through responsive services to the consumer. Improved communications between the dealer and the OEM could facilitate the growing consumer interest in customizing a new vehicle, optimizing factory options. This combination of factors has put retailers in a very powerful position within the supply chain.

2.4 Creating information visibility in supply chains

2.4.1 What is information visibility?[1]

Information visibility within the supply chain is the process of sharing critical data required to manage the flow of products, services, and information in real time between suppliers and customers. If information is available but cannot be accessed by the parties most able to react to a given situation, its value degrades exponentially.

Increasing information visibility between supply chain participants can help all parties reach their overall goal of increased stockholder value through revenue growth, asset utilization and cost reduction. These multiple levels of trading partners need to share forecasts, manage inventories, schedule labor, optimize deliveries, and in so doing reduce costs, improve productivity, and create greater value for the final customer in the chain. Software for Business Process Optimization (BPO) and Collaborative Planning, Forecasting and Replenishment (CPFR) are evolving to help companies collaboratively forecast and plan amongst partners, manage customer relations, and improve product

[1]This section is based on a benchmarking report developed by the following associates of the Supply Chain Resource Consortium: Steven Edwards, Meenakshi Lakshman, and a number of undergraduate students at North Carolina State University.

life cycles and maintenance. Traditional supply chains are rapidly evolving into ‘dynamic trading networks’ (Cole *et al.*, 1999) composed of groups of independent business units sharing planning and execution information to satisfy demand with an immediate, coordinated response.

Some of the considerations that must be planned for in implementing an information visibility system include the size of the supply base and customer base with which to share information, the criteria for implementation, the content of information shared and the technology used to share it. Clarifying these issues will help to ensure that all participants have access to the information required to effectively control the flow of materials, manage the level of inventory, fulfill service level agreements and meet quality standards as agreed upon in the relationship performance metrics.

Perhaps no other company has been as successful in implementing information visibility as a competitive strategy than Dell Computer. Dell has fulfilled its commitments to customers through the company’s direct model, in which it holds only hours of inventory yet promises customers lead-times of five days. Component suppliers who wish to do business with Dell have to hold some level of inventory, since their cycle times are typically much longer than Dell’s (Lewis, 2001). Dell has developed a business model that features a lean, build-to-order manufacturing operation. By utilizing the web, Dell provides its supplier with forecasting information and receives information about the supplier’s ability to meet the forecasts. Communication between engineering changes, component availability, capacity, and other data between Dell and its suppliers flows both ways, in addition to forecasting and inventory data. Dell is also able to review suppliers and place web-based orders into their factories in hours. Dell’s build to order web-based customer model has become the benchmark for other organizations such as General Motors and Ford who are seeking to create ‘build-to-order’ models using the web as the platform for taking customer orders.

2.4.2 Benefits of information visibility

Information regarding forecasts, changes in production schedule levels and on-going supply chain performance metrics needs to be conveyed by customers to suppliers on a regular basis. Information flows from suppliers to customer can include current order lead times, capacity levels, order status and inventory levels. Receiving and conveying the correct information will ensure that the suppliers are aware of what needs to be produced while at the same time, the buying firm is sure that it is possible to receive ordered quantities on time, every time. The most important benefit of a visibility system is not that the system is able to correct a supply chain problem, but that it allows people to become aware of problems earlier, and thus take corrective actions more quickly than they otherwise would. The benefits of information visibility include reduced lead times, improved constraint management, better decision making, lower costs, and increased profits. Although problems such as shortages, changes in customer orders, engineering changes, obsolete inventory, and equipment failures can still occur with a visibility system in place, the effects of these problems are less than if the participants in the supply chain were not made aware of these problems until a later date.

When implemented properly, a visibility solution results in the following additional benefits that promote improved supply chain performance:

- *Breaks organizational barriers.* Enables sharing of mission-critical information about business activities and interaction on a near real-time basis across the supply chain.
- *Builds visibility into supply chain.* Provides people a real-time snapshot of supply chain performance metrics.
- *Managing by metrics.* Aligns performance metrics with cross-organizational business processes and assigns ownership of processes and metrics to specific individuals.
- *Reduces the decision cycle process.* Allows an upstream or downstream participant to respond to market or customer demand in hours or days, not weeks or months.
- *Encourages decision-making collaboration.* Facilitates the ability to make decisions collaboratively on the Internet, bringing relevant internal and external stakeholders into the process.
- *Reduces opportunity and problem resolution latency.* Measures and monitors supply chain activities iteratively, allowing people to respond quickly to events as they occur.

Conversely, the dangers of poor execution of supply chain processes include increased lead and cycle times, higher costs, and less informed decision-making.

This case study focuses on an analysis of only those processes that are directly related to the vehicle convertible top material that is manufactured by a large textile manufacturer (A) and is handled further up in the supply chain by a company that treats the fabric (B), one that completes the cut and sew operations (C) and the final OEM assembler in Michigan (D). A broad view of the supply chain map was developed from public information with additional content from industry interviews and a questionnaire sent to each supply chain partner. The focus of the questionnaire was to study the inventory levels, service and responsiveness in the supply chain, and to identify gaps in the supply chain. The data collected from supply chain members was then used to identify:

- Areas of low inventory turns in specific areas of the supply chain.
- Potential areas of improvement across the supply chain members.

- Information requirements to help alleviate the problems detected during analysis.

2.5 Market analysis

Scale and efficiency are extremely important to the automotive industry's large manufacturing firms in order to keep costs down and enhance profit margins. According to *The Economist* (Anon, 2005), 'if their affiliates as well as their wholly-owned companies are counted, the top five company alliances account for 75% of the global market, while adding the next five takes this to 90%, with producers in China, India and Malaysia making up the rest.' 'Suppliers make up 70% of OEM costs, and Tier 1 suppliers passed the cuts down the chain' (Ward's, 2003, p. 63). David Cole of the Center for Automotive Research predicts that as industry consolidation continues, the Tier 1 and Tier 2 suppliers will develop and deliver more complete subsystems to the assembly plants, thus taking on 'significantly higher levels of responsibility' (SAE, 2007, p. 103).

2.5.1 Major global players in automotives

Most major technologies and technical expertise became available in the 1990s from global suppliers which prompted competitive pricing, and emphasized innovative product development to distinguish products. By 2007, the number of textile suppliers has been reduced, either closing operations, declaring bankruptcy in order to reorganize their operations, or being absorbed into larger organizations. Guilford Automotive has reorganized solely as an automotive supplier, particularly in warp knitted headliner fabrics. Milliken & Company remains stable as a privately owned diverse product company.

2.5.2 Structure of supplier value system

In the automobile industry, suppliers to OEMs do not have much power – the automobile manufacturers pass down the general specifications, and it is unlikely that any one supplier could cause the major manufacturers any problems due to the number of current suppliers and potential suppliers who desire to be in the automotive supply chain. The cost pressures of OEMs have intensified, resulting in long-term contracts being opened for new more competitive bidding from global suppliers. Many textile suppliers are reported to have suffered losses as the Big Three have lost market share to Asian companies. Contracts with OEMs, which earned little or no profit for textile companies, are reported to have contributed to the demise of suppliers such as Collins and Aikman. Failure to deliver components can drastically affect production and shut down assembly of vehicles. If a supplier loses a contract then it could take months or years to secure replacement business (Sherefkin, 2005).

The retail buyers, defined as the dealerships, do have some legal power as a group. To date, they have been able to stop the major manufacturers from forming a direct link to the end-consumer, but that may change soon. Again, however, no one dealer has the power to cause major problems for any of the manufacturers.

The automotive industry is very capital-intensive, requiring plants to be built, equipped with machinery, and staffed with people. In general, this makes the threat of new entrants relatively low, as any company wanting to get into this industry would have to expend large amounts of cash before seeing even the slightest return on investment. However, many textile manufacturers possess the capital equipment necessary to manufacture products for the automotive industry by realigning their products/markets. Companies such as Interface, Glen Raven, Freudenberg and IAC Group are positioned to establish themselves further in the automotive textiles market. With the demise of global textile trade quotas in 2005, additional suppliers from Asia entered the North American market. Japanese textile suppliers such as Seiren, Kawashima and Suminoe and Europeans, Eybl and AundE, are not only shipping into international markets but some are also establishing manufacturing plants in regional markets as lead times for developing and producing products become compressed and the costs of transportation increase (Powell, 2004). With approximately 23 textile suppliers in Europe, not including the subsidiary plants, the opportunities for shifts in the supplier chain are likely (Global Insight, 2007). No one supplier of textile fabrics has dominated the market for any length of time, and to remain competitive in the global supply chain, every player must maximize their value to the supply chain.

Experts forecast that the number of cars and light trucks on global roads will reach 1 billion by 2020 (Plunkett, 2007). In the year 2000, the US automobile industry again set an all-time record high in sales of automobiles and light trucks by reaching 17.4 million units. This rise was attributed to the US economy, higher personal income growth, and enhanced consumer confidence. However, the US economy has recently begun to soften, with North American production of cars and light trucks in 2006 falling to 16,374,670 units. Table 2.1 reflects the recent sales by region and forecasted production. The forecast for 2007 for US light vehicle sales will be the lowest in nine years. According to *Automotive News*, European production was 20,811,446 units in 2006 while Asia-Pacific production was 24,828,397. Total global production of cars and light trucks in 2006 was 67,723,891 units (*Automotive News*, 2007). Global production is forecasted to reach 70 million by 2010 (Bhagwat, 2004) and an extended forecast is reflected in Table 2.1. Global competition at all levels will be forced to drive costs down and focus on specific areas of competition.

Table 2.1 Automotive forecast production

Forecast 2010	Region	Sales	Production
	Europe	17,934,370	20,694,029
	North America	20,699,218	17,275,662
	India	1,860,699	2,277,656
**	China	8,831,707	8,834,815
	Japan	6,108,709	10,639,100
Total		55,434,703	59,721,263

**2002 China production was 3 million, and in 2005 5.06 million, 2002 China Sales were 2.7 million and in 2005 4.99 million
Source: Global Insight, 2007, Automotive News Data Center, J.D. Power Automotive Forecasting, and Mexican Automotive Manufacturers Association, Japan Automobile Importers Association, Japan Automobile Dealers.

The US automobile manufacturers have continued to emphasize profitability over market share. However, profit margins are under pressure for both General Motors and Ford. Any significant reduction in production volume will put these two companies' profits under severe pressure. Currently, the US market for new passenger cars and light trucks is quickly approaching saturation. There's little indication that, on a long-term basis, annual growth will be over 1–2%. As a result, the major automakers are turning to developing countries for additional growth. These countries include China, Malaysia, Indonesia, and India. In 2006, China became the world's second largest market for new vehicles, surpassing Japan and exceeded only by the United States, registering sales of 7.22 million units, up 25.13% year-on-year, according to the China Association of Automobile Manufacturers (http://china.org, 2007). Russia ranks number 8 and India number 10 in global vehicle sales market share in 2006 including passenger and commercial vehicles (*Automotive News*, 2007). While some of these are rather large markets, the average incomes are low. This could prevent sales penetration in the short run. Nevertheless, US penetration into these international markets will likely be lower due to competition from European and Asian automotive manufacturers.

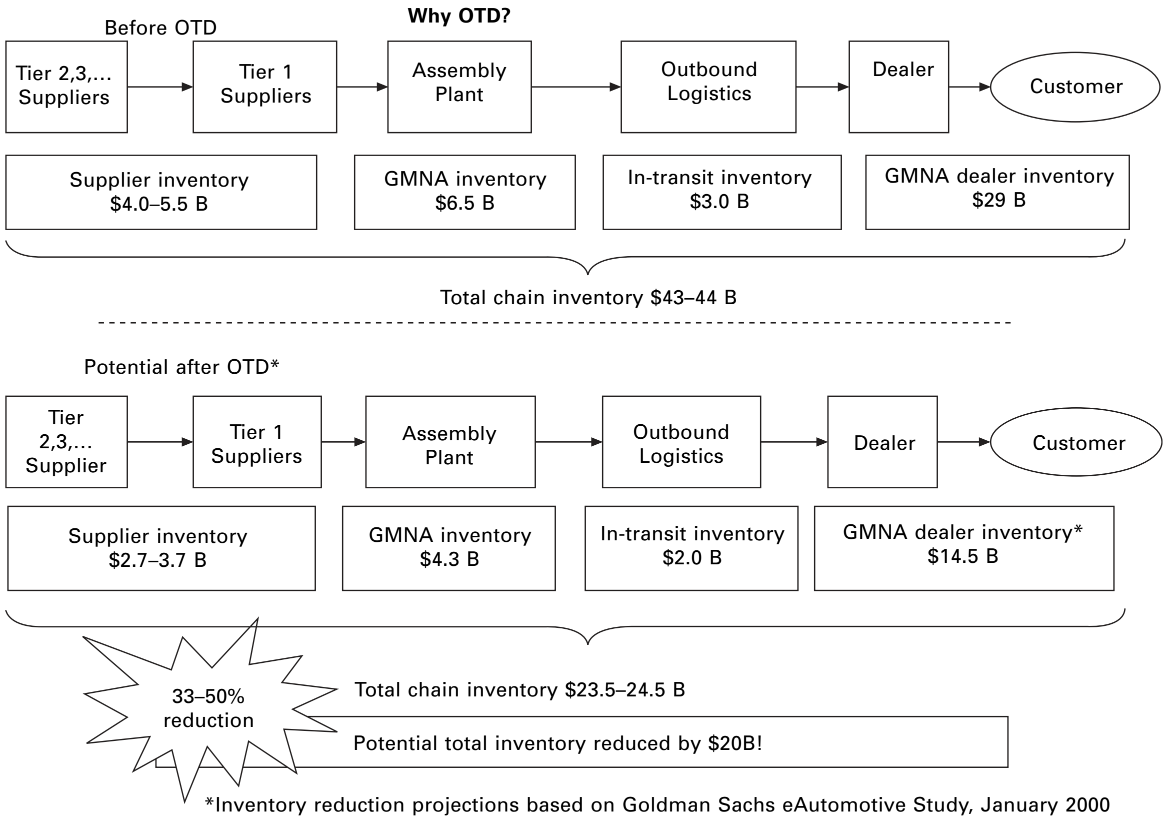
Today the growth of markets worldwide and the growth of production in developing economies like China and India forecast major opportunities for global suppliers and consumers. The mounting economic pressures on the supply chain will demand significant investments and mature strategies to succeed in global competition. The single biggest expected change is the growth of the Internet in researching and purchasing material goods. Consumers are increasingly using information from the Internet to determine such things as features, specifications, styles, and designs of different makes and models. It is reported that 62% of new car buyers use the Internet during purchase (AAIA, 2007). In addition, consumers are increasingly demanding more and more flexibility and options in what they can purchase. The industry may soon be able to implement the process of mass customization, thereby circumventing the middleman and dealing directly with the purchaser. This is an effort to reduce the huge amount of inventory that exists in the automotive supply chain (see Fig. 2.1).

2.5.3 Cut and sew operations

The cut and sew industry is considered fragmented, with a great number of competitors providing this service. The level of key computer integration and automation distinguishes the key competitors from the rest of the competition. Some competitors rely almost exclusively on manual labor while others have computer-controlled pattern cutting to allow for exacting specifications. It is expected that since this is a Tier 2 supplier to the automakers, both the mentioned cut and sew operations would fall into the latter (automated) strategic group. The automotive components supplier business (cut and sew) is also fairly fragmented. This industry is also mature with some consolidation amongst competitors. These participants are competing fiercely and directly with one another in many of the markets, including apparel and upholstery, serviced by this industry. Different competitors compete directly on a cost, quality and flexibility basis or carve out niche markets such as convertible tops in which they are differentiated by their technology and 'turnkey' systems. Rivalry among participants is high, but this soft top is a niche market with few players. In fact, it is not unusual for a Tier 2 or 3 company in this specialized convertible top market to have a market share of 60% or greater.

2.5.4 Just In time component suppliers

The automobile manufacturers possess significant power due to their small number in the OEM sector and relative size compared to the remaining tiers in the supply chain. The automobile assemblers are not likely to backward integrate into this niche market, as it would not fit their core business. On the other hand, companies within the various tiers are a credible threat for forward integration. For example, Collins & Aikman became a major supplier of textile products to the transportation industry with over 60% of its business involved in the automotive industry by the mid 1990s. At that time a strategic decision was made to become a major supplier to the first and second tier suppliers in the automotive supply chain. This was accomplished through mergers and acquisitions of companies in other supply chains serving the automotive industry. Collins & Aikman acquired Textron's TAC-Trim unit, nearly doubling sales. However, this rapid growth and the unsuccessful attempts on the part of stakeholders to solve profitability issues may have contributed to the demise of C&A today (Barkholz, 2006). By 2006, Collins & Aikman's



2.1 Impact of mass customization of autos on automotive supply chain.

automotive textile business was closed, and the automotive flooring and acoustic components businesses were available for sale within the bankruptcy court (Anon., 2007, p. 2)

Forward integration does, however, have limitations, since companies may be less of a threat to the completed convertible top automotive component market due to the complexity of mechanical design for these parts. Substitutes for these products include vinyl tops and conventional steel hardtops. A car buyer interested in a convertible vehicle has likely decided that neither of these is a legitimate option, keeping the threat of substitution low.

2.5.5 Competitive advantage

Demand for convertible top products tends to be proportional to fluctuations in demand for automobiles/light trucks in general (Hoovers, 2003). 'Overall sales volume may now be settling at a higher plateau. In 1999 it surged to 16.9 million units, reaching 17.35 million units in 2000. With fast-pace production techniques available to the automotive industry, by 2005 there were over 57 million new cars produced globally per annum' (Plunkett, Automotive Industry Statistics, 2006). These results suggest a possible breakout from the old range into a permanently higher annual sales rate, even though cyclical variations are likely to remain. Leading the increase has been rising sales of non-passenger car vehicles, such as light pickup trucks, SUVs, and minivans. While passenger cars sales declined by 6.1% between 2002 and 2003, light truck sales rose 3.6%, bringing market share for trucks to 54.3% in 2003, up from 48.5% in 1998. Plunkett Research reported that in 2005 total new car sales were 44% of the US market with trucks being 56% (includes light and medium/heavy trucks) (Plunkett, 2007).

The most important trends in the automotive industry are generally centered on two related developments: intensifying competition and globalization. Due to increased domestic competition, manufacturers are trying to enter foreign and niche markets by leveraging their brand and other competitive advantages. Innovative design and innovative features such as safety measures, sensors and global positioning systems are crucial for successfully expanding the niche customer base.

The suppliers of original vehicle parts and replacement parts (also called aftermarket parts) are being forced by automakers to provide parts that are of better quality and last longer than ever before. While good for the consumer and carmakers, this trend has weakened profitability for manufacturers and sellers.

Faced with retail pricing pressure (from both dealer showrooms and aftermarkets), the Big Three in recent years have demanded substantial cost reductions from their outside parts suppliers. Suppliers, in turn, have responded with aggressive programs to enhance productivity and improve efficiency, learning to function in an era of price freezes and reductions. As automakers pare their rosters of suppliers, they increasingly favor companies that can deliver modules (a combination of attached parts) and systems (a functional combination of modules), rather than individual parts. Their ever-increasing demands are leading to consolidation among automotive parts suppliers, for whom mergers and acquisitions are ways to cut costs and provide more modules and systems.

2.6 Results of supply chain mapping: current practices and linkages

After collecting the data from an actual automotive supply chain, it was organized into three key areas: operations, orders, and logistics. The data in each of these areas was used to determine where each company stood with respect to the entire supply chain.

2.6.1 Operations

The first area is operations, which contains information such as cycle time (in days), the forecast communicated to the upstream partner, batch size, and the number of days supply in inventory. As can be seen in Table 2.2, the current inventory in the system rises by a large margin at the partners before D. As well, the communicated forecast from C down is about three weeks, where D gives 20 weeks to C. Inconsistencies in batch size exist between D and C (downstream), and A and B (upstream). This could also be a cause for the high inventory in the system. Finally, the cycle time in days increases dramatically as you move up the chain, from three days at D to 40 days at A. This, combined with the lack of an accurate forecast, could be contributing to a bullwhip effect throughout the chain.

2.6.2 Orders

Orders comprise days of lead time, mode of receipt, and how often it sends an order to the next partner in the chain. The mode of transmission and type

Table 2.2 Material management in automotive supply chain

	Cycle time (days)	Forecast communicated	Batch size	Inventory (days)
D	3	20 weeks	Lot-for-lot	1.3
C	13	3 weeks	Lot-for-lot	59
B	14	20 weeks rolling, 3–4 week lock	4,000 yards	42
A	40		5,000 yards	53.2

of information exchanged varies between the various supply chain partners, as shown in Table 2.3. While EDI (electronic data interchange) is used between the majority of partners, phone/fax is used between A and B. This could potentially cause problems in terms of order entry and confirmation, and also forecast entry and confirmation. While not a primary cause, this, along with the frequency of information exchange, could be a minor factor in the excess inventory in the system that was shown above.

2.6.3 Logistics

The final area is logistics – how the material gets from supplier to customer. Key points in this transaction (shown in Table 2.4) are transit time (and batch size), how often an order requires premium freight, and how often shipments are sent.

The transit time, while minor in most cases, really balloons at C, with five days internal and five days external shipping. This is largely due to their cut and sew operation being located outside the US. This decoupling of processes can cause more inventories to be held in the system – indeed, it seems as if approximately a month's worth of inventory is being held at both B and C to account for the international transit (redundant inventory). As well, the transit batch sizes are very different – 4,000 yards to B every week, 4,000 yards to C every 25 days, but only 55 tops (or approximately 110 yards) to D every day.

One key point to note in this data is the lack of premium freight. While, at first glance, this appears to be a good thing, it is the result of the excess inventory that is present throughout the system. It seems unusual, especially

Table 2.3 Automotive supply chain ordering patterns

	Lead time (days)	Order receipt mode	Frequency
D	–	–	1 week
C	7	EDI	3 weeks
B	21	EDI	4 weeks
A	28	Phone/fax	–

Table 2.4 Logistics of material flow in supply chain

	Transit time (days)	Size	Premium freight	Shipment frequency
D	1	–	<1%	Daily
C	5 (internal) 5 (external)	55 tops	<1%	25 days
B	2	4,000 yards	<1%	Weekly
A	3 (internal)	4,000 yards	<1%	–

in a supply chain of this size, with the great geographic disparity, to have a consistent less than 1% of all shipments be premium freight. While this is not the cause of a problem, it definitely seems to point to too much inventory in the system.

2.6.4 Ideal management practices

Across an ideal supply chain, operational parameters, information management and logistical issues would be balanced to optimize the entire chain's total value proposition. This would provide equitable economic value added for each of the chain participants. Implementation would involve minimizing forecast variance, seamlessly transferring accurate forecast and order data on a real-time basis and maintaining optimal inventory levels at strategic points along the chain.

Ideal operations

The ideal management system across an entire supply chain integrates functions between parties at each of the interfaces between partners. These typically are information transfers (forecasts and orders), inventory management and logistics. In turn, optimal management of these allows for all parties to optimize purchasing, inbound logistics, inbound quality control, receiving and storage, inventory control, order processing, production planning and scheduling, warehousing, outbound transportation and customer service within their own organization. Each member of the chain may have the opportunity to trade inventory management for information management.

Ideal information flow

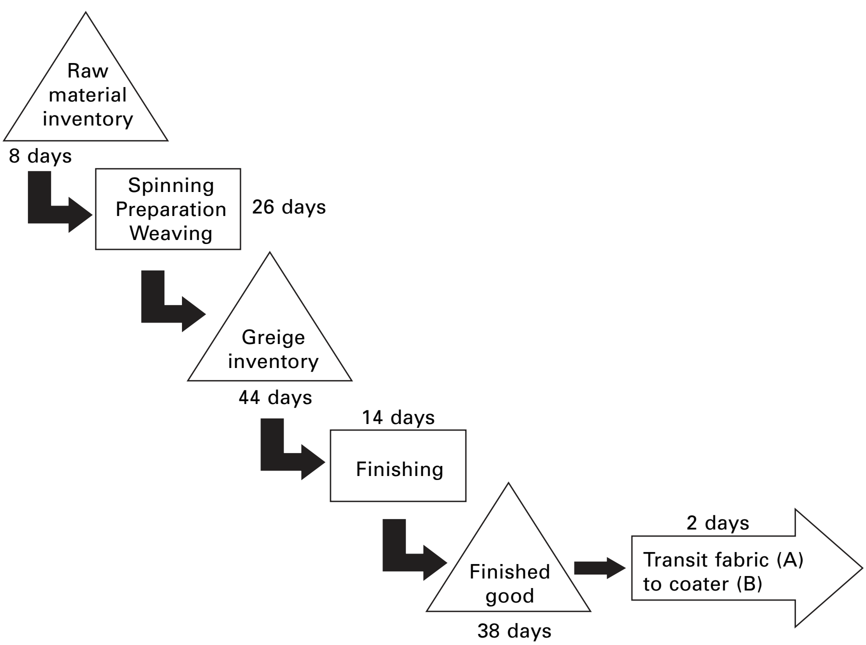
Ideal information flow provides accurate, reliable electronic data interchange with high frequency and minimal personal intervention. This is optimal because it provides real-time forecast and planning data that provides extended visibility and stability to the suppliers' planning and production efforts. Orders that are transmitted with reduced personal intervention are less likely to contain errors that can disrupt information and operational flows. Likewise, visibility into supplier inventory and in process commitments can give the purchaser some insight into the flexibility of the supplier to meet a special order or need, should one arise.

Ideal logistics

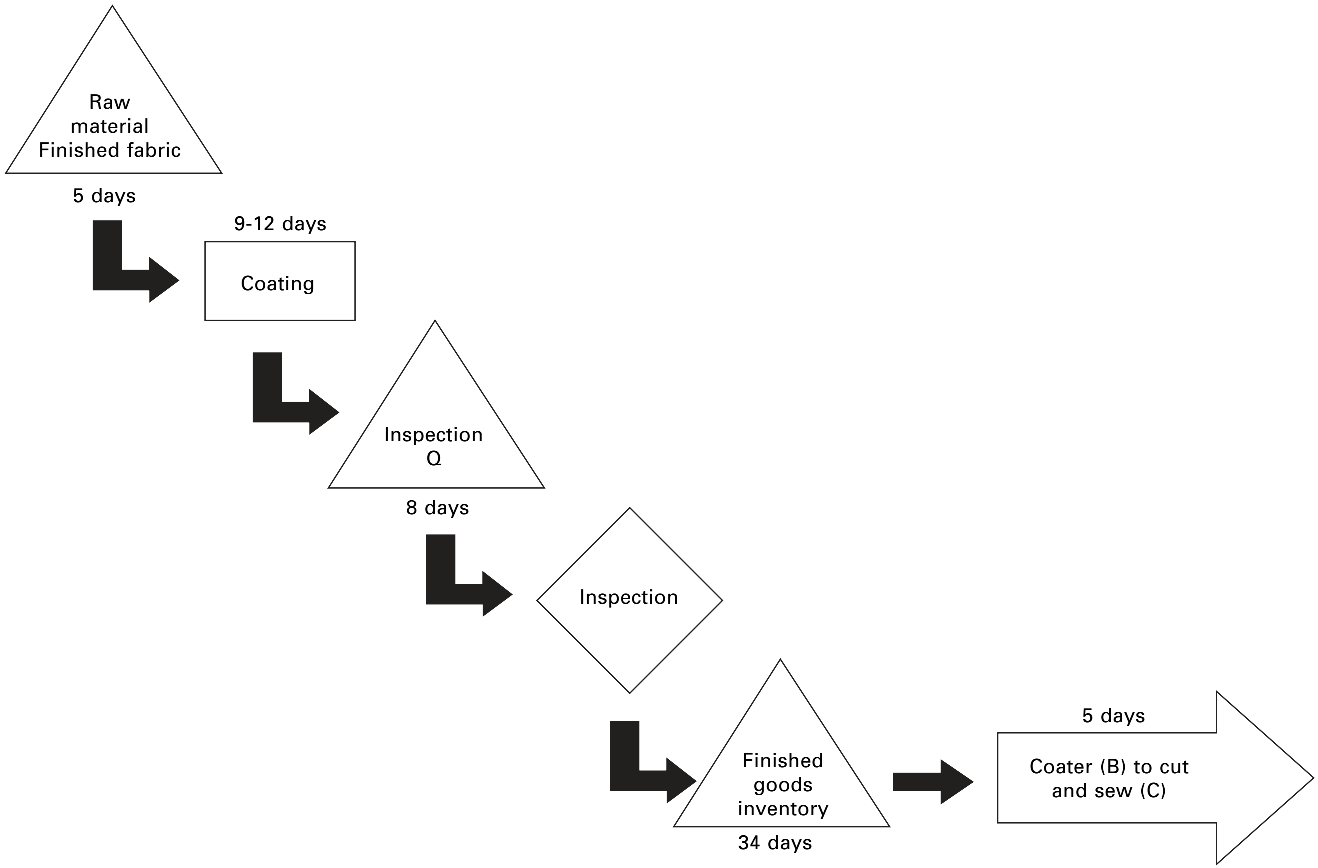
Negotiation, dialogue and agreement would occur to reduce logistical bottlenecks that may inhibit material flow between parties. Strategic placement of inventory and optimization of freight operations, minimize the threat of stock outages or excessive inventory and obsolescence. The benefits of just in time delivery and manufacturing (low to no inventory carrying costs) might be obtained through cooperative efforts between supply chain partners. By analyzing the entire chain from a logistical standpoint, it may become evident that there has not been any optimization of the strategic placement and flow of material between members of the supply chains and significant savings may be available through a cooperative effort.

An entire supply chain overview provides an opportunity to optimize material and information visibility, availability and reliability within and between each supply chain member. Through ideal flow of information, cooperation regarding inventory placement and volumes, and optimization of logistical issues, each member of the supply chain would benefit. Each participant would have the best information available to establish optimal batch sizes to serve customer needs and plan operations to optimize use of assets and potentially improve cash flow. The entire flow of the supply chain is shown in Figs 2.2–2.5.

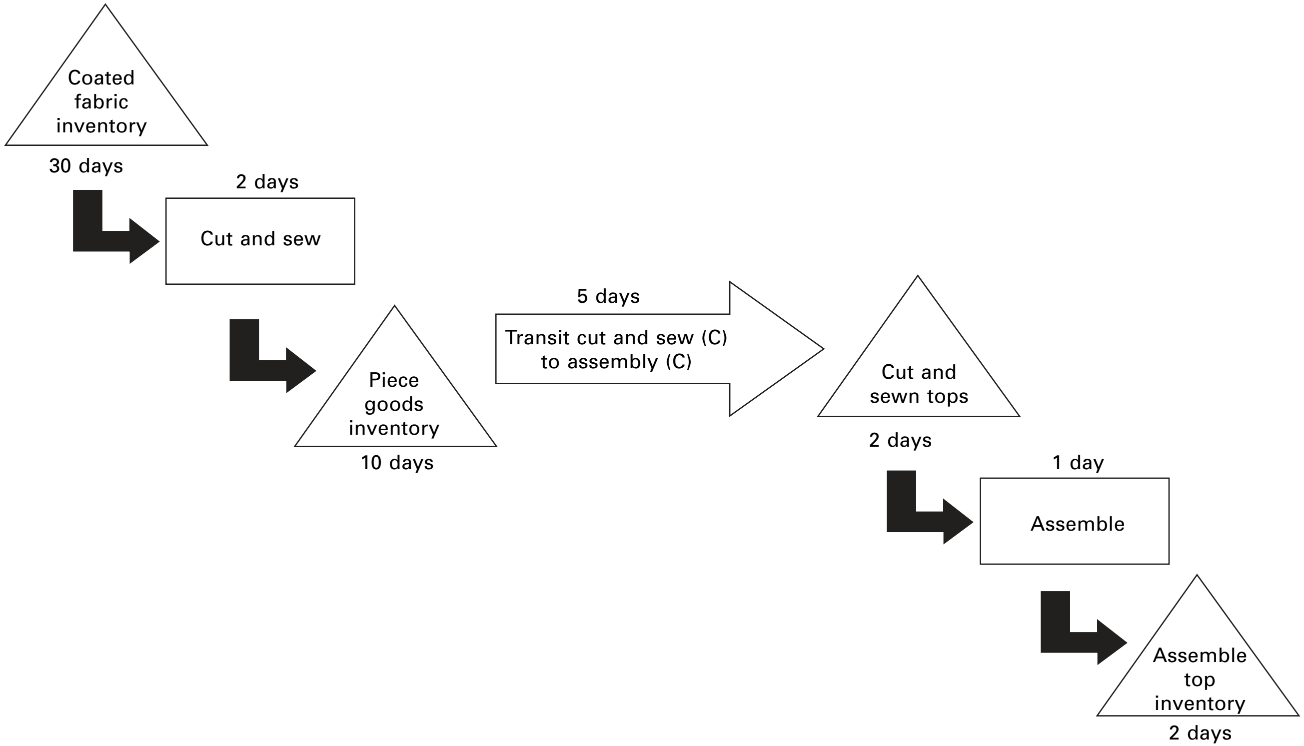
Some of the potential reasons for this inventory based on analysis of the supply chain are shown in Fig. 2.6. Further, the amount of inventory in the chain is illustrated in Fig. 2.7. The classic pattern of the bullwhip effect is evident, as the final company in the supply chain (the textile manufacturer)



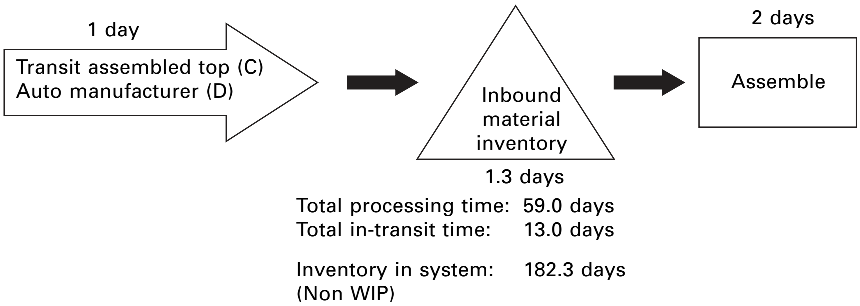
2.2 Supply chain map, fabric manufacturer to coater.



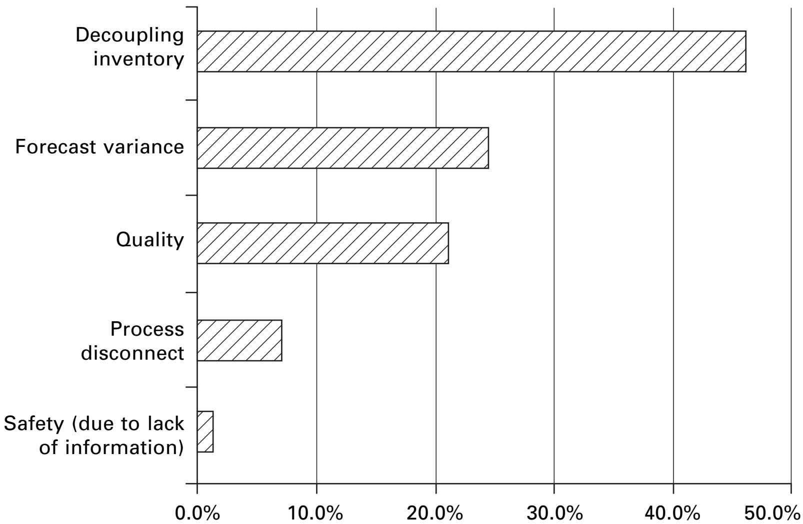
2.3 Supply chain map, coater to cut and sew.



2.4 Supply chain map, cut and sew to assembly.



2.5 Supply chain map, assembly to installation.

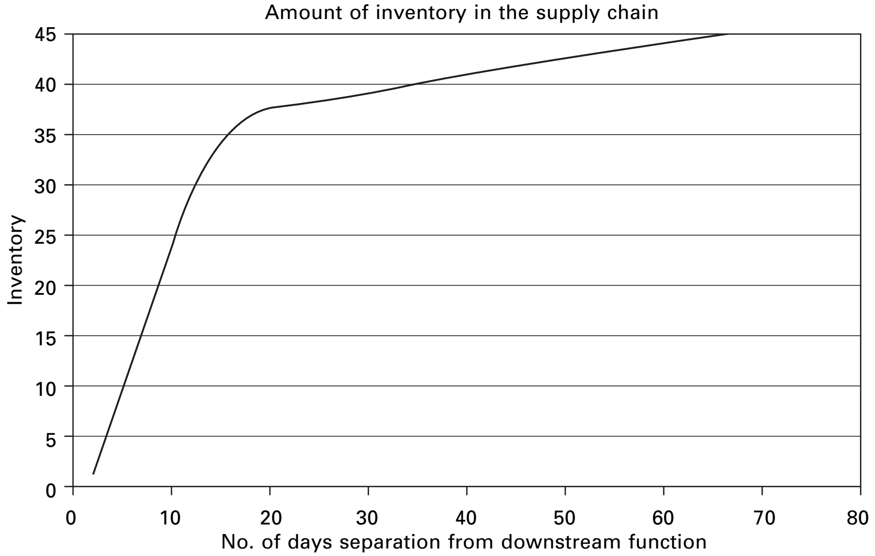


2.6 Reasons for inventory in the automobile supply chain studies.

is left with the greatest level of inventory to hold, due to poor information visibility.

2.7 Tactical recommendations for supply chain mapping

When looking at any supply chain situation, one of the first areas for improvement is optimization of inventory levels. The proposed optimized supply chain in Fig. 2.8 addresses these needs directly. The first recommendation is based on the removal of redundant and excessive inventory. As mentioned above, the finished goods inventory held by B and the materials



2.7 Bullwhip effect in automotive supply chain.

2.8 Potential inventory reductions by type.

inventory held by C are redundant. The two inventories occupy the same inventory point on the supply chain, separated by transportation time. It is our recommendation that B should eliminate its finished goods inventory. By placing its cut and sew plant offshore, C increased the uncertainty and transit times in the entire supply chain. Therefore, it should be the one to incur the inventory holding costs. This inventory at B could be 'replaced' with information, which could be provided by increased visibility of the forecast and improved information flows.

The second recommendation is that the forecast visibility should be improved across the entire supply chain. D generates a 20-week forecast that is shared with C. However, C only shares a three-week forecast to B and ultimately A. If B and A were afforded the original information, a more effective manufacturing process and inventory management system would be possible. Likewise, providing access to the one-week sequence schedule of D would decrease uncertainty at B. Increasing the forecast visibility would allow for more effective and efficient planning schedules that would reflect demand more closely, thus allowing overall reduction of inventory. All of the recommendations mentioned to this point would also improve the area of flexibility for the supply chain partners, by allowing for lower carrying costs, thus freeing capital. Ultimately, the area of customer service would be improved as well, due to each member of the chain (under D) being 'leaner' and more flexible. This would allow responsiveness to improve among the members.

Another area identified for improvement is information flow. Currently, A receives orders via fax from B. However, an EDI or web-based ordering system would prove much more effective. First, the orders would be much easier to track. The possibility of human error is greatly decreased as the ordering system becomes more and more automated. Next, an order placed by fax has a chance of being misplaced, especially if the fax machine utilized serves other different purposes. An electronic means of ordering would provide a 'dedicated' place for orders to be received. Finally, there is the issue of speed. With Internet connectivity growing faster each day, the time saved by ordering electronically instead of filling out and faxing a form could turn into a significant savings opportunity. Improved information flows would not only allow for faster reaction to orders, improving customer service and responsiveness, but would also provide real time information about demand.

2.7.1 Insourcing/outsourcing consideration in the value system

A final area requiring further study involves significantly reducing the size of the supply chain as a whole. It would improve the entire supply chain if the international plant of C's cut and sew operation could be eliminated. A thorough cost/benefit analysis would need to be performed. However, the time in transit alone serves as justification for exploring alternatives. If C is willing, the operation should be relocated to the US, preferably in a location closer to B's or C's assembly plant. On the other hand, another alternative would be for B to forward integrate into this area, shipping the material directly to C's assembly operation. Further, a second option would be to outsource the cut and sew function to another company, preferably more conveniently located to the entire supply chain.

2.8 Conclusions

There are several essential requirements to going forward and realizing the recommended improvements in the automotive supply chain. The first step is an improved mechanism for sharing and receiving information. Currently, information is shared on a periodic basis ranging from weekly to monthly. This inconsistent information sharing amplifies the bull-whip effect in the supply chain. The validity of the information is in question as well due to intermediate suppliers hedging demand to insure sufficient materials are on-hand. A solution to this inefficient visibility system is for OEM assemblers to provide visibility in depth throughout the supply chain. By penetrating deep into the supply base, variability and uncertainty can be reduced significantly by eliminating demand hedging activities and delays in information transfer between the different tiers of suppliers. This system also allows assemblers to control the type of information that is shared and reduces the likelihood of data entry errors.

Supply chain evaluation and control should be incorporated into the system to measure current performance and the effect of supply chain initiatives. A series of shared metrics that accurately reflect the drivers of value and cost in the system is required to accurately gauge performance. Metrics should be non-financial in nature to allow for measures that accurately reflect supply chain performance while maintaining firm privacy. A series of recommended supply chain performance metrics that ultimately lead to increased value and lower total cost of ownership in this supply chain are shown in Table 2.5.

Table 2.5 Recommended supply chain performance metrics

Value area	Metric
Customer service	On time delivery Correct shipments Customer inquiry response time EDI transactions
Flexibility/reliability	Value added and non-value added time Inventory days Response to change in demand
Costs	Distribution as a percentage of sales

2.9 Sources of further information and advice

2.9.1 Supply chain resources

Journals

Academy of Management Review
Management Science
International Journal of Operations & Production Management
Production and Operations Management
British Journal of Management
Sloan Management Review
Harvard Business Review
Journal of Marketing
Journal of Management Studies
Journal of Business Logistics
IIE Transactions
International Journal of Production Research
Supply Chain Resource Cooperative (http://scm.ncsu.edu)
The Economist Intelligence – Automotive Forecast World: Economic Outlook

Books

Title: *Supply Chain Management*
ISSN: 1359-8546
Publisher Information: Emerald Group Publishing Limited
60/62 Toller Lane, Bradford, West Yorkshire BD8 9BY, United Kingdom

Title: *Journal of Business Logistics*
ISSN: 0735-3766
Publisher Information: Council of Logistics Management
Suite 200, 2805 Butterfield Road, Oak Brook, Illinois 60523, USA.

2.9.2 Automotive textile resources

Journal of Textile and Apparel, Textile Management www.tx.ncsu.edu/jtatm
MobileTex – Textile Media Services
Office for the Study of Automotive Transportation, University of Michigan www.osat.umich.edu
Transportation Research Institute, Ann Arbor, Michigan
Center for Automotive Research http://www.cargroup.org/
Wards Auto – www.wardsauto.com
www.just-auto.com

2.9.3 Industry and market research

J.D. Power www.jdpower.com
CSM www.csmresearch.com
US Dept of Commerce – Office of Automotive Affairs www.commerce.gov
US Department of Transportation www.dot.gov
US Bureau of Census www.census.gov
Bureau of Labor Statistics www.bls.gov
Alliance of Automobile Manufacturers www.autoalliance.org
International Monetary Fund – World Economic Outlook www.imf.org
Transportation Reseach Institute, Automotive Analysis Division, University of Michigan, www.aad.umich.edu
Center for Automotive Research, College of Engineering, The Ohio State University http://car.eng.ohio-state.edu

2.9.4 Global players in the supply chain

International Auto Components Group – North America
Safety Components International/International Textile Group www.safetycomponents.com www.itg-global.com
Lear www.lear.com
Johnson Controls www.johnsoncontrols.com
Magna International/Intier www.intier.com www.magna.com
Faurecia www.faurecia.com
Tachi-S www.tachi-s.co.jp
Toyota Boshoku www.toyota-boshoku.co.jp
Eybl International www.eybl-international.com
Milliken www.milliken.com
  Viktor Achter Ltd
Fezko www.fezko-as.cz
Fibertex www.fibertex.com
Guilford www.guilfordproducts.com
Aunde (Aunde Achter & Ebels) of Germany www.aunde.com
  Gamma Car Fabrics
  DeWitte Lietaer
Autoliv www.autoliv.com
Seiren www.seiren.com
Kawashima www.kawashimaselkon.co.jp/
Kuraray http://www.kuraray.co.jp http://www.clarino-am.com
Suminoe www.suminoe.co.jp.
Tatsumura Textile Co., Ltd. 29, Morimachi, Mibu, Nakagyo-ku, Kyoto 604-8862, Japan
TRW www.trwauto.com

Borgstena www.borgstena.com
DuPont Automotive www2.dupont.com/Automotive/en_US/
Freudenberg www.nonwovens-group.com
Takata Highlands www.takata.com www.highlandindustries.com
Grupo Copo www.grupocopo.com
International Auto Components Group www.iacgroup.com

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3

Woven and knitted fabrics used in automotive interiors

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Abstract: After an introduction to the demands of automotive textiles, an overview is given of the different types of textile components in car interiors and of market data of textiles in the automotive production. Details are given of the construction of woven, flat and 3-D knitted fabrics and of the finishing process with lamination to multilayer systems.

For testing, the different and most important standards are mentioned as well as special measuring devices for the haptic, soil release or self cleaning and electrostatic charging.

As for future trends, the R&D in fibre polymers and in the simulation of textile constructions are considered.

Key words: automotive textiles, texile components, market data, textile construction, woven fabric, knitted fabric, 3-D knitted fabric, finishing, lamination, testing, standards, haptic, soil release, self cleaning, electrostatic charging, FEM, simulation.

3.1 Introduction

Textiles play an important role in the growing worldwide vehicle market. Owing to the various applications in which they are used, they have to meet a comprehensive list of requirements with regard to their visual, comfort, security and fastness qualities. Therefore they have to pass corresponding test procedures to determine their relevant mechanical, physical and chemical properties.

The finishing of textiles, using processes like weaving, knitting and warp knitting, plays an important role in their mechanical and surface-related properties. The use of spacer textiles is attractive as they have the advantage of improving air permeability and humidity in a seat's construction. To produce the final product, a textile material often has to undergo processes such as lamination, coating, deep drawing and make-up. In future, new fibre developments will extend both the resources available and areas of application. These developments will be supported by new numerical simulation tools for their construction, processing, and application in vehicles.

3.2 Various types of textile component in car interiors

3.2.1 Basic requirements

Textile components in automotive applications have to provide a good visual impression, as well as comfort and safety. Therefore they have to fulfil complex demands:

- colour, light and appearance have to be considered
- for comfort, their bio-physiological properties have to be adapted
- textile properties that have to be considered include:
  - haptic, temperature behaviour (cold-hot)
  - contact with other materials like clothing, human skin
  - resistance to ageing
- for noise in the interior, sound absorption has to be integrated.

The application areas for textiles in automotives are extensive, and include:

- seat coverings in combination with trim panels such as side and back panels
- door and side coverings with airbags
- roof rack, pillar lining, sun shield, headliner, boot trim
- floor area, dashboard trims
- security elements such as safety belts, airbags
- filter materials (air, oil, petrol, interior)
- external soft top, wind deflector for convertibles
- reinforcement in fan belts, tyres, tubes
- sound absorption in the engine compartment.

Up to 10 m^2 textiles, 160 cm in width (without the headliner) are needed for an automotive interior [1].

Apart from design, textiles have to fulfil a certain list of technical requirements, which strongly depend on the application. One can divide them into the following groups:

- Processing properties such as:
  - sewability
  - sewing strength
  - seam slippage resistance
  - stiffness
  - elongation
  - tensile strength.
- Service properties such as:
  - mechanical behaviour (strength, elongation, bending and folding, tear propagation strength, dimension stability, pressure resistance)
  - ageing behaviour (heat/cold, temperature, humidity, light) [2]

- colour fastness (friction, light, chemicals, sweating)
- friction behaviour (brushing-up, abrasion, pilling, fibre migration)
- bio-physiological demands (air permeability, heat and humidity transport in upholstery)
- emission behaviour (toxic elements, smelling, fogging, total emission) [3]
- contamination and cleaning behaviour
- electrostatic behaviour
- flammability
- optical, haptic, design.

Depending on the application, some additional specific requirements may have to be considered.

New designs in automotive construction are increasingly influenced by the legal regulations on emissions and those on the waste from old vehicles, which require the use of materials that can be recycled. These influence nearly all textile developments in the automotive sector.

3.2.2 Market data

Quite a large number of different textiles are used in the production of a car [4]. In the global vehicle market, about 65.9 million vehicles are produced each year. The forecast is for 56 million cars and 22 million light trucks, a total of 78 million vehicles in 2011 [5]. Some 5 to 8 kg (15 to 18 m^2) of textiles are used in a car interior. This adds up to about 240 million square metres of textiles used for car interiors in Europe and 91 million square metres of carpet and boot linings. The EU is the world's largest automotive manufacturer, producing about 16 million new passenger cars and 1.8 million light commercial vehicles in 2006.

The different textile usage for major components is:

- 6–8 m^2 – seating
- 5–6 m^2 – floor
- 2 m^2 – headliner
- 3–3.5 m^2 – boot/cargo
- 0.6–0.8 m^2 – door panels
- 0.4–0.5 m^2 – pillar cover
- 0.7–0.8 m^2 – parcel shelf [4].

These textiles are made from woven, knitted, warp knitted, tufted and laminated fabrics, and nonwoven, electrostatic flocked surfaces [6].

Fibres are chosen with regard to the demands for fastness, comfort and price.

3.3 Overview of main types of textiles used

Different textile materials are used depending on the part of the automotive in which they are to be used [7]:

- A-, B-, C- pillar, headlining: knitted fabrics
- door panel: upholstery material
- floor: carpet
- seat: upholstery material
- boot: carpet.

It is interesting to note how much fabric is actually used for the seat and door covers, including the headrests, compared to the fabric used in the headliners and parcel shelf covers. It has been found that around 88% of the fabrics used in the automotive industry are used in seating and door covers.
Polymer materials are used as follows:

- polyester (mainly for upholstery)
- polyamide (mainly for carpet, and on a limited scale for upholstery)
- polypropylene (for carpet, and on a limited scale for upholstery)
- polyurethane (as an additive fibre for technical applications, e.g. elasthan)
- polyacrylic (for convertible roofs)
- wool or cotton (as additional fibres).

A large proportion of these contain spun-dyed polyester fibres with about 40 000 tons of polyester yarns used in Europe. As well as man-made fibres, natural fibres such as hemp, flax, wood fibres and cotton are used in composites, with each vehicle containing about 16 kg. Flame-retardant properties are provided by blending different fibres.

Therefore, polyester dominates the raw materials used in fabrics in the automotive industry, its share of the total materials used being about 78%. Of this percentage, 59.4% is air-textured PES yarn (ATY), followed by PES friction-textured yarn (FTY) at 30.6%.

So more than 70% of automotive textiles are made from textured yarns, of which the major portion, approximately 60%, is air-jet textured (Taslan) and the remaining 40% is false-twist textured. The proportion of air-textured yarns used has risen over the last few years because of the increase in the use of woven fabrics, where the overall count at 550 dtex has become finer. The quality of the yarns used has improved, so the desired abrasion resistance properties can be achieved, even using a finer count. Also, using air-texturising, a natural-looking appearance can be more easily achieved, when several components are fed into the jet with different levels of overfeed to achieve a special colour blend.

In 2005, the worldwide production of automotive textiles [8] was calculated to be:

- fabrics, knits 214 000 tons
- nonwovens 114 000 tons
- composites 976 000 tons
- others 179 000 tons

with an astonishingly high increase in China.

3.4 Woven and knitted fabrics

3.4.1 Woven fabrics

Some facts and figures can be found at www.inteletex.com: woven fabrics dominate this sector with 51% of interior automotive fabrics produced by this method. These fabrics are mainly dobby weaves, with 32% of the share, followed by Jacquard weaves with 18% but this share is increasing. Very little woven plush is used (0.45%). All this fabric is used for the seat and door covers. Jacquard- and dobby-designed fabrics are used mainly in the seat area and the dobby woven plain fabric is found in the seat wings, bolsters and rear covers of the front seats.

3.4.2 Flat knits

Circular knits are the second largest fabric group, having a 19% share of this particular market. Leading the way are circular knitted velour fabrics with 15% and circular flat fabrics (single or double jersey) with nearly 4%. Circular velour is used on the seat and door covers, with flat circular knits used mainly for the rear covers of the front seats and headliners.

Meanwhile warp knitted fabrics are the third most popular group with a 12% market share. These include the Tricot family of knits (6%), brushed or structured, with Tricot pile sinker fabrics having a 4% share. Raschel knits represent just 0.79%.

3.4.3 Spacer knits

Spacer textiles in upholstery are made from warp knitted (double-Raschel machine) or knitted (circular knitting machine [9]) fabrics [10]. They are made from two separate textile layers which are connected by stiff spacer yarns.

Monofilaments (single) are mainly used for spacer yarns. The height of the structure is governed by the distance of the two needle bars of the Raschel machine and by the distance between the cylinder and rib discs in the circular knitting machine. The force that is necessary to keep the two textile layers apart depends on the material, thickness and structural integration of the spacer yarns (monofilaments) into the basic layers.

Spacer structures have an elastic pressure behaviour: by pressing on the surface they are compressed. When the pressure is released, they relax in an elastic way. The space between the two layers is an air-filled cavity from which the air is removed during compression, and into which air is sucked during decompression. Unlike foam constructions, these textile constructions are able to breathe.

An increasing interest is being shown in spacer structures and their use in different applications. Nearly all the available textile and non-textile yarns can be used for their production. Due to their construction, spacer structures have the following advantages:

- light weight, soft touch, skin friendly
- breathability (high air permeability, defined climatic conditions)
- humidity transport and humidity absorption
- defined elasticity in length and breadth
- thermo regulating
- fastness to washing
- good reaction to long-term loading
- sound absorbing
- filtering
- sewability
- resistant to ageing.

Spacer textiles on a base structure of knitted textiles can be used to advantage in applications with climatisation requirements. In different project studies, several vehicle seats were developed that regulated the climate in the seat according to the time of the season and the temperature. Since 1990, such ventilation systems for seat climatisation have been in mass production for the back of the seat. The construction consists of a combination of ventilation and breathable seat layers. When the driver perspires, humidity is able to escape between the back and seat upholstery through the textile into the inner layer of the seat, where a circulating air flow removes the humidity. The laminate used has a protection layer and a very thin Gore-Tex membrane. The water vapour crosses through this laminate into the deeper air channels of a spacer textile connected to the air ventilation system, which transports the humid air outside.

Spacer structures offer further advantages to applications:

- Due to their broad flexibility with regard to mesh structure, it is possible to choose the inner and outer material, together with spacer yarns of different material, fibre type, density, structure and space combinations.
- The back side can be adapted separately to the front side to obtain good properties of lamination, bending radius, elongation and stiffness.

There are significant differences between knitting and warp knitting, which can be used to advantage – depending on the application and production conditions:

- The main advantage of spacer knits is the free design of Jacquard patterning, which is also possible in warp knitting, but with more limitations.
- The elongation of knits is often higher than that of warp knits.
- Spacer knits are of interest for small and medium-sized production runs due to their high flexibility in circular knitting machines. No work-intensive warp beams have to be prepared for the production of spacer knits. It is possible to produce them with only a few cones to fulfil the total technical requirements.
- The front surface of spacer knits can be designed by electronic patterning, free from limitations, optimally fulfilling visual requirements and technical demands. The electronic needle allows large and small patterns to be produced in the same way.

The advantages of flexible production and free patterning are becoming of more and more interest. Machine and construction development is taking place at ITV Denkendorf.

3.5 Finishing of textiles

Great demands are made on the properties of textiles for the interiors of vehicles. Many of these properties, as well as special functions and their permanence, are achieved by the finishing of textiles and must be considered separately. Important properties include the following: low susceptibility to soiling, excellent cleanability, no or only very low emissions of temporary organic bonds which smell or condensate (fogging), high resistance to abrasion, good pilling behaviour, excellent fastness to rubbing, colour, welding, good humidity transport behaviour (seat climate), high degree of light fastness, high resistance to flammability, and little tendency to produce electrostatic charge.

The most problematic types of spots and soiling on textiles are based on aqueous and/or oily materials. Chemical compounds, therefore, are used as protection against them, thus preventing textiles from being wetted by oily materials (oleophobicity). Textile finishing, additionally, affects water repellence behaviour (hydrophobicity) while also reducing dry soiling. Textiles finished as described above show a very low degree of surface energy. The forces of adhesion between a textile surface finished with oil-repellent agents and oily liquids are very low so that the forces of cohesion predominate, thus preventing the textile surface from being wetted.

The compounds mainly used are fluorocarbons, which are based on a structural component composed of acrylic acid or polyurethane and perfluorinated alkyl radicals. The polysiloxane bonds represent a further product group which, however, cannot affect the repellence of oily bonds.

Bacteria, fungi, mildew, yeasts, and algae can be killed by means of an antimicrobial finish on textiles. However, its contact with the skin of the driver and passengers, in those particular areas of automotives where it is unavoidable, has a detrimental effect because it also has a cell-toxicological effect on the aforementioned elements in human cells. Long-term stability is restricted because of the continuous release of cell toxins required to achieve the desired effect.

Many of the formerly used antimicrobial agents are no longer used for textile finishing in most industrial countries because of their enormous toxic effect and/or environmental impact. Phenols and organometallic bonds of quicksilver, for example, are included in those materials. Many antimicrobial agents show poor biological degradation behaviour. Further side-effects involve the danger of the emergence of resistant bacteria and fungi as well as of allergies.

Non-ionic antimicrobial agents – also designated as heterocyclic compounds and benzimidazole derivates – are used instead. Their advantage is that they are free from heavy metals, phenols as well as halogens, and thus cause fewer problems for wastewater. Salicylanides – mostly halogenated and barely water-soluble – are used for both bacteria and fungi. Their permanence to washing is improved by combining them with resin pre-condensates. Undecyclic acid derivates – especially alkylamines – are considered to be particularly skin-tolerant for humans.

The finishing of textiles requires – independent of the material system used – the following:

- The textile's visual impression (structure, colour) and feel must be preserved.
- The finishing agent must be permanent with regard to washing and use.
- Downstream processing such as laminating, gluing, bonding or sewing must not be adversely affected.
- Fogging values, emission behaviour, fastness, mechanical-physical properties as well as antistatic behaviour must not be impaired.

3.6 Processing multilayer systems

The textile properties of these fabrics could be greatly affected by subsequent processes such as coating and laminating (e.g., flame-laminating of pdyurethane foams). Problems between the lamination partners have to be taken into account with regard to evenness, adhesion, emissions and resistances [11].

Knitted fabrics are mainly used for rear window shelves or headliners. For these applications, foams should also be replaced by non-wovens. In particular the acoustic properties have to be taken into account.

Upholstery fabrics are mainly made of polyester, sometimes with a small wool component. For upholstery, the use of flocked yarns or knitted fabrics is declining, although combinations of different fabrics or textured fabrics have become common [12] (e.g., floatings).

Leather and leatherette are fashionable for use in automotive interiors. An unsolved problem for leatherette is its poor light- and colour-fastness. Nevertheless, because of its price advantage compared to leather, it is in demand.

Direct processes for the assembly of composites made from renewable raw materials (flax, hemp) are improving rapidly. In these the adhesive, in the form of hot-melt fibres, is mixed into the non-woven material and the composite is formed and cured by heat in a press [13], thus saving some laborious production steps.

Using back injection for fabrics, inherently stable component parts could be generated. It is most important to have a close and durable bonding to the three-dimensional mould, which mostly consists of plastic materials. For back injection as well as for deep-drawing, there are special requirements for strength and extension (sometimes more than 40% is required), with an even and tight surface and heat resistance. The penetration of liquid plastic through the fabric during back injection could be avoided by using an additional layer, e.g. a bonded non-woven [14].

Supporting components made of fibre-reinforced composites, e.g. axle carriers for buses, are being produced. The benefits of these parts are:

- lightweight construction
- integration of further functions which is not possible if using metal
- the natural frequency decreases by about 10 Hz, which increases travelling comfort.

A new development in the field of lightweight constructions is the combination of two layers of steel sheet with a textile layer in between, bonded together by adhesive [15]. Using this composite, high stiffness and very good deep-drawing property in addition to body sound damping could be combined for the first time.

3.7 Test procedures and special properties

3.7.1 Standards

To characterise textile materials for the automotive industry and ensure uniformity for each delivery, besides the numerous national and international test standards, standards exist which are produced by the automotive manufacturers themselves, the so-called 'Technical delivery conditions' (TC).

They describe characteristic properties such as material composition, construction and physical properties, as well as application-oriented characteristics with their nominal values. They also contain test specifications (TS), which are relevant for the determination of the characteristics. These test specifications are developed and supervised through the members of the automotive association (in Germany this is the VDA). This ensures that the high requirements and obligations of textile components for the automobile are guaranteed.

Tables 3.1 and 3.2 exemplify the requirement profiles that should be met for a bonnet fabric.

The test methods for the burning behaviour of a car interior are [16]:

- 95/28/ES (European Directive coaches) oMVSS 302 and
- Producer's specification.

Until now, haptic has been the next most important impression for humans (after visual impression, smell and noise). The evaluation of the haptic is still difficult to reproduce, because most of the tests are based on people's impressions [17]. The Kawabata test procedure is quite comprehensive and needs great experience in evaluation. So there are intensive trials to reduce the test demands to a small number of methods and to calculate a summary number of the individual results. In the industry, the well-known measuring unit – the FAST System – characterises the haptic by the three properties of thickness, bending and compressibility.

ITV Denkendorf proposes an alternative technique using the Pulling-Through Method. During the test, developed by ITV, a sample strip is pulled through a testing ring that is small in comparison to the sample's width, with a specified constant speed (see Fig. 3.1), and is formed by it. The forming resistance, which is influenced by the friction between sample and ring, is measured as a pulling-through resistance in the form of a distance-dependent

Table 3.1 Identifying characteristics

Characteristics	Standard/test specification	Test conditions
Mass per unit area	DIN EN 12127	
Thickness	DIN EN ISO 5084	
Tensile strength	DIN EN ISO 13934-1	• original • after water storage • after thermal storage
Tensile elongation	DIN EN ISO 13934-1	• original • after water storage • after thermal storage
Air permeability	DIN EN ISO 9237	• original
Tear growth strength	DIN EN ISO 13937-2	• original • after water storage • after thermal storage

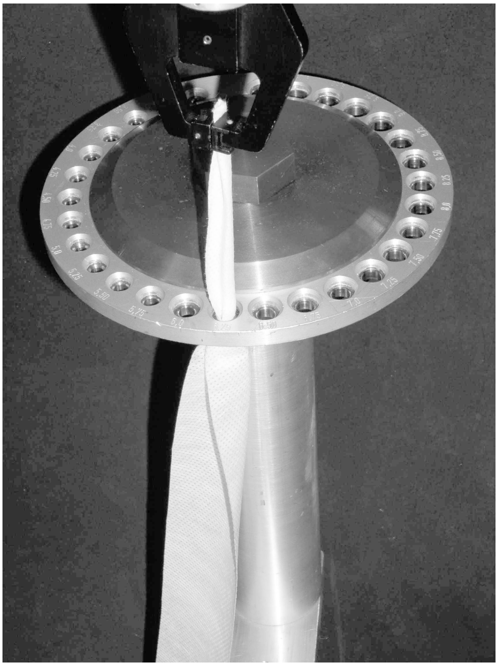
Table 3.2 Application-oriented characteristics

Characteristics	Standard/test specification	Test conditions
Adhesion	DIN 53357	• original • after thermal storage
Dimensional stability	DIN 53892/Test specification	• original • after thermal storage
Stitch tear resistance	DIN 53331	• original
Water penetration; hydrostatic pressure	DIN EN ISO 4892-2	• original • after thermal storage
Fabric/seams	DIN EN 20811	• after aging
Abrasion resistance	DIN EN ISO 12947-4	• original
Colour fastness to rubbing	DIN EN ISO 105-X12	• original
Repeated flexure test	DIN 53359	• original • after thermal storage
Stiffness under flexure	DIN 53121	• original • after thermal storage
Break-through force	DIN EN 13567	• original
Scratch resistance	Test specification	• original • after thermal storage
Rot resistance	Test specification	• original
Static/dynamic elongation	Test specification	• original • after thermal storage
Water repellence test	DIN EN ISO 24920	• original • after thermal storage
Resistance to media	Test specification	• original
Light fastness	VDA 75202	• original
Heat/light fastness	VDA 75202	• original
Aging behaviour	DIN EN ISO 4892-3	• original
Fogging behaviour	DIN 75201	• original
Odour under temperature	VDA 270	• original
Flammability	DIN 75200	• original
Soiling and cleaning behaviour	Test specification	• original
Mould culture	Test specification	• original

force. This strength reflects those measurement categories which essentially influence tactile properties, such as tensile force, dynamic friction, bending and shear force. The diameter of the testing ring d_{MR} is adapted to the mass per unit area of the particular sample, as defined by the following relation:

$$d_{MR} = PV \cdot \sqrt{mF}\,(1/100)$$

$$= \frac{p_N - p_{RX}}{p_N} \cdot 100\,\sqrt{mF}\;1/100$$



3.1 Pulling-through resistance device with different ring diameters.

where d_{MR} = diameter of the testing ring in mm, PV = pore volume of the sample in %, mF = weight per unit area in g/m^2. This relation applies for a sample width of 50 mm.

The pulling-through resistance is easily measured as a force-distance signal, when the testing ring is fixed horizontally in a tensile testing machine and the sample is pulled through the ring under a combined tension and compression.

The following test conditions were used:

sample width:	50 mm
deforming rate:	500 mm/min
distance between testing ring and clamping arrangement:	100 mm

The sample is folded twice in the clamping range so that a sample width of 6.25 mm results. The measurements were carried out in warp and weft directions.

3.7.2 Methods to test soil release

Numerous methods are used in the automotive sector for the evaluation of soil release. They differ with respect to:

- the type of soiling: dry soiling or wet soiling
- the soil substance used (sand, smut, oil, fat, butter, ketchup, red wine)
- the method of applying the soil (Martindale, shaking in a bottle or other appliance)
- after cleaning: suck off or wash off (soil-release or oily-stain-release methods)
- type of cleaner (foam cleaner, tensides, stain removal)
- the rating (photographic standards, visual rating, relative colour strength, grey standard).

3.7.3 Electrostatic charging in seat upholstery

Textile materials and products made from them are electrostatically active and become charged under certain conditions, for example from rubbing against other textiles or objects, separation, gas flows or ultraviolet radiation. In most cases this static charge is not only a problem during manufacturing and processing but also an annoyance when the product is being used. In a car, static charges of either the upholstery fabrics or of the car passengers themselves may not only affect passengers' comfort but may also endanger sensitive electronic components or even cause an explosion during refuelling. Accidents – in some cases during refuelling – always happen at a relative humidity below 50%.

Electrostatic charging of passengers in a car by the upholstery is one of several sources of electrostatic charging in the overall passenger/car system which has to be considered. The unpleasant charge exchange when leaving the car, caused by touching the bodywork for example, depends on the electrical resistance of the 'person/clothing' system in which the electrical resistance of shoes plays an important role.

The problem of electrostatic charge when leaving a car can, in principle, be solved. Textile-related solutions exist:

- by using conductive fibres and yarns in the upholstery fabrics used for car seats
- by giving upholstery fabrics a permanent antistatic finish
- by inserting electrically conductive layers between the upholstery fabric and the foam.

Attempts to find practicable solutions must, however, take into consideration the overall system within which the upholstery fabric will be used. This must include the stresses resulting from use, such as compression, friction, moisture, contamination and the design of the seat – especially its electrical grounding. Even interactions with the environment and environmental influences, for example contamination problems in the context of long-term behaviour, are factors exerting a decisive influence.

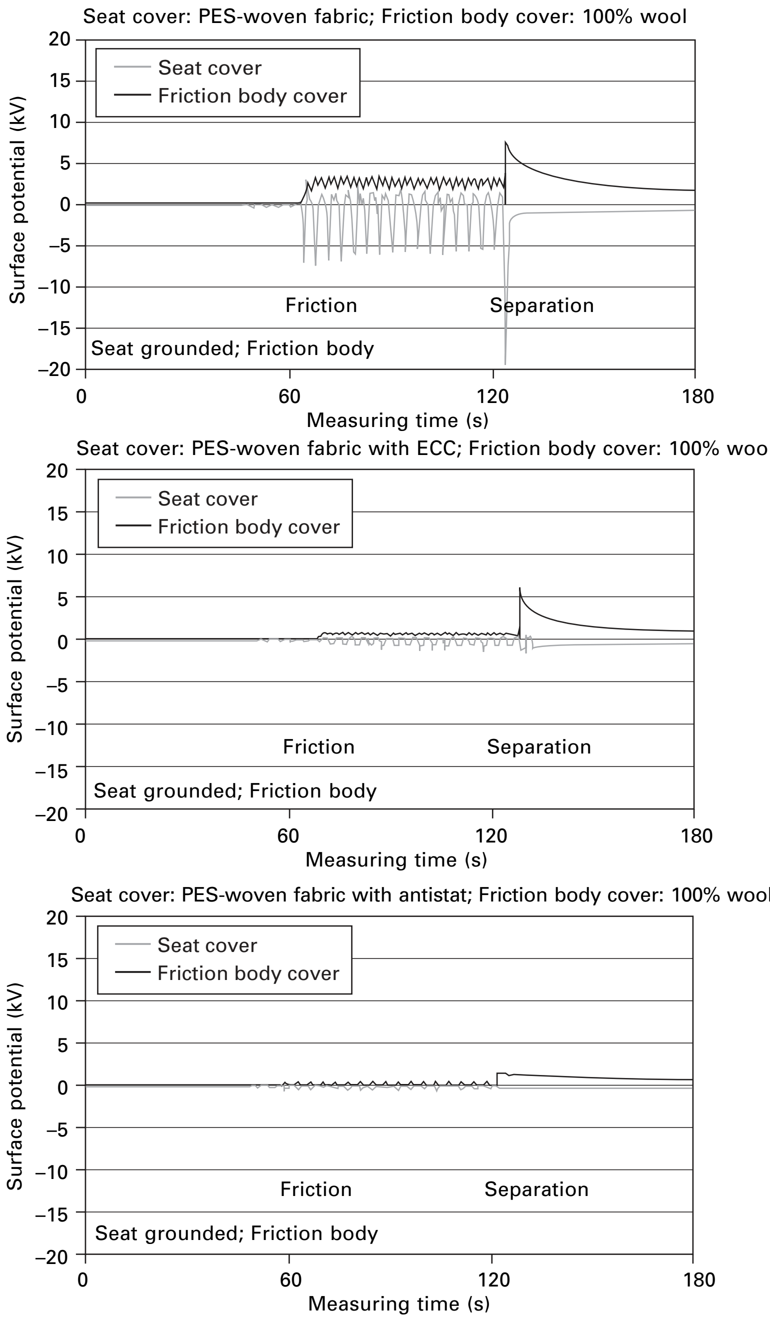
The development of practicable and economically efficient solutions has so far been difficult since previous laboratory test methods have been restricted to investigating the electrostatic properties of the upholstery fabric alone. An evaluation of the effect of 'antistatic measures' on upholstery fabrics will not, however, be possible unless the entire system of 'seat and environment' is examined. To this end suitable testing and measuring methods are being established at ITV Denkendorf. These not only include material testing but also the development of a simulation method which comes close to real conditions of use:

- Investigation of the dynamic charging and discharging of textile samples by means of test equipment available or developed by ITV.
- Analyses of combinations of materials and of entire systems by realistic simulation testing in an ITV upholstery testing device.
- Measurements of the seat/person system to validate the simulation tests.
- Assessment of long-term durability on the basis of the change in electrostatic properties which result from ageing.
- Evaluation of the influence of contamination properties and other environmental properties.

The investigations and developments should consider the following interrelationships:

- Correlations between the electrostatic charging and discharging of persons leaving a car and the physical design of textile upholstery systems.
- Effect of the textile construction of the seat as a total system on electrostatic charging and discharging.
- Effect of electrically conductive elements in upholstery systems on contamination properties.
- Determination of constructive requirements in design for charge dissipation or charge distribution within the seat system.
- Influences of temperature and relative humidity.

On the basis of these results, new textile constructions and also new total systems are being developed. Figure 3.2 shows three typical measurement reports of simulation testing: In each case the electrostatic charge of the upholstery fabric and 'friction body' – simulating a car passenger – are recorded. Here the seat is grounded but the 'friction body' is not. The first diagram shows a standard upholstery fabric of relatively high charge level. The second diagram illustrates the charge behaviour for an upholstery fabric with conductive components. The electrostatic charge of the upholstery fabric is reduced by a factor of 10 although this reduction is not so great at the separation of the material systems – which simulates the passenger leaving their seat. Practical experiences confirm these lab values. The last diagram shows the charge behaviour for an upholstery fabric with an antistatic finish.



3.2 Test records for simulation testing on the ITV upholstery testing rig: electrostatic charging of different upholstery fabrics (PES) and friction body cover (WO); seat upholstery grounded, friction body not grounded. ECC: conductive components.

The charging can also be reduced to a low level at the separation of the material systems.

Investigations of the upholstery fabrics with regard to tribo-electric charge and discharge properties when grounded – on a separate test device – correlate with these results. In the case of incorporated electrically conductive elements, the maximum charge level is reduced by a factor of 2–3.

The friction partners (upholstery and clothing) have a considerable influence on the charge level as well as on the measured polarity. Wool in combination with polyester, which is usually used for seat covers, generally shows a high charge level while colours also have a certain influence. Distinctly higher charges can be measured on separating the textiles compared to those for the friction process. The influence of grounding the upholstery doesn't appear to be significant since none of the materials shows a specific conductive behaviour.

The measurements of the upholstery simulation device correlate well with trials using people getting up from upholstery. For real-life tests, apart from the influence of clothes, the state of the test person with regard to, for example, their skin humidity and the corresponding electrical conductivity, also has to be considered.

With decreasing relative humidity, the charge level increases considerably – as expected – while the conductive elements (e.g., finish) also have strong influence. The effect of antistatic agents on hygroscopic bases is strongly influenced by the 'relative humidity' factor.

3.8 Future trends

3.8.1 Trends in fibres and composites

Improvements may be achieved in the design or engineering of textile materials. Enhanced materials are of more significance than individual new developments that hit the front page [18].

Approved fibres based on polyester (PET) [19] can be continually improved with regard to light-fastness and colour-fastness. Spun-dyed fibres, especially, have advantages over yarn-dyed or piece-dyed fibres. The extraordinarily high light- and weather-fastness (in particular UV-fastness) of polyacrylonitrile (PAN) is utilised for convertible soft tops. Airbags are still made of polyamide (PA), because polyamide yarns have advantages over polyester yarns in terms of their low initial modulus. Attempts are being made to replace the 'weak point seam' by alternative designs in weaving. For composites consisting of a singular type, spun-dyed polypropylene (PP) is used [20], which is mixed in composites or carpets as filling material.

For renewable materials, attempts are being made to increase market shares by creating more homogeneous fibre qualities in terms of equalising seasonal oscillations and by adjusting the fibre fineness through the retting process. For hemp, new disintegration methods, e.g. the 'impact method' [20], or fermentative methods [21] provide a higher fibre quality.

New applications for using carbon fibres for seat heating are opening up. Their advantages over common copper strands are their flexibility, corrosion resistance and the punching quality of the warp knitting. The yarn count ranges from 67tex (1000 filaments) up to 800tex (12 000 filaments) [22]. In particular, staple fibre yarns, flat yarns as well as elastic yarns (air-bulked, knit-de-knit and false twist) [23] are in use.

Apart from woven and knitted fabrics with a Jacquard effect that are used for their attractive designs, it is mainly non-wovens that are increasingly being used. Great efforts are being made to replace polyurethane foams as upholstery backing and solutions using bonded fibres [24] and needle-punched structures [25] have been found.

In summary, it is likely that new raw materials will be used in automotive textiles. These new fibres and filaments will have higher strength against abrasion, more elongation for easier fabric moulding (like PBT), less flammability (like CS or FR), more antistatic properties and more bacterial resistance. The drive towards lightweight/fuel-efficient vehicles could also mean more use of textiles in the engine compartment [26], and increased use of raw materials such as Nomex.

It is likely that there will also be an increase in the use of knitted fabrics in automotive textiles subject to new fabric developments for seating like the Raschel knitted spacer fabrics.

Self-lightening textiles, which are in the development stage in different labs, will have a great future. There will be additional opportunities for the use of textiles in combination with electronics, the so-called smart textiles, integrating sensors or actuators in textile constructions.

3.8.2 Finite element computations of textile products

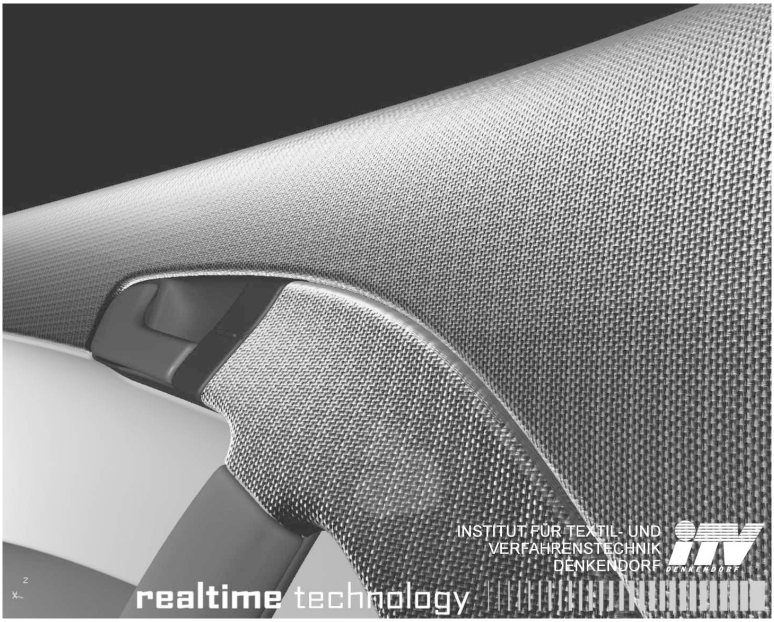
Numerical simulation using the finite element method (FEM) is widely used in the automotive industry to compute car deformation, energy absorption, safety belts, inflating of airbags and their interaction with people. Because of the complex mechanical behaviour of textiles, FEM will gain more and more importance. Intensive research work, increased computational power, new modelling techniques and costly material models will enable us to compute deformations, draping, drawing, stabbing, ballistic impacts and saws.

The aim of computing is to find the optimal product properties with reference to the application. This is a quite complex and time-consuming task because of the large number of yarn types and textile constructions. Beside the mechanical behaviour of textiles (stiffness, stress-strain behaviour, bending rigidity, stabbing, tear resistance, drapability), many other properties such as thermal behaviour or visual appearance play an important role too.

Therefore a great deal of knowledge is required, not only of material behaviour, physics and testing methods but also of textile producing techniques and finishing treatments.

Numerical simulation using the finite element method (FEM) can be a very helpful tool. ITV uses a new micro-modelling technique which is unlike other modelling techniques using membrane elements, as in the simulation of airbag inflation. Here all threads, and to a certain degree even filaments, are included in the fabric model [27, 28]. All threads/filaments can move in the simulation under friction conditions and are checked for collision during the complete simulation. The single-thread modelling technique has made it possible to simulate monofilament behaviour in woven fabric with reference to bending, strain and breaking properties. This has been shown by simulating the penetrating resistance of wire fabric of fencing masks. Further developments have also led to yarn models which can represent multifilament yarn behaviour in textile fabrics, which now opens up a wide range of possibilities for using FEM in textile applications including brand new FE simulations of the textile manufacturing process itself. Examples are the process of weaving a fabric of aramid multifilament yarns, braiding cords and knitting loops.

Micro-models of fabrics including yarns and filaments have another huge advantage over other common fabric models, which is that they look very



3.3 Real-time rendering of a woven fabric on a car door based on a computed micro-model of textile fabric showing realistic reflections and shadows.

realistic. The visual appearance of textile fabrics is a result of yarn and binding structure, density, yarn/filament colour, reflection and shadows. As ITV's new micro-models consider all these important features, turning the 3D-fabric model under any desired light conditions shows the reflections, shadows and colours as they would look in reality. In addition, these complex fabric models can also be loaded with tensile, draping or shear stresses, so simulations can show how the fabrics would look when draped on arbitrary complex formed parts, as shown in Fig. 3.3. This enables the designer to evaluate any change in textile appearance and leads to a new kind of virtual prototyping facility for textile products. In the near future this will play an important role in textile design, especially in the automotive industry (e.g., car interior parts like seats, side panels, etc.).

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4
Nonwovens used in automobiles

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Abstract: Nonwoven fabrics are essential components in modern vehicles with over forty areas of application depending on the vehicle type and technical design specifications. An overview of the main uses and functions of nonwoven fabrics in vehicle interiors, filtration and acoustic insulation is provided with reference to polymer composition and fabric construction. Current and future requirements for nonwoven automotive fabrics are summarised including the need for recyclability at the end of life.

Key words: filtration, headliners, acoustic insulation, bonnet liners, parcel shelf, seat, carpet.

4.1 Introduction

This chapter considers the utilisation of nonwoven fabrics in OEM (Original Equipment Manufacturer) automotive interiors and in automotive filtration. The importance of nonwovens in the automotive industry continues to be fuelled by the ability of such fabrics to be customised and engineered to meet the requirements of modern vehicle assembly operations and technical performance in use. Nonwovens are particularly attractive in the automotive industry because of their ability to:

- be integrated into multi-layer, modular components with other materials including foam
- be incorporated into lightweight and low-density modules
- meet stringent cost-performance targets in what is a highly price-sensitive industry
- be deep-draw moulded into complex shapes at relatively low temperature
- contain recycled raw materials and still meet performance requirements
- be compatible with emerging recycling processes.

The global market for automotive interiors was approximately US$165 billion in 2005 and is expected to grow to an estimated US$210 billion up to 2017 (1). The total weight of textile components including nonwovens as a proportion of the total vehicle weight has gradually increased. Looking to the future, in a medium-sized vehicle (segment D), the weight of textile materials is expected to rise from a current average of about 21 kg to 35 kg by 2020 (1). Of the current 21 kg, about 8 kg is interior textiles, 4.5 kg of which is floorcovering and the remaining 3.5 kg is the headliner and upholstery (1).

Some of the existing automotive applications for nonwoven fabrics are summarised in Table 4.1 (2) and Fig. 4.1. In vehicle interiors, nonwoven facings contribute to the overall aesthetics of the interior while fabrics that are hidden in the construction of automotive parts perform reinforcing, filtration, barrier, sealing or acoustic insulation functions. The growing importance of nonwoven fabric reinforcement in composites and in foam replacement is a further major area of development that is considered elsewhere in this book. The interior use of textile and nonwoven fabrics according to vehicle segment is summarised in Table 4.2 (1). Woven fabrics still predominate in automotive interiors irrespective of vehicle segment. With the exception of Alcantara® or Ultrasuede® as it is known in the USA, utilisation of nonwovens is confined mainly to the lower cost vehicle segments A, B, C, vans, SUVs and MPVs with limited utilisation in the D, E and F vehicle segments. The fibre composition and selection of fabric types also varies amongst vehicle manufacturers in the different global regions. The type and cost of the vehicle influences the choice of fabric; for example, in Europe, group C vehicles and above traditionally have a tufted rather than a needlepunched floorcovering.

In Japan and Europe nonwoven fabrics are more extensively utilised throughout the vehicle than in the NAFTA (North American Free Trade Agreement) countries of the USA, Canada and Mexico. While standard specifications and test methods relating to nonwoven materials used in vehicles have been introduced by organisations such as the VDA (German Association of the Automotive Industry), the SAE, the ASTM, DIN and the AATCC, each vehicle manufacturer operates its own bespoke test specifications relating

Table 4.1 Automotive applications for nonwoven fabrics

Facing fabrics	Backings and fillings	Filter media	Miscellaneous components
Headliner	Headliner	Cabin air	Electrical insulation
Main floorcovering and boot liner	Main floorcovering and boot liner	Engine air	Composite (panel) reinforcement and veils
Seating and rear seat backs	Seating	Transmission	Tyre reinforcement
Bonnet liner	Door and dashboard panels	Oil	Gaskets and seals
Parcel shelf	Acoustic insulation	Brake hose	Catalytic converter
Door panel and trim	Thermal insulation		Battery separator
A, B, C pillar coverings	Adhesive layers		Side impact airbag sleeves
	Fire barriers		

1 Covering material for sun-visors
2 Padding for sun-visors
3 A, B, C, column padding
4 Door trim pads
5 Fuel filters
6 Oil filters
7 Battery separators
8 Cabin air filters
9 Loudspeaker cover
10 Covering for moulded seats
11 Transmission tunnel
12 Carpet & carpet reinforcement
13 Car mats
14 Vinyl backing for seat covers
15 Backing for tufted carpeting
16 Covering for seat belt anchorage
17 Covering for seat belt
18 Decorative fabric
19 Polyurethane coated backing
20 Seat slip agents
21 Boot (trunk) liners
22 Moulded fuel tanks
23 Bodywork parts
24 Window frames
25 Headliner facings
26 Upholstery backing
27 Loudspeaker housing
28 Sunroof
29 Saloon roof

Acoustic absorber applications

30 Doors
31 Headliner
32 Inner & outer dashboard insulation
33 Under engine shield
34 Moulded bonnet liner
35 Rear wheel arch liner
36 Cowl
37 Pillar trim panels
38 Parcel shelf
39 Trunk trims
40 Rear seat strainer
41 Air extractor
42 Wheel arch liners

4.1 Nonwovens in automotive applications (courtesy of EDANA).

Table 4.2 Interior automotive fabrics by type of fabric construction (%)

Vehicle segment	Woven	Circular knitted	Raschel	Tricot	Leather	Nonwoven		
						Alcantara	Needlepunched	Other Nonwoven
A	45.9	24.1	4.9	0	11.3	0	2.2	11.5
B	48	23.1	2.2	10.2	4.7	1.1	3	7.9
C	49.2	23.9	0.5	14.8	7.7	0	1.6	2
D	49.4	14.6	0.4	12.4	19.4	3.3	0.5	0
E	57.5	7.9	0	7.1	27.5	0	0.2	0
F	55.8	0	0	9.9	33.4	0.9	0	0
G	20.9	2.9	0	3.9	61	9.2	1	0
H	56.7	23.4	9	0	0	0	0	11
Vans	43.3	13.4	2	19.6	10.2	4.6	1.5	5.3
MPVs	56.6	26.3	1.3	6.1	2.4	0	1.7	5
SUVs	31.4	0	0	5.7	58.2	2.5	0	2.2

Where the segments indicate the following vehicle types:
A Segment = Micro-size
B Segment = Mini-size
C Segment = Compact size
D Segment = Medium size
E Segment = Large size
F Segment = Luxury
G Segment = 2-seater sports
H Segment = Box vehicles
Vans = includes compact vans
Note: the data includes parcel shelf, headrests, headliners, bolsters and seat covers but excludes boot linings and interior carpets.

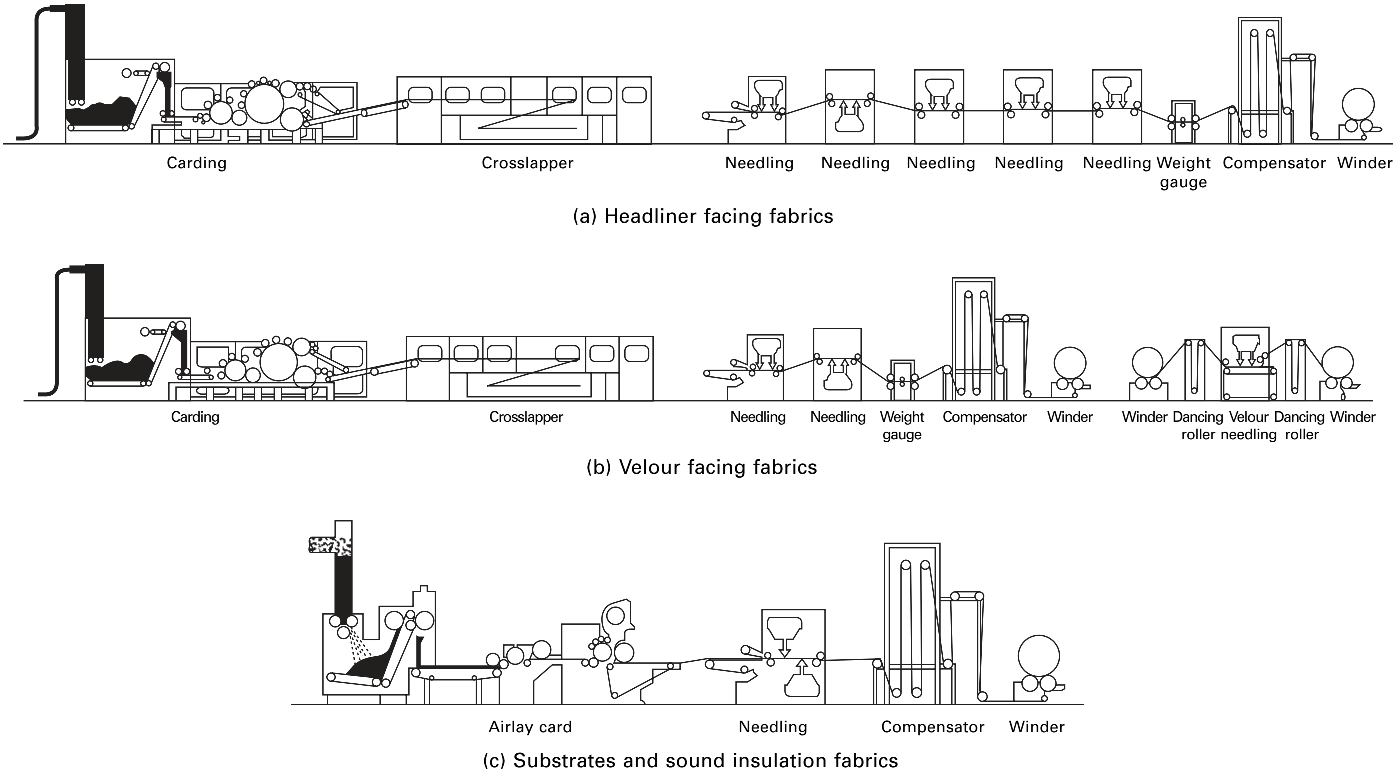
to various aspects of fabric performance. Some of the important technical performance parameters in automotive nonwoven fabrics include: colour uniformity and light fastness (effects of temperature and UV degradation), fogging (e.g. with latex backing), flame resistance, soiling and cleaning, sound absorption, static electrification, mouldability, abrasion resistance and durability.

4.2 Headliners

Headliners are modular parts fitted tightly into the interior roof of a vehicle to provide aesthetics, sound absorption, thermal insulation and cushioning in a light-weight construction. They are semi-rigid modules consisting of at least three layers laminated together: an aesthetic facing fabric, a foam backing and the substrate, which is also referred to as the core. Nonwoven fabrics in headliners take the form of facings, backings or substrates depending on the engineering design of the particular module.

In Europe, warp knitted tricot fabrics account for 50.7% of facing fabric production, while needlepunched and stitchbonded fabrics represent 24.6% and 15.6% respectively (1). Circular knitted fabrics make up the remainder. In the USA, OEMs traditionally produce headliner and pillar trim facing fabrics from tricot warp knitted polyamide fabrics. The choice of facing fabric in headliners is influenced by the prevailing automotive specifications in different countries, which are not uniform. Particularly in Japan and Europe, headliners faced with dope-dyed 100% PET needlepunched fabrics have to a large extent replaced conventional warp knitted fabrics partly because they are readily assembled and fitted into the roof of the vehicle. Fabrics produced from 100% PP are also available. Traditionally, the higher durability standards for vehicle interiors in the USA have meant that knitted and woven facing fabrics have been selected in preference to needlepunched fabrics since to meet these specifications nonwoven fabrics of relatively high fabric weights are required, reducing their cost competitiveness. In low–medium segment vehicles, needlepunched headliner fabrics are common in Japan and Europe; the fabrics have acceptable abrasion resistance and particularly good thermal moulding characteristics, which aids the vehicle assembly process.

Nonwoven facings are made of needlepunched, stitch-bonded or to a more limited extent, hydroentangled fabrics produced from dry-laid (usually carded and crosslapped) spun-dyed PET fibres with a linear density of ≤3.3 dtex and a mean fibre length of 50–60 mm, which compete with traditional warp knitted tricots. Flat or random velour needlepunched facings are selected depending on application. Because of the large uninterrupted visible area provided by the headliner in the vehicle, colour consistency and freedom from faults such as fused fibres or contamination in the fabric is particularly important. An example of a process line arrangement for producing flat



4.2 Production of needlepunched fabrics for automotive products (courtesy of Oerlikon Neumag, Austria).

needlepunched headliner fabric is given in Fig. 4.2(a). Multiple needle looms are arranged in sequence to achieve a high needling density and a dense, flat fabric surface that is uniform in appearance. To increase competitiveness, lighter-weight needlepunched fabrics are produced by decreasing the fibre linear density in the fabric to compensate for the reduction in weight, which has the added benefit of improving softness. There is also an increasing requirement to make headliner facings soil resistant. In addition to needlepunched nonwovens, hydroentangled fabrics that are durable and soft have attracted attention. Evolon® fabrics produced from spunlaid and hydroentangled splittable PA/PET bicomponent fibres have excellent strength and softness and may be printed to give a tailored appearance (3). Other hydroentangled fabrics launched for headliners, visors and trim components include Miratec® fabrics, which can be made with a variety of highly complex three-dimensional structures and are jet-dyeable (4).

The incorporation of semi-rigid polyurethane foam in laminated headliners provides a means of controlling the stiffness of the headliner when the foam is cured, increases sound absorption and provides impact cushioning for the vehicle occupants. However, lamination of foam directly to the facing fabric can negatively affect the mouldability of the laminate, particularly where highly contoured and deeply recessed shapes are required. Recycling the fabric component at the end of life is also complicated in modules containing foam. An alternative approach is to eliminate foam altogether and to bond the facing directly to a high-loft nonwoven fabric that functions as a sound absorber and provides impact cushioning; these components may also be bonded directly to the substrate (core). An advantage to this approach is the possibility of making the entire construction from a homogeneous polymer such as polyester or polypropylene, thereby simplifying the end of life recycling. In Europe, needlepunched PET facing fabrics, with a PET substrate have been developed to promote recycling of the module at the end of life in line with the European End of Life Vehicle (ELV) Directive. Reclaimed fibrous materials may also be used as foam replacement; refiberised mixed garment waste is dry-laid and combined with thermo-curable phenolic resins to form a thermoformable nonwoven layer providing mouldability, dimensional stability and sound insulation properties. In headliners containing foam, polyester spunbonds are utilised for lamination and chemically bonded glass fibre nonwoven fabrics provide reinforcement and stiffness. The glass component of the headliner in a foam laminate may be introduced in various ways including (5):

- Deposition of chopped glass fibres on to a scrim coated in adhesive followed by the application of adhesive to the glass fibre surface to improve adhesion and permit the attachment of a foam board layer. This arrangement of layers may be built up sequentially to produce a thicker structure and is pressure-laminated in an oven.

- Formation of a glass mat (instead of providing loose fibres) which is adhered to a spunbond fabric and another glass mat to produce a tri-layer, chopped glass/spunbond adhesive/chopped glass structure. The construct is pressure-laminated in an oven.

Alternatively, the individual layers of the headliner may be laminated inside the mould itself and simultaneously moulded in a one-step process (6). Glass fibre fabrics are particularly useful in noise reduction but have the disadvantage of a relatively high density compared to polymers, which increases the weight of the module, and there are perceived health and safety concerns in handling during vehicle manufacture. Partly for this reason and the desire to improve environmental sustainability, high modulus natural fibre reinforcements have been evaluated including flax, hemp, sisal and jute as well as blends with recycled fibres. In addition to headliners, this is of course particularly relevant to door panel trims, boot liners and parcel shelf construction. Research by Yan *et al.* (7) revealed that acrylic-copolymer bonded composites exhibited good mechanical properties but there was no significant difference in thermal conductivity compared to polyvinyl-alcohol bonded composites. To replace glass reinforced PU foam headliner cores and increase opportunities for end of life recycling, polyolefin foams have been introduced as well as 100% PET headliner modules. Additionally, the development of nonwoven fibre cores in place of foam provides opportunity to reduce the weight of the module (8).

Requirements in passenger comfort and safety are also influencing headliner design. Developments include the incorporation of side impact airbags (such as the inflatable tubular system) within the headliner unit that deploy downwards when triggered (9, 10), internal storage rails with mounts in the headliner (11) and additional small storage areas fitted within or on to the headliner module. Additionally, there has been a migration of electronic switches and controls to overhead positions mounted in the headliner including one for an internal fire suppressing system (12) as well as audio and telecommunication controls. The integration of LEDs in to the headliner to control ambient lighting has been developed (13) and optical fibres for lighting as well as electrically conductive filaments within fabrics offer potential for the development of an improved vehicle cabin environment.

4.3 Bonnet liners

The bonnet or hood liner and associated fabric linings in the engine compartment have both thermal and sound insulation functions. The bonnet liner provides a protective layer between the top of the engine and the underside of the bonnet, which may be constructed from metal or a fibre reinforced plastic composite depending on the vehicle manufacturer. Bonnet liner modules are composed of a stiffening component such as a glass fabric, foam or a resin-bonded nonwoven fabric composed of reclaimed fibres covered in a nonwoven facing such as a PET spunbond. Bonnet liner fabric construction depends on the vehicle manufacturer. Spunbond, dry-laid chemically bonded and dry-laid needlepunched fabrics are all utilised. A traditional construction is a nonwoven fabric composed of glass fibre combined with a film layer but these have evolved into more sophisticated nonwoven fabrics composed in part of microfibre nonwovens. Nonwovens containing high temperature resistant fibres, for example oxidised PAN, are also available. Modern bonnet liners enable active rather than passive noise reduction limiting the vibration reaching the cabin. Since road noise generated by tyre contact with the surface is a major source of noise entering the cabin, the selection of linings for the wheel wells is also of major importance and can contribute to noise reduction through appropriate tuning. Mouldable and recyclable nonwoven fabrics composed of PP and PET have been developed that are needled to a facing fabric producing a fully integrated acoustic component.

4.4 Boot (trunk) liners

In the boot and luggage compartments, specific applications of nonwoven fabrics include the boot-liner facing fabric, including reinforcements for coated liners, the liner found under the parcel shelf immediately above the boot, the rear-panel inside the boot enclosure and on the back of the fold-down seats. Irrespective of geographical region, nonwovens are predominant in boot liners and luggage compartments. In Europe about 85% of boot liner fabrics are nonwoven, with 10% tufted and 5% being composed of other materials (1). In European vehicle segments A–D flat needled fabrics are important of *ca.* 180–350 gm^{-2} or needled velour fabrics with an average weight of 400 gm^{-2}. A large proportion of boot liners in the USA are also produced from needlepunched fabrics. Facings are commonly staple fibre PET or PP needlepunched fabrics in either flat or velour construction. Cost is one driver for the selection of PP together with the increased opportunities for recycling the trim waste. To improve sound insulation, these are frequently backed with either fabrics produced from waste fibres reclaimed from pulled clothing waste or low-grade bast fibres, e.g. jute, depending on region. Needlepunched underlay fabrics for boot linings are produced from batts composed of recycled fibres obtained from pulled clothing waste. The fabrics are produced by chemical bonding or by thermal bonding when the waste fibres are blended with PP fibre. The PP is either virgin or reclaimed waste fibre. These substrates are faced with either needlepunched PP or PET fabrics that match the rest of the vehicle interior or with durable and impervious polymeric coatings.

4.5 Door and parcel shelf

In the door, the panel trim including the inserts or bolster, underlying reinforcement fabrics and lower facing fabrics may be composed of nonwovens. The facings are composed of flat or random velour needlepunched materials but there is also potential for use of hydroentangled fabrics. Nonwoven interior fabrics are subject to high levels of UV light exposure and this is particularly true in the parcel shelf. For this reason, spun-dyed fibres are preferred. This is true throughout the automotive interior. In the USA, needled fabrics are traditionally produced from PP fibre of 15–18 denier whereas in Europe and Japan finer spun-dyed PET fibre is preferred of 6 denier, or below. This partly reflects the lower abrasion resistance specifications that exist outside the USA (14). Commercially, white hydroentangled fabrics are designed to be joined with facing fabrics or foamed polyurethane to protect from glue or latex penetration in pillar trims, door panels and injection moulded dashboards. Such fabrics are composed of 100% PET, 75% PET/25% viscose or 50% PET/50% PP and are in the range of 0.5–2 mm thick and 50–200 gm^{-2} (15). The reinforcements are normally based on spunbond fabrics. Environmentally sustainable natural fibres are also found in door panel applications. Short-cut bast fibres, such as flax and ramie have been used to reinforce thermoplastic composite structures for some years. More recent developments have included the use of needlepunched hemp (*Cannabis sativa*)/flax fabrics (50/50) to reinforce thermoset compression moulded composite products. Epoxy resin is used as the impregnation medium in the BMW 5 series.

4.6 Seat

Nonwovens are extensively used as backings, bolster fabrics, reinforcements (particularly coating substrates) including needlepunched, hydroentangled and spunbond fabrics. Durability, soil resistance, UV resistance and appearance retention, are obvious requirements in facings for automotive seats, which traditionally has limited the penetration of nonwoven fabrics. Flat woven fabrics are particularly important in European vehicles with woven velours being more popular in Japan and NAFTA countries. Other facings are constructed from leather, double needle bar Raschel, circular knits, tricot and warp knits.

Nonwoven fabrics in seat facings are limited to durable, synthetic suede, microfibre nonwovens, which may be impregnated with polyurethane resin to simulate natural leather. Traditionally, the fabrics are produced from islands in the sea bicomponent fibres that are separated by dissolution of the matrix after needlepunching. Such fabrics represent only a small proportion of the total seating market (*ca*. 2%). One of the best known synthetic suede fabrics used in automotive interiors is Alcantara® (16). The fabrics are used by many of the main vehicle manufacturers, usually but not exclusively for sports and medium to high-end models. The fabrics were originally produced by the Italian ENI Group based on Toray technology patented in the early 1970s. Such fabrics are incorporated not only in seat facings and trimmings but also in door trims, dashboard trims and headliner facing fabrics. Other high quality synthetic leather fabrics, which may or may not be coated with polyurethane include Evolon® and Amaretta®. The recent development of nonwoven roll goods produced from 75–80% reclaimed leather fibres has the potential to find applications in automotive seating applications. The process involves hydroentangling a web of reclaimed natural leather fibres blended with synthetic fibres. The synthetic thermoplastic bicomponent fibres are heated prior to hydroentanglement to fuse and form a supporting network for the leather fibres (17).

In addition to facings, nonwoven substrates coated with pigmented PVC or polyurethane resin (PUR) are used as side or rear panels for leather seats. In backings, considerable research has been conducted on foam-replacement materials composed of PET and other polymeric fibres produced from perpendicular-laid nonwovens, based principally on the STRUTO process. Carded webs containing bicomponent or low-melt fibres are continuously corrugated (the corrugations aligned in the CD) and then through-air bonded to stabilise the structure. In addition to 100% PET constructions, fabrics are produced from reclaimed waste fibres intimately blended with thermoplastics to meet particular price-points. The vertical orientation of fibres relative to the fabric plane increases the lateral compression-resistance and recovery of the fabrics as compared to a carded and cross-lapped fabric and can be engineered by the introduction of a scrim or by adjusting the corrugation amplitude and frequency, the percentage bicomponent fibre content, the fibre type and fibre diameter. Rear seat-back facings include those produced from latex-backed flat and velour needlepunched fabrics composed of spun-dyed PET or PP staple fibres.

4.7 Floorcovering

Automotive facings in floorcoverings are either tufted or needlepunched fabrics produced from spun-dyed PA (mostly tufted), PET or PP fibres (needlepunched) depending on the durability, cost and required specifications, which vary globally between vehicle manufacturers. In respect of tufted fabrics, cut pile is more extensively selected than loop pile. A high proportion of facing fabrics in North American vehicles is tufted, whereas in Japan and Europe a larger proportion is needlepunched, particularly in vehicle segments A to C. Of the interior carpet about 55% is composed of nonwoven fabrics with tufted accounting for 45% (1). In Europe, needled velour fabrics are found in vehicle classes A to C, where cost is paramount, but there is also some penetration in more expensive vehicles (segments D and F) where tufted fabrics have hitherto dominated the main floor areas. The gradual shift towards needlepunched fabric is being driven principally by a desire to reduce cost but also reflects technical progress in achieving improved aesthetic appearance, abrasion resistance, pile stability and cleanability of needled fabrics, which historically have been inferior to tufted fabrics.

Needlepunched facings are made in flat or structured (random velour and rhombic) constructions by carding, crosslapping and needlepunching spun-dyed, crimped PET staple fibres of *ca*. 6.7–17 dtex in Europe with PP staple fibre finding applications in the USA. Abrasion resistance increases with fibre linear density, and in PET velour constructions, different fibre linear densities may be blended together to balance pile stability and aesthetic requirements. To produce velours, the batt is pre-needled and then structured on a second loom to form a surface pile. In the case of rhombic patterns, the velour fabric is needled again on a velour machine. Fig. 4.2(b) is an example of a needled velour fabric production line. Random velours are produced using crown (three barbs, one on each apex) or fine fork needles rather than conventional barbed needles found in flat needlepunching, and the conventional perforated bed-plate is replaced with a brush conveyor to support the pre-needled fabric. As the needles penetrate, a pile surface is formed on the side of the fabric in contact with the brush conveyor. To compete with tufted carpets, the durability of needled fabrics has been progressively improved by increasing the pile stability. A major contribution has been the introduction of double velour needlepunching, where two fabrics are needled together in a second random velour machine to produce a high density velour surface. Increasing the density and mechanical durability of needled velours facilitates a potential reduction in the fabric weight. In vehicle segments A and B there is a trend toward low-weight flat needlepunched fabrics of <350 gm^{-2} in the mainfloor areas with even lighter-weight fabrics of *ca*. 180 gm^{-2} in the boot. Needlepunched velour fabrics range from *ca*. 350 gm^{-2} in the mainfloor of vehicle segments A and B to *ca*. 500–750 gm^{-2} in vehicle segments C and D.

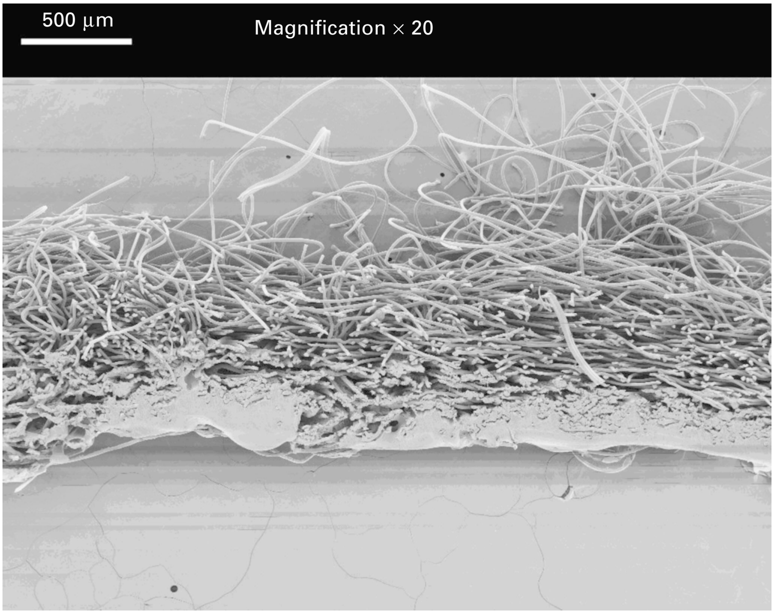
In addition to increasing the fabric density, the introduction of two differently coloured fabrics during double velour needlepunching provides the opportunity to introduce complex design effects in the facing. One example of a needlepunching system capable of producing patterned rib and velour structured fabrics is the Orelikon Neumag Carpet Star; the system also enables a surround and borders on all sides of the fabric. A rapid advance system transports the fabric during the intervals between needle penetrations to produce patterns in the main carpet and in the borders. While structuring looms provide the possibility of producing highly patterned constructions, unpatterned, single colour fabrics (usually black or grey) still predominate.

The type of backcoating on the floorcovering depends on the particular vehicle segment and includes latex backing, thermoplastic PP backing and thermoplastic PE powder backing. When heated, a thermoplastic backcoating on the fabric aids fitting of the floorcovering to the complex three-dimensional shape of the vehicle floor compartment. Conventionally, both flat and velour needlepunched fabrics are latex-backed with, for example, SBR. Figure 4.3 highlights the differences in transverse structure between flat and velour needlepunched fabrics. Compared to tufted fabrics, needlepunched fabrics have a shorter pile and a different surface structure, which affects the appearance and wear resistance of the floorcovering, particularly in relation to pile crushing/ recovery and soiling. Recent developments include the introduction of durable, latex-free needlepunched facings produced using binder fibres to facilitate reduced levels of fogging in the cabin, simplify module assembly and recycling at the end of life.

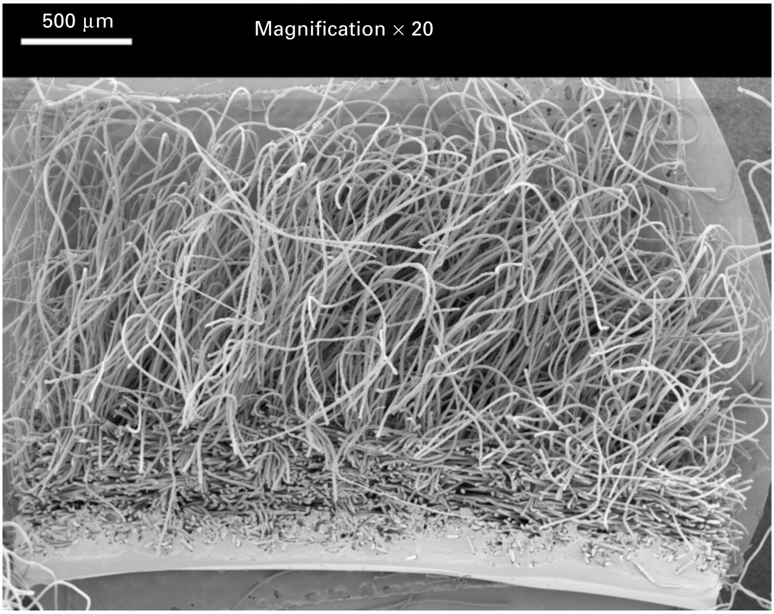
In tufted fabrics, spunbond primary backings are required to secure the tufted yarns in place (Fig. 4.4). During tufting, filament yarns are pushed through the nonwoven backing by the needles to form the tufted pile. The backing facilitates deep moulding of the tufted fabric during formation of the floorcovering module and contributes to tuft-holding and dimensional stability during and after the moulding process. The inherent mouldability of isotropic nonwoven primary backings in tufted carpets is particularly advantageous (Fig. 4.5). Automotive floorcoverings are produced as deep moulded modules and are pre-assembled with the underlying sound insulation ready for integration into the vehicle. Nonwoven backings are *ca.* 100 gm^{-2} thermally bonded spunbond fabrics composed of either PET (e.g., Lutradur®) or thermally bonded sheath-core bicomponent filaments consisting of a PA6 sheath and a PET core (e.g., Colback®).

4.8 Acoustic insulation

The reduction of noise in the cabin is a key objective in vehicle design in both small and large vehicles. A passive or active approach to noise reduction may be adopted or a combination of both. Nonwoven fabrics are extensively utilised in passive noise reduction where the sound absorption coefficient is particularly important at the material and component levels. There are three basic acoustic effects that can be influenced by the choice of nonwoven fabric: sound reflection, sound transmission and sound absorption. Sound transmission and sound absorption are the main factors affecting sound isolation in vehicles and depend on the interaction of the sound wave with the fibres in the nonwoven fabric. While nonwoven fabrics are good sound absorbers, particularly at high frequency, they make less effective sound barriers partly because of their low density. In sound barriers, the transmission loss is particularly important, which is the ratio of the sound energy incident on a

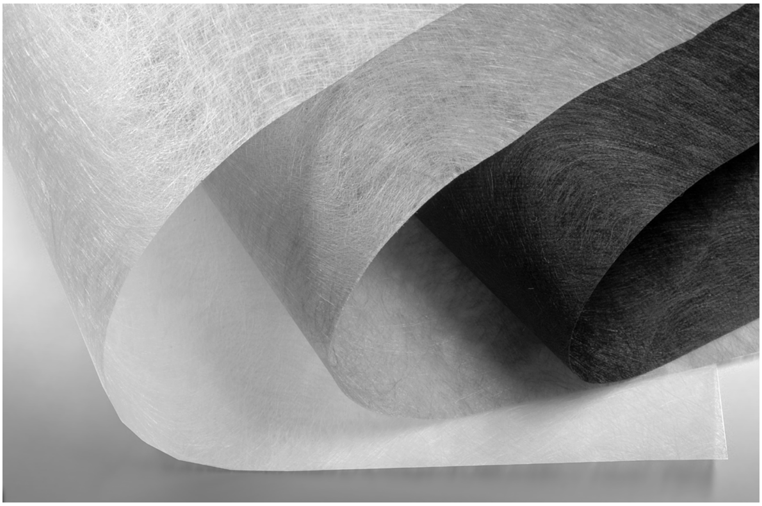


(a) Flat needlepunched

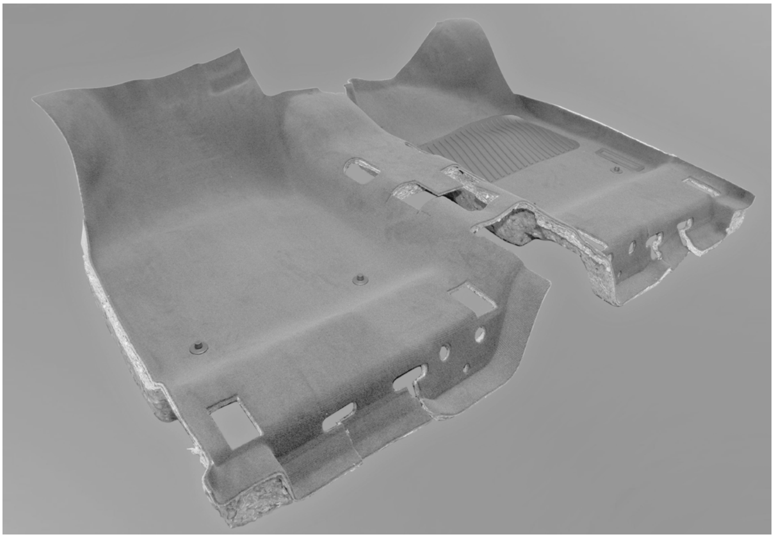


(b) Needlepunched random velour

4.3 Structure of latex-backed PET needlepunched automotive floorcovering facing fabrics.



4.4 Colback® mouldable primary backing fabrics (courtesy of Colbond bv, The Netherlands).



4.5 Moulded main floor module (courtesy of Ideal Automotive).

material to the transmitted sound energy (dB). In practice, the transmission loss in the bulkhead between the engine compartment and the cabin is important in controlling cabin noise and in other areas of the vehicle interior, sound absorption is of major importance. The sound absorption coefficient α is the ratio of sound energy absorbed by a surface to the sound energy incident upon it. The value depends on the angle of incidence of the sound wave, and since in a typical vehicle cabin, there are many different angles of incidence and different surface materials these have to be averaged. In a vehicle cabin that contains various surface materials and angles of incidence, the average absorption coefficient α may be determined for different, n surface materials as follows (18):

$$\alpha = \frac{\sum_{i=1}^{n} S_i \alpha_i}{\sum_{i=1}^{n} S_i}$$

where S = surface area.

The precise sound field inside a vehicle cabin cannot be easily determined because of the complexity of the interior shapes that are contained within it. The reduction of noise is a particularly important requirement even in low-cost vehicles and many nonwoven vehicle components contribute to its suppression including the bonnet liner, under dashboard insulators, wheel arch covers, boot liners, body-shell linings, floorcoverings, floor mats, headliner, parcel shelf, A/B/C pillars (where A = windscreen support pillars, B = vertical pillars at the side of the vehicle and C = rear window pillars), door trims and seals. In addition to reducing noise in the vehicle cabin, the incorporation of nonwoven fabrics in place of higher density materials has enabled substantial reductions in weight.

Needlepunched fabrics composed of either PET or reclaimed textile fibres, spunbond and meltblown microfibre fabrics are all used in acoustic insulation. Low density nonwoven insulation fabrics laminated to thin scrims are also important. Normally, to produce a highly efficient acoustic barrier a high density material is needed, which does not favour nonwovens. Porous nonwoven fabrics are particularly well established in sound absorption and, historically, such fabrics have been produced from fibres recycled from mechanically pulled waste clothing known as shoddy. This is still a cost-effective source of raw material for the production of relatively thick, dry-laid acoustic insulation fabrics. Chemically bonded jute nonwoven fabrics and other low grade fibre materials are also encountered depending on the particular vehicle manufacturer. Fig. 4.2c is an example of a production layout for producing nonwoven automotive sound insulation fabrics based on air-laying and needlepunching. Recycled fibres are incorporated into mouldable nonwovens for sound absorption in vehicle body shells (under the floorcovering) and boot liners. A typical moulded nonwoven fabric composed of reclaimed fibres is illustrated in Fig. 4.6. Nonwoven acoustic pads composed of recycled fibres must incorporate thermoplastic fibres to facilitate thermal moulding of the entire laminated component. Sometimes, microporous films are incorporated with the acoustic pad and in so doing

4.6 Airlaid nonwoven insulation fabric composed of recycled fibres for installation in to the inner dashboard (courtesy of Rieter Automotive).

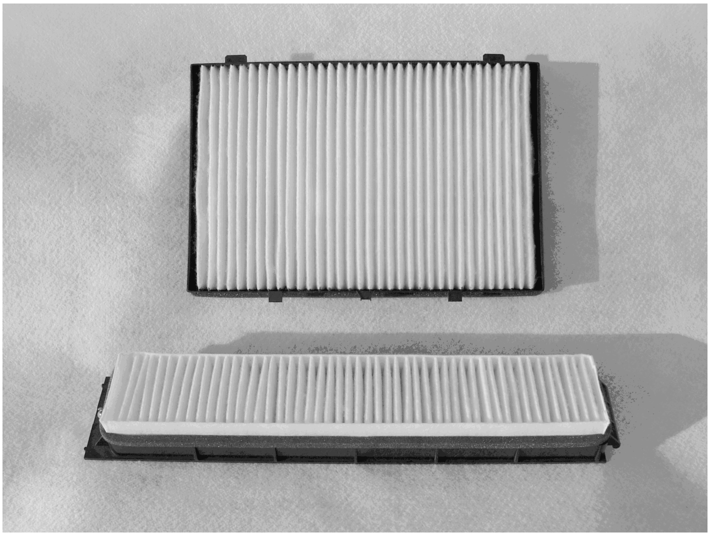
there is potential to reduce the overall weight of the acoustic absorber, which is a major advantage. Unfortunately, in nonwoven acoustic fabrics, the sound absorption is frequency-dependent over the audible range and low frequency sound absorption is usually worse than at high frequency.

To improve the low frequency sound absorption and transmission loss performance, sophisticated multi-layer nonwoven fabrics have been developed containing, for example, high-density fibre materials such as glass in at least part of the construction. Increasingly, interior vehicle modules consist of laminated fabrics consisting of at least two distinct layers. The first layer is normally a nonwoven fabric that provides high sound absorption and is laminated to a high density layer providing high sound reflection. In relation to nonwoven fabric dimensions and structure, sound absorption varies with airflow resistance, which is influenced by fibre diameter, fibre cross-sectional area, fibre alignment relative to the incident sound wave and fabric porosity. The restriction of air movement in porous materials due to air resistance produced by fibre surfaces normally has a beneficial effect on sound absorption. Improved sound absorption at low frequency has been observed in nonwoven fabrics produced by sandwiching a low density layer between two higher-density surface layers (19). Acoustic insulation fabrics containing hydrophobic meltblown microfibres such as Thinsulate™ are intended for incorporation in vehicle door panels, headliners, wheel wells, pillars, and instrument panels. In reverberation room studies, the density of fabrics containing microfibres has been found to have a larger effect on sound absorption than fabric thickness or weight. In one study, the noise reduction coefficient increased to its highest value at a fabric density of about 0.14 g/cm^3 and then decreased (20). Compared to flat fabrics, hydroentangled nonwovens containing longitudinal voids within the cross-section (Hydrospace) are claimed to increase sound absorption providing potential use in, for example, automotive headliners.

In addition to passive sound absorption, work on adaptive technology based on sound cancelling or active noise control has been developing. The automotive cabin is a three-dimensional sound field enclosure. While active noise control in such environments is difficult, progress can be made in reducing the reverberation in such enclosures by the incorporation of active absorbers along the walls, which has been useful in the cancellation of engine noise (21). The incident sound is received by microphones which connect to the loudspeakers whose acoustic input impedance is matched to the sound field. Four-stroke internal combustion engines have an inherent imbalance at twice the rotational speed known as the 'second engine order', which often coincides with the frequency of the fundamental cabin resonance of vehicles, leading to a booming noise (21). Noise synchronisation facilitates active sound cancellation controlled by computer and appropriate software. While this approach can deal quite effectively with engine noise, there are other sources of noise and vibration within and outside the cabin that are difficult to control. Therefore, cabin noise persists, particularly in small vehicles.

4.9 Automotive nonwoven filters

Nonwoven filter media are important in fuel, lubrication oil and air filtration. The latter relates both to cabin air filtration and to vehicle air intakes. Cabin air filters protect vehicle occupants from air-borne pollutants and allergens by removing suspended particles drawn in to the cabin from outside; they play a major role in improving cabin air quality. Cabin filters are produced from either pleated synthetic fibre nonwovens, including laminated, multi-layer fabric constructions or paper fabrics. Efficient removal of small particle contaminants can be accomplished by increasing the fibre specific surface area, usually by decreasing fibre diameter. The microfibre nonwoven fabric layer is sandwiched between a pre-filter fabric and a carrier fabric. An example of a synthetic fibre HVAC cabin air filter is micronAir®. The concentration of gases such as ozone, NO_2, SO_2, benzene and unwanted odours entering the cabin are reduced by the incorporation of an activated carbon layer within or laminated to the nonwoven media. Such media are referred to as combination or combi-filters (22). Electret filter media are capable of high air filtration efficiency with a low pressure drop (Fig. 4.7). Electrostatically charged air filter media include Filtrete™ meltblown PP treated by a corona discharge and dry-laid electrostatically charged media such as Technostat®. The latter is produced by triboelectrical charging of finish-free fibres during



4.7 Filter panels containing pleated Technostat fabric for installation in vehicle passenger cabin ventilation systems (courtesy of Hollingsworth & Vose Filtration).

carding. Two fibre types occupying different positions in the triboelectric series such as polypropylene and modacrylic or acrylic are intimately blended and then carded: this produces multiple separations of the constituent polymers leading to electrostatic charging at the fibre surfaces.

The efficiency and increasing longevity of vehicle engines is partly due to improved air and oil filter media technology. Air intake filters help to protect engine components from wear and their size, porosity and air permeability vary according to the type of vehicle. Traditionally, these have been produced from wet-laid, resin impregnated cellulose papers although synthetic fibre nonwoven fabrics provide an effective alternative to paper in air intakes. In contrast to paper, such nonwovens are more durable and by controlling the fabric thickness, porosity and fibre diameter, either depth filtration or surface filtration conditions can be created. Improved burst strength is also possible by increasing the synthetic fibre content in the fabric. In one example of a tri-laminate filter medium containing synthetic fibres (23), a top layer of trilobal PET spunlaid fabric is bonded to a middle layer of 100% PET homopolymer and co-polymer PET filaments (either 4.5 dpf (diesel particulate filter) trilobal or 2.2 dpf filaments with a circular cross-section) and a bottom layer of bonded high-loft PET crimped fibre fabric with an isotropic fibre arrangement. The middle layer acts as a 100% PET scrim facilitating thermal lamination to the upper and lower surface layers. The tri-laminate fabric is mechanically integrated by needlepunching and also by thermal-bonding. A density gradient through the filter cross-section facilitates depth filtration by selective removal of particles of different size. QualiFlo® is an example of a polyester fibre intake filter that relies on depth filtration to remove dust particles and a fire retardant version has also been introduced. Other advances in air filtration include cellulose fibre fabrics surfaced with nanofibre webs to improve the particle holding capacity and minimise the rate of blinding (24, 25) by facilitating surface rather than depth filtration.

In some high temperature-resistant engine oil filter media, traditional phenol formaldehyde resin-impregnated paper fabrics have been replaced with multi-layer laminated synthetic fibre nonwoven fabrics to increase temperature stability, burst strength and durability (26). High performance engine development is expected to further increase opportunities for nonwoven filter media. Common rail-diesel injection technology subjects the fuel to very high pressure necessitating its thorough filtration prior to entering the engine's injectors. Wet-laid cellulose and meltblown composite media have been developed to address these demands (27). Continuing concern about the environmental impact of automobile emissions has already led to legislation providing a stimulus for development of high efficiency nonwoven filter media. Important regulatory developments include the European Euro V vehicle exhaust emission limits relating to gas (NOX, HC and carbon monoxide) and particulate matter emissions for both petrol and diesel vehicles. Diesel particulate filters (DPF) that are designed to be regenerated have been developed based on ceramic wall-flow filters but low-cost, replaceable filter media based on nonwoven fabrics composed of high temperature resistant fibres could provide an alternative solution (27). Nonwoven oil coalescing filter media are intended to contribute to lower environmental emissions by removing oil droplets from air flows. One example is in crankcase ventilation (CCV) where oil is removed from the mist and coalesced on to the fibre surfaces to prevent its emission to the environment (27). Nonwoven fuel filtration media include those designed for diesel and petrol engines in which there are multiple filter units. Fuel filter media are based on either 100% wet-laid cellulose fibre fabrics, blends of cellulose fibre with polyester or microfibre glass and multi-layer constructions containing cellulose fibre and meltblown glass fabrics (27). Glass paper fabrics for hydraulic and lubrication oil filtration in large vehicles may be stabilised by latex binder impregnation or by lamination to a polyester spunbond fabric, which also facilitates pleating.

4.10 Other components

High performance vehicle engines operate at high temperature, which affects the design and selection of thermally stable materials for incorporation in the engine compartment, the firewall barrier and other areas such as the exhaust system where thermal shielding is required. Temperature-resistant nonwoven materials are also required in electrical wire insulation, hoses and housings to protect sensitive parts of the vehicle from thermal damage. While glass fibre nonwovens are a low-cost solution for thermal shielding, they complicate recycling of the module and potential alternatives include nonwoven fabrics composed of aramid and pre-oxidised fibres. Nonwoven fabric seals fitted between adjacent surfaces, for example within plastic-plastic, plastic-metal and plastic-glass interfaces, provide a simple means of reducing rattling noises, particularly in the cabin.

4.11 Future trends

Growth in Eastern Europe, Russia, China and India is expected to increase nonwoven fabric consumption in the automotive sector (1). The rising cost of raw materials, particularly synthetic polymers and the continuation of OEM price-down agreements with suppliers is fuelling the desire for more cost-effective materials, vehicle components and assembly processes. As a result of the globalisation of automotive manufacturing, geographical differences in the choice of fabrics for vehicle interiors are expected to diminish. Advances in the construction of headliners, floorcoverings (including sound absorption), boot liners and parcel shelves are expected in the areas of fabric composition, construction and three-dimensional module design. There are already developments in the field of non-structural composites reinforced with natural fibres in headliners and floor modules that are likely to increase the importance of nonwoven fabrics in the future. More durable, lighter-weight nonwoven fabrics and laminates that provide potential for further significant weight reductions in the vehicle are important. The integration of electronic components within fabrics prior to module installation, electro-magnetic shielding of the interior (1) and the introduction of functional coatings developed elsewhere in the nonwoven industry to improve aspects of performance such as stain resistance and odour control are progressing.

In the European Community, the ELV Directive is intended to reduce the waste from vehicles when they are scrapped. It tightens the environmental standards for vehicle treatment sites, requires that the last owners have to dispose of their vehicles free of charge from 2007 (and requires producers to pay all or a significant part of the free take-back from this date), sets higher targets for reuse, recycling and recovery and restricts the utilisation of hazardous substances in both new vehicles and replacement vehicle parts (28). Specifically, the 2000/53 EC Directive has required the automotive industry to increase re-use and recovery to 85% with re-use and recycling being increased to a minimum of 80%. By 1 January 2015, the re-use and recovery target increases to 95% with re-use and recycling increasing to a minimum of 85%. The directive expects future vehicles to be designed and manufactured for efficient dismantling, re-use and recycling at the end of life. Also addressed is the requirement for continuous improvement in the handling and recycling of plastic materials. While the directive is improving the environmental impact of the automotive industry, partly as a result of the ELV, there is an increasing amount of short fibre textile waste being recovered from vehicles at the end of life and opportunities for converting this into useful products including nonwovens are being explored. Improving the ease of recyclability at the end of life, which is associated with the ELV encourages the adoption of a homopolymeric construction by eliminating blended fabrics and multi-laminate materials composed of different polymers and adhesives. To promote improved recyclability there is continued interest in polypropylene nonwoven fabrics, particularly in view of developments in elastomeric polyolefin foam technology, which provides scope for moulding modules from a single type of polymer.

4.12 Acknowledgements

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5
Recycling of automotive textiles

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Abstract: Sustainable production is increasingly important in the European automotive sector, including the need to produce components that are 100% recyclable. This chapter discusses the development of nonwoven automotive textiles made from thermoplastics which are both functional and easy to recycle. These new nonwovens can be used in engine air filters and as automotive insulation materials.

Key words: sustainability, automotive nonwovens, thermoplastics.

5.1 Introduction

Nowadays, environmental requirements are increasingly important in all industrial fields and notably in the European automotive sector, owing to the European Directive on end-of-life vehicles. This necessitates working more upstream to develop some new products that are 100% recyclable. At present, automotive products are composed of many raw materials which are difficult to separate and only partially recyclable.

The principal objective of the studies presented in this chapter consisted of developing textile structures (nonwovens) composed of thermoplastic (recycled or not) mono material having the same characteristics (acoustic, comfort, mechanical behaviour, filtration efficiency, dust holding capacity, pressure drop, etc.), or even better than existing products in the automotive market. This new concept will enable the reduction of end-of-life waste production in the automotive sector and also the definition of a new method of valorisation in the production cycle of an automotive product.

The aims of the studies were:

- To replace the classical engine air filter [1], manufactured using several raw materials which are difficult to separate and only partially recyclable, with a filter made from a thermoplastic (recyclable or not) mono material. The recycling of this mono material was studied for automotive applications or for other fields.
- To replace classical acoustic insulation products [2], manufactured using several raw materials which are difficult to separate and only partially recyclable, by textile structures (nonwovens) made from a thermoplastic

(recyclable or not) mono material. The recycling of this mono material was studied for automotive applications or for other fields.

5.2 Legislative considerations with regard to the disposability of used vehicles

A European Directive [3] lays down minimum thresholds for the reuse, recycling and recovery of the component parts and materials of new vehicles with the aim of facilitating the reuse, recycling and recovery of parts in order to fulfil the planned 2015 objectives for recycling and recovering end-of-life vehicles. From 15 December 2008, vehicles which do not comply with the requirements of this Directive may not be granted EC type approval or national type approval. From 15 July 2010, moreover, the marketing of new vehicles which do not comply with the requirements of this Directive will be prohibited.

By the Resolution of 14 November 1996, the European Parliament called on the Commission to legislate on waste streams, in particular end-of-life vehicles, on the basis of product liability. The Commission took the view that a specific directive was necessary, given the importance of this type of waste.

The Directive defines an end-of-life vehicle as any type of vehicle which is waste within the meaning of Directive 75/442/EEC. The scope of the Directive therefore covers:

- any end-of-life vehicle designated as category M1 or N1;
- two- or three-wheel motor vehicles and their components.

The provisions of this new Directive apply to cars, station wagons and people carriers (category M1 vehicles) and to light-duty trucks (category N1 vehicles), new models and models already in production in accordance with a timetable set out in the Directive.

The new Directive does not apply, however, to special-purpose vehicles (armoured vehicles, ambulances, etc.), to multi-stage built light-duty vehicles (provided that the base vehicle complies with this Directive), or to vehicles produced in small series (fewer than 500 vehicles a year in each Member State).

Waste prevention is the priority objective of the Directive. To this end, it stipulates that vehicle manufacturers and material and equipment manufacturers must:

- endeavour to reduce the use of hazardous substances when designing vehicles;
- design and produce vehicles which facilitate the dismantling, reuse, recovery and recycling of end-of-life vehicles;

- increase the use of recycled materials in vehicle manufacture;
- ensure that components of vehicles placed on the market after 1 July 2003 do not contain mercury, hexavalent chromium, cadmium or lead, except in the applications listed in Annex II of the Directive. The Council or the Commission may amend the Annex where scientific and technical progress allow these substances to be avoided.

The Directive also introduces provisions on the collection of all end-of-life vehicles (Article 5). Member States must set up collection systems for end-of-life vehicles and for waste used parts. They must also ensure that all vehicles are transferred to authorised treatment facilities, and must set up a system of deregistration upon presentation of a certificate of destruction. Such certificates are to be issued when the vehicle is transferred, free of charge, to a treatment facility.

The storage and treatment of end-of-life vehicles is also subject to strict control, in accordance with the requirements of this Directive and those of Annex I to the Directive. Establishments or undertakings carrying out treatment operations must strip end-of-life vehicles before treatment and recover all environmentally hazardous components. Priority must be given to the reuse and recycling of vehicle components (batteries, tyres, oil).

At the moment, 75% of end-of-life vehicles are recycled (metal content). The aim of this Directive is to increase the rate of reuse and recovery to 85% by average weight per vehicle and per year by 2006, and to 95% by 2015, and to increase the rate of reuse and recycling over the same period to at least 80% and 85% respectively by average weight per vehicle and year. Less stringent objectives may be set for vehicles produced before 1980.

Member States must ensure that producers use material coding standards, which enable identification of the various materials during dismantling. The Commission must establish European standards on material coding and identification.

Economic operators must provide prospective purchasers of vehicles with information on the recovery and recycling of vehicle components, the treatment of end-of-life vehicles and progress with regard to reuse, recycling and recovery.

5.3 Shortcomings in the textile materials used today

The demand for enhanced comfort and improved safety in the automotive sector will result in a significant increase in the use of textile materials in a typical mid-size car over the next five years – from less than 21 kg in 2005 to 26 kg in 2010. Furthermore, by 2020 textile usage is predicted to reach 35 kg. These are the findings of a study by the Saxony Textile Research Institute in Germany ([4]).

5.3.1 The raw materials used in passenger cars

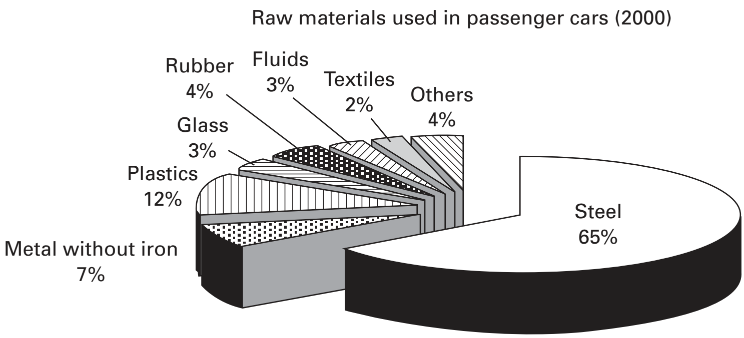
In the manufacturing of passenger cars (Fig. 5.1) in 2000, the most important raw material used was steel (65%); textiles represented only 2% of the raw materials used.

5.3.2 The textiles used in passenger cars

The application of textile materials in motor vehicles is becoming widespread, owing to the fact that in regions like the USA, Japan and Western Europe customers expect more comfort and better safety. There is still high growth potential in the business sector of equipping motor vehicles.

Textiles have long been used in cars. 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 (Table 5.1). It is up to the textile industry to convincingly outline the advantages that textiles offer with regard to manufacturing, raw materials, design, combinability, functionality and recycling.

Table 5.2 gives an overview of the proportions of textiles used in different applications in motor vehicles, adding up to an overall total of about 20 kg.



5.1 Raw materials used in passenger cars.

Table 5.1 Textiles used in passenger cars

Amount in kg in a typical car	Year		
	2000	2010	2020
Total	20	26	35
Product and application like 2000	20	14	10
New products for known applications	–	9	15
New products for new applications	–	3	10

Table 5.2 Automotive textiles according to usage

Application	kg
Carpets, interiors	4.5
Upholstery	3.5
Belts, tubes, tapes	1.6
Tyre cord	1.5
Safety belts	1.3
Airbags	1.2
Composites	4.5
Others, e.g. filters	2.2
Total	20.3

Table 5.3 Worldwide production of automotive textiles: type of textile [5]

	Production in kt				
	1985	1990	1995	2000	2005
Fabrics, knits	953	1125	1170	1221	1214
Nonwovens	95	109	107	111	114
Composites	284	443	521	736	976
Others	76	97	119	152	179

Table 5.4 Worldwide production of automotive textiles: type of fibre [6]

Type of fibre	Years							
	1995		2000		2005		2010	
	kT	%	kT	%	kT	%	kT	%
Natural	139.8	6.6	166.6	6.7	250	8.8	399.8	12.0
Recycled	81.1	3.8	75	3.0	64.8	2.3	71.2	2.1
Synthetic	1354.3	64.0	1553.5	62.7	1722.5	60.9	1941.6	58.2
Inorganic	542.3	25.6	683.8	27.6	790.6	28.0	925.5	27.7
Total	2117.5	100.0	2478.9	100.0	2 828	100.0	3338.2	100.0

From a design-related aspect and looking at quantities, a number of classical knits and wovens rank first. Textile composite materials are expected to have the greatest growth potential as they can be tailored to serve the applications in question (Table 5.3).

5.3.3 The fibres used in passenger cars

More and more natural fibres are being used in passenger cars. The use of recycled fibres has remained at the same level since 1995. The use of other fibres (synthetics and inorganics) has also increased (Table 5.4).

5.3.4 The engine air filters used in passenger cars

In the European market, engine air filters are made using classical cellulosic filters made with wood pulp. These filters are manufactured using the wet-laid nonwoven process. The main manufacturers of these filters are:

- Sogefi/Fram
- Mann & Hummel
- Mécaplast
- Knecht/Mahle
- Tecafiltre

In the international market, engine air filters are made from classical cellulosic alone by manufacturers making synthetic filters for the trademarks Toyota, Suzuki, Hyundai and Mitsubishi. Synthetic filters are manufactured using the dry-laid nonwoven process.

5.3.5 The acoustic insulation structures used in passenger cars

The acoustic insulation structures used in passenger cars are made from foams or nonwovens. Often the foams are manufactured using polyurethane. Nonwovens are manufactured from recycled or virgin fibres. These filters are manufactured using the dry-laid nonwoven process.

5.4 Conception of recyclable engine air filters for the automotive industry

5.4.1 Market analysis

Almost all the filter elements for engine air admission are manufactured from cellulosic media, whether for the original equipment or its replacements.

At the end of 2001, the only engine air filtering elements made from a synthetic medium that were sold for original equipment were manufactured in Japan and the USA by the Japanese equipment supplier Denso, mainly for the Toyota, Suzuki, Hyundai and Mitsubishi ranges. Various designs are on the market which have been analysed and tested, the most advanced being a mono material and thermo-formed filter element with an integrated seal.

In the replacement and spare parts market sectors, filter elements in a synthetic medium have also appeared, whether mono material or not, manufactured mostly by Asian companies. In Europe, manufacturers are taking a close look at these filtering elements owing to their filtration performances, and to their potential for integration into the under-the-bonnet architecture. Many projects, some very advanced, are under development and the first marketing of these by European manufacturers will probably be seen in the near future.

5.4.2 Bibliographical analysis

The various mechanisms for trapping particles in a fibrous network were listed to understand the operation of a filtering medium, and to define the textile structure and fibre composition giving the best filtration results. A comparative analysis using laboratory and airborne dust types was made. Finally, an analysis of the incidence of the ingestion of particles into an internal combustion engine has made it possible to classify them, and treat any risks on a hierarchical basis.

Pollutants

As an example, those particles influencing the wear on an engine have a diameter of between 1 and 40 microns. They are responsible for the wear of the segments, the sleeves and the bearings. Most harmful are those whose size is close to 5 to 10 microns. As well as the size of the particles, their hardness and their type are the other parameters that have a great influence on engine wear. The most harmful particles are dusts of a mineral type, while the carbonaceous types present no danger to the engine.

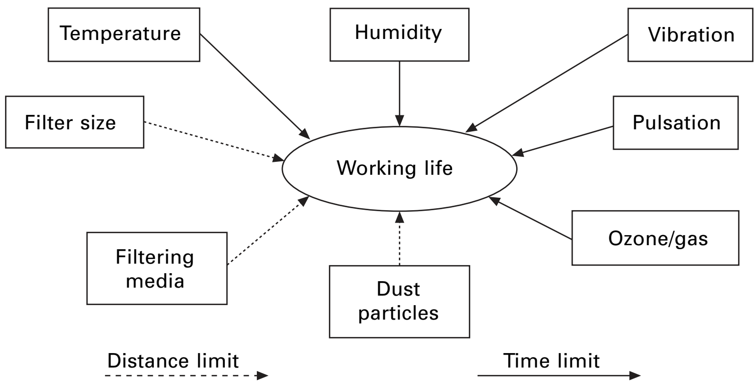
The dust types used in the laboratory and approved by the car manufacturers are the purely mineral dust types (SAE fine and coarse). Their representivity compared to airborne dusts is relatively low, which is confirmed by clogging tests, both in bench and vehicle testing. *Ashrae* dust is additionally interesting as it also contains carbonaceous soot types.

Air in the atmosphere is composed of SO_2, NO_2, NO, O_3, CO; hydrocarbons (benzene, xylene); heavy metals and dust types in suspension. Their proportions and their concentrations differ according to the weather conditions and location. Road dusts sucked in by the engine come primarily from the vehicles themselves (exhaust fumes, brake linings, tyre wear, etc.), or from the roadway. Their concentrations vary from 0.1 mg/m^3 (clean roads) up to 50 mg/m^3 (tracks), and even up to 1000 mg/m^3 in dusty countries.

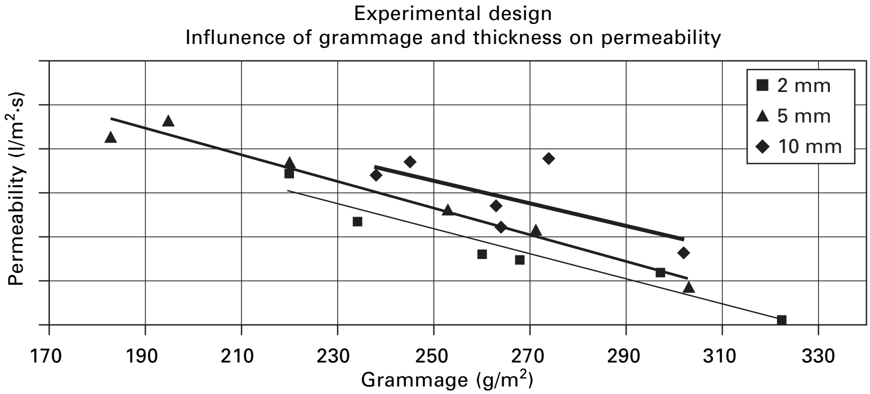
Factors influencing filter working life

The principal requirement of an air filter is to maintain its filtration performance throughout its working life (Fig. 5.2). This can be estimated in the laboratory, or calculated, but with variable precision as it depends enormously on the running conditions encountered.

Patents: a bibliography was created for the patents on the media and on the filter manufacturing processes.



5.2 Factors influencing filter working life.



5.3 Influence of grammage and thickness on permeability.

5.4.3 Design of the filtering medium

An analysis of 204 synthetic medium filter types on the market was carried out, and the most interesting were subject to close analysis. This study also led to research on the choice of multi-layer filtering media, and on the use of fibres of different grades and section types. An experimental design was then made up and samples were tested on a laboratory scale by IFTH-Lyon. These media were tested and ranked in line with their filtration performances, while the parameters influencing these performances could then be targeted, quantified and optimised (Fig. 5.3).

Production of several media on an industrial scale was then carried out by Mécaplast (Fig. 5.4) and using these industrial media, the influences of the parameters affecting the various stages of their manufacturing methods could be refined. Lastly, at each stage in the manufacturing of the media, several

5.4 Mécaplast media manufacturing line.

technologies were tested before adopting the optimal configuration from a technical-economic viewpoint.

5.4.4 Filter manufacturing process

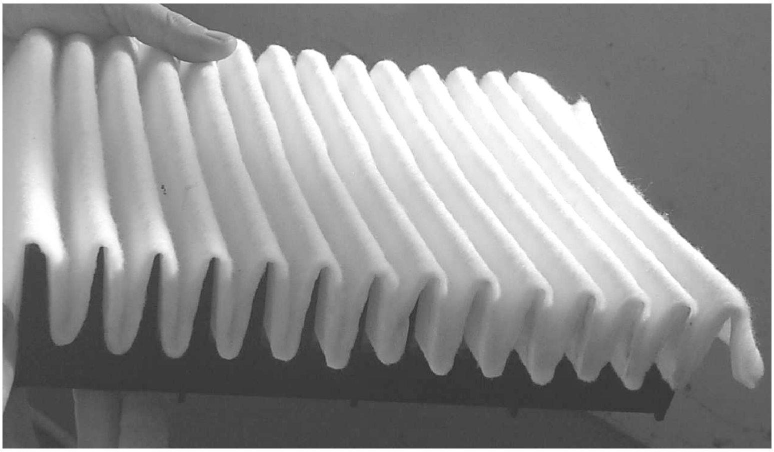
Thirteen major patents were analysed, and in parallel several design concepts were invented and protected, with three of them offering more obvious advantages. Machines and tools were then designed to produce prototypes using the technologies of the three design concepts. The technologies involved are very diverse but they call upon techniques already mastered by Mécaplast, or similar to those already used.

The first stage of the process consists of folding the cellulosic medium to increase the filtering surface, but supplementary modules had to be added to the usual pleating machines used for cellulosic media (Fig. 5.5). The following stage consisted of stabilising the pleating geometrically, while the final stage involved completing the filtering element while ensuring, if this was not already achieved, that the sealing function for the tank and lid of the filter was working.

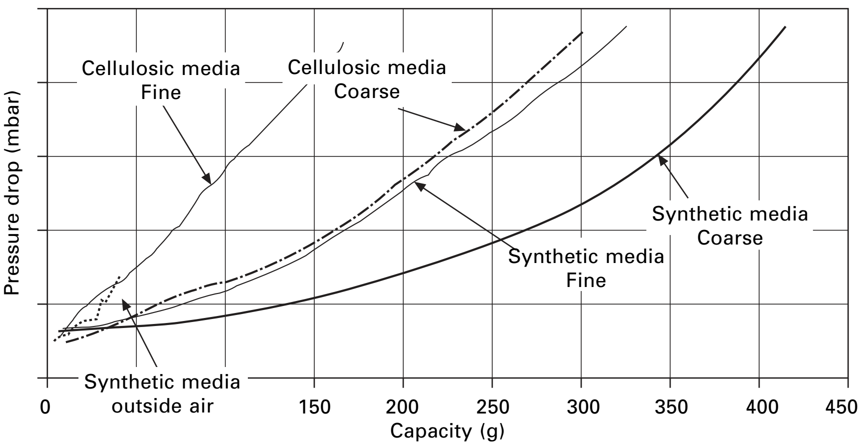
5.4.5 Checking the filters

Blocking with various dust types

The filtration tests quantified the primary function of the filtering element. They were carried out on aeraulic benches with laboratory dust types, on an endurance bench with external air, and on vehicles. The various test conditions selected made it possible to explore the behaviour of this medium type. The development of specific media proved necessary for the different vehicle



5.5 Folding synthetic media filter manufactured by Mécaplast.



5.6 Blocking with various dust types.

applications (room available, environment, etc.) and manufacturers' specifications. A comparison could, in particular, be made between the filtering elements in a cellulosic medium and those made of a synthetic medium. Figure 5.6 illustrates this, showing the curves of clogging achieved with various pollutant types.

Water resistance

On the basis of the car manufacturers' specifications, water ingestion tests were carried out on a specific Mécaplast bench and these demonstrated a high fold stability using the synthetic media, even when impregnated, with regard to depression in the admission line. The risk of seeing chevrons and stripes appear as with cellulosic medium filtering elements, definitively deforming the folds, is nil.

Fire behaviour

At present, a limited number of manufacturers apply a specific self-extinguishing treatment to their cellulosic medium filtering elements. However, following various accidents and catastrophes occurring in Europe which implicated the car, fire safety regulations will be reinforced, both for the inflammability of materials and for their toxicity. Two examples of accidents already observed show the risk of a vehicle catching fire caused by the filtering element: the suck-in of a still-burning cigarette end, and to a lesser extent, a flame light-back in the admission line.

These situations were reproduced on a calorimetric cone and comparative tests of synthetic/cellulosic media were carried out, with the tests showing:

- a fire flare-up much earlier with a paper rather than a synthetic medium;
- a less energetic combustion with a paper medium compared to a synthetic medium;
- smoke emission with the combustion of a paper medium less significant than with a synthetic medium; and
- toxicity from the combustion of a paper medium higher than that from a synthetic medium.

The synthetic fibres involved did not have any specific flame-retardant treatment. However, these treatments do exist, either via a fire-proofing agent (chemical product) fixed on the fibres, or via an *in-situ* treatment of the fibres during their manufacture. In addition to their price, the major disadvantage remains the environmental aspects of such chemical substances. Research programmes by Mécaplast, partnered by chemical manufacturers, aim to optimise these fire treatments from both economic and ecological standpoints.

5.4.6 Environmental aspects

Working life

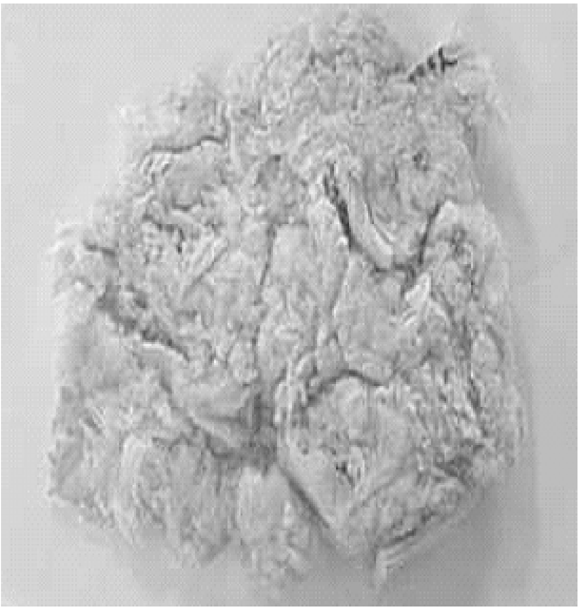
Cycles of cleaning/clogging synthetic medium filters showed interesting performances: a gain in initial efficiency after cleaning, and an increase of 10% to 30% in the dust loading capacity according to the cleaning parameters. The total working life of a filter can thus be prolonged, which corresponds to an appreciable lengthening of replacement intervals (between 30 000 and 80 000 km according to the car manufacturers). Over the life of a vehicle, the number of filters to be recycled can thus be reduced, but the application of this technique on an industrial scale does require some new thinking for the car manufacturers, notably in terms of logistics and organisation.

Recyclability

Shredding tests (Fig. 5.7) and crushing tests (Fig. 5.8) on shear crushers were carried out, and they demonstrated the industrial feasibility of these recycling techniques. The transformation of the residues into thermoplastic pellets by fusion/compounding/extrusion is a proven technique and applied on an industrial scale, in particular, for wall-to-wall carpeting. As for the recovery aspects, techniques have already been patented by certain recyclers who have had several material grades approved for cars. Other grades with lower performance properties are already used in less technical applications such as horticulture, etc.

A profitability study based on simulations of waste volumes has been undertaken, and it demonstrated the viability of such recycling operations provided that a regular minimum volume could be treated.

Lastly, the need to set up a sizable logistics organisation to collect all the waste, and then treat it in the optimal manner, remains a major issue for study by the industrialists concerned.



5.7 Shredding material of blocked filter.

5.8 Crushing material of blocked filter.

5.5 Development of recyclable textile acoustic insulation structures for the automotive market

5.5.1 Market analysis and state of the art

In order to orientate this study, it is necessary to know the existing position of products in the automotive market. Mechanical characterisations (resilience, compression, etc.) and acoustic characterisations (absorption, intrinsic parameters) were carried out on a material set of products, porous and fibrous, present in the automotive market. At the same time, an analysis of the state of the art was carried out.

Some mechanical characterisations (carried out by IFTH) and some acoustic characterisations (carried out by Mécaplast) were carried out on a panel of 12 representative samples of the automotive market. The mechanical characterisations consisted of determining the energies (compression, indentation, resilience, etc.) and the deformation combined with expressing the compression behaviour of damping thick materials. The acoustic performances were obtained by some measurements of absorption coefficients (measured with an impedance pipe) and intrinsic parameters (air passage resistivity, tortuosity, and porosity, thermal and viscous characteristic lengths) which enabled the materials to be assessed and the acoustic behaviour (absorption, impedance, etc.) of fibrous and porous materials to be predicted.

Simulation software provided fast, low-cost results for complexes that matched the car manufacturers' requirements.

The acoustic and mechanical characterisations demonstrated that:

- the more a fibrous material is compacted,
  - the more the driving in, the porosity, characteristic lengths and the absorption performances decrease,
  - the more the resilience, the air passage resistivity and the tortuosity increase;
- the more alveolar material (such as a foam) is dense, the more the driving in decreases and the resilience increases.

The analysis of the state of the art, based on consulting several databases on patents and articles and using specific key words, highlights that:

- The 100% recyclable acoustic textile materials that are used in the automotive industry are mainly polyester, used in headliner applications.
- Generally, textile structures are nonwovens with thermobonding fibres used for conversion of the web in automotive products, their mechanical characteristics and their resilience. There is also interest in double-faced textiles (wovens, knitted fabrics and also nonwovens (3D web linker such as NAPCO technology)) for the products being analysed. Within this framework, several kinds of fibres are used: microfibres for their acoustic properties, fibres with a good reputation for their cost and their mechanical properties, and highly crimped fibres for their resilience.
- Two or more layers of different densities are present in some materials; the more dense for their mechanical characteristics and soundproofing, the less dense for their acoustic absorption properties.
- The parameters having an influence on nonwoven resilience are mainly the grammage, the presence or not of several layers, the orientation of fibres, the fibrous mixing used, the bonding technology (needling and/or thermal bonding and/or chemical bonding), the density of each layer and the fibres' characteristics (length, title, crimp, shape, surface state, spin finish or treatment, etc.).

5.5.2 Determination of virgin fibre complexes by an acoustic study

Following on from the benchmarking and determination of the state of art, a design experiment was carried out, taking into consideration the specifications of car manufacturers (the idea of products taking the environment into account, passenger and pedestrian safety and responding to the specifications for lower price and lighter weight). This experiment's plan allowed for evaluating the fibres' influence, the fibrous mixing and web structures, on acoustic performance and other characteristics (mechanical, climatic ageing, etc.).

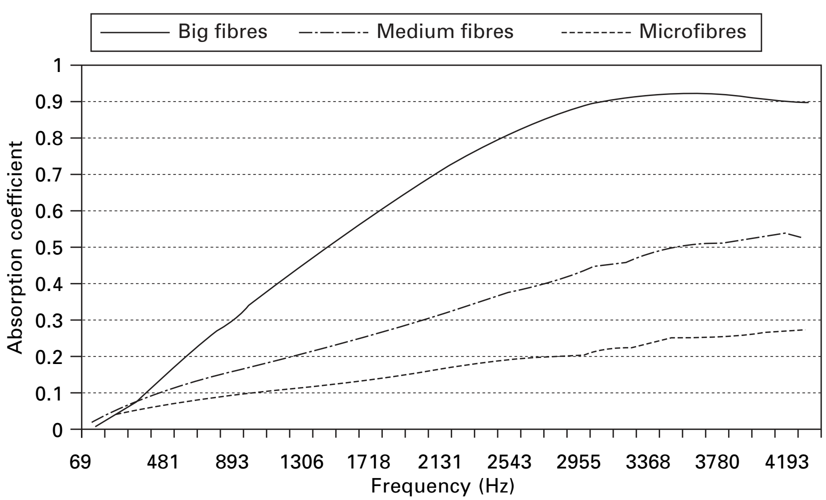
Twenty or so fibrous structures were made. These webs were nonwovens of the same grammage (500 g/m^2) and the same thickness (25 mm), needled or not, bonded in an oven or not. The first parameters studied were the raw fibres' materials (influence of the fineness, the form, and the chemical composition) and the web structures (superposition of webs or intimate mixing).

Several fibres were used; fibres of different densities (0.9 dtex microfibres, 7 dtex medium fibres and 5 dtex large fibres), of different shapes (multilobed, cylindrical and empty fibres) and different raw materials (PP or PES). In the same way, several intimate blends were studied; 100% (to evaluate the real influence of fibres) and 50%/50% (to evaluate the influence of intimate blends). Other blends were studied by adding 20% of thermobonding fibres to the original compositions for the thermal bonding.

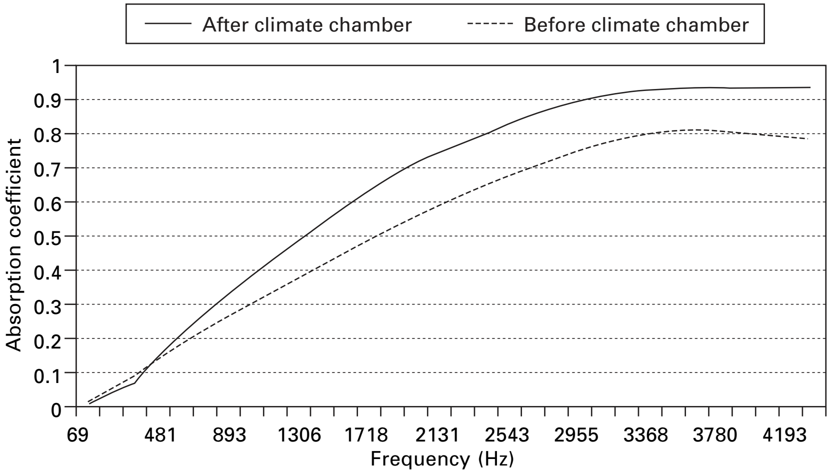
The process used to carry out laying, needling, superposition of webs and needling for the bi-layer nonwovens used an oven passage (climatic chamber) for the products with thermobonding fibres.

Acoustic measurements and prediction calculation

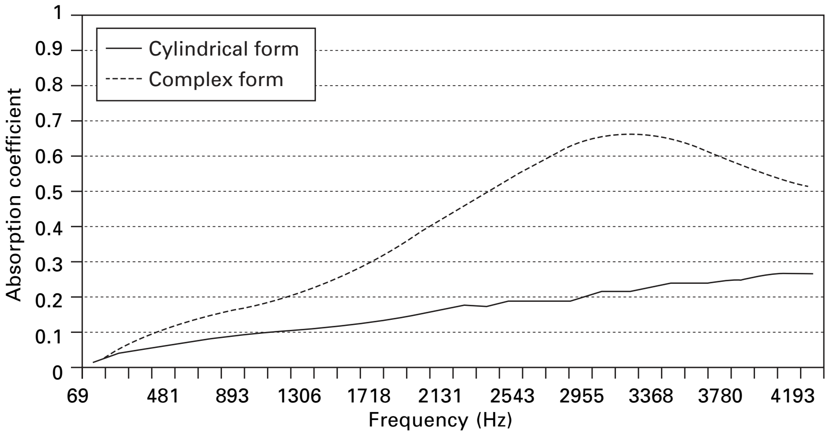
The different absorption measurements carried out by Mécaplast quantified several tendencies, illustrated by the figures below. The presence of microfibres in a fibrous structure significantly improves the acoustic performance (Fig. 5.9). Compared with mechanical bonding, heat bonding improves the acoustic performance (Fig. 5.10). Finally, a structure composed of complex shape



5.9 Fibre fineness.



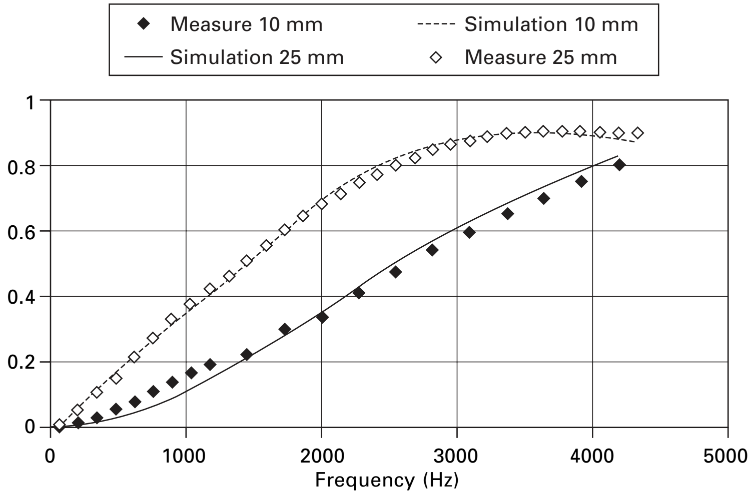
5.10 Mechanical/heat bonding.



5.11 Fibre shape.

fibres absorbs more than a structure composed of cylindrical fibres (Fig. 5.11).

In the same way, measurements of intrinsic parameters and a prediction calculation were made to evaluate the correlation between measurements and calculation (Fig. 5.12). The five intrinsic parameters (air passage resistivity, tortuosity, porosity, thermal and viscous characteristic lengths) were measured on precision equipment. A correlation failure for a measurement of absorption coefficient is necessary to improve parameter values (in particular the thermal characteristic length that is obtained with respect to a multiple of the viscous characteristic length).



5.12 Measurement correlation.

The prediction calculation enables the grammage of a complex bi-layer (web + aspect) for a thickness to be optimised, avoiding the necessity for making prototypes and reducing the development time.

Acoustic measurements

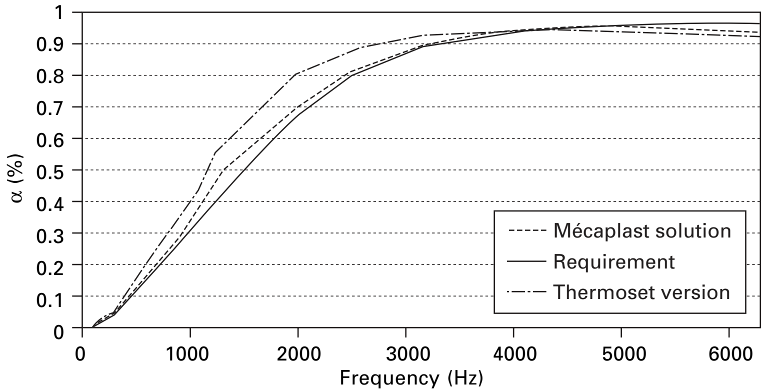
Following this acoustic study, the acoustic absorption measurement was carried out by Mécaplast for the headliner application. A comparison between the complex optimised by this study and the technology usually used, a thermoset felt (cotton waste felt with 30% phenolic resin), is illustrated in Fig. 5.13.

No acoustic degradation is observed for a grammage reduction by 2 (passage of 1450 g/m^2 for the thermoset version at 750 g/m^2 for Mécaplast solution).

Mechanical, thermal and chemical characteristics

Laboratory validations were carried out for the headliner and floor carpet applications according to the car manufacturers' specifications.

Bi-layer and tri-layer complexes were designed for the headliner application. The most important characteristics for this application are engine fluid behaviour (water, antifreeze, diesel fuel, cooling liquid, oil, essence, etc.), the combustibility test and the peeling test of the fibrous structure. The engine fluid behaviour is confirmed by its appearance. This appearance is treated oilphobic and hydrophobic. More polyester fibres, principal components of the fibrous structure, have a reduced absorption. A fireproof product is



Mécaplast solution: nonwoven aspect 60 g/m^2 + fibrous web 600 g/m^2 + nonwoven back 90 g/m^2
Thermoset version: nonwoven aspect 60 g/m^2 + thermoset felt 1300 g/m^2 + nonwoven back 90 g/m^2
Requirement: car manufacturer specifications

5.13 Acoustic comparison between thermoset technology and Mécaplast solution.

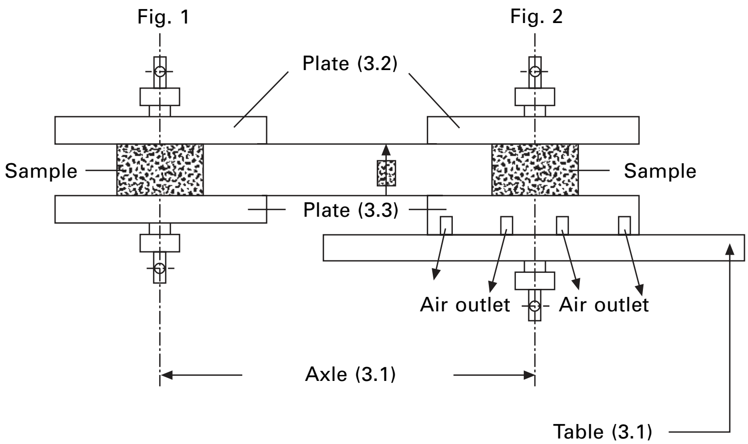
obtained when a fibrous structure composed of polyester fibres contains Panox fibres in its make-up. The heat bonding of the fibrous structure is an important parameter because this bonding enables a good cohesion to be obtained and addresses the requirements of the peeling test.

For the floor carpet application, composed of aspect, septum and spring, a specific study on the spring (injected foam or felt) has been carried out. The spring deformation, when a pressure is applied, is a very important factor. In particular, the floor carpet must not be crushed when passengers get into the vehicle. For that two tests exist: the lift test and the residual compression deformation test.

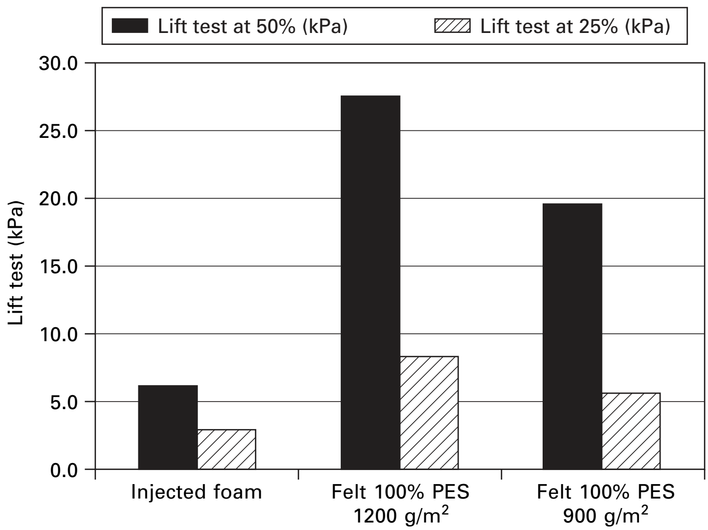
The lift test consists of applying a pressure to the spring to compress it at 25% and 50% compared with the initial thickness. The samples are compressed between two plates (Fig. 5.14) fixed on traction equipment. To avoid crushing of the floor carpet, it is necessary that the value of the lift test increases. The springs that have a high lift test are the fibrous structures developed in this programme. The higher the grammage of the fibrous structure, the better is the lift test (Fig. 5.15).

The residual compression deformation enables the springs to be characterised in static compression. This test consists of placing a weight of 5 kg on the samples for 22 h at 23°C or 70°C (Fig. 5.16). The weight is removed and the residual compression deformation (thickness loss percentage) of samples is measured after 15 min of relaxation and after 7 days of relaxation.

To avoid having crushed floor carpet, the residual compression deformation must be as small as possible. The fibrous structures developed in this programme



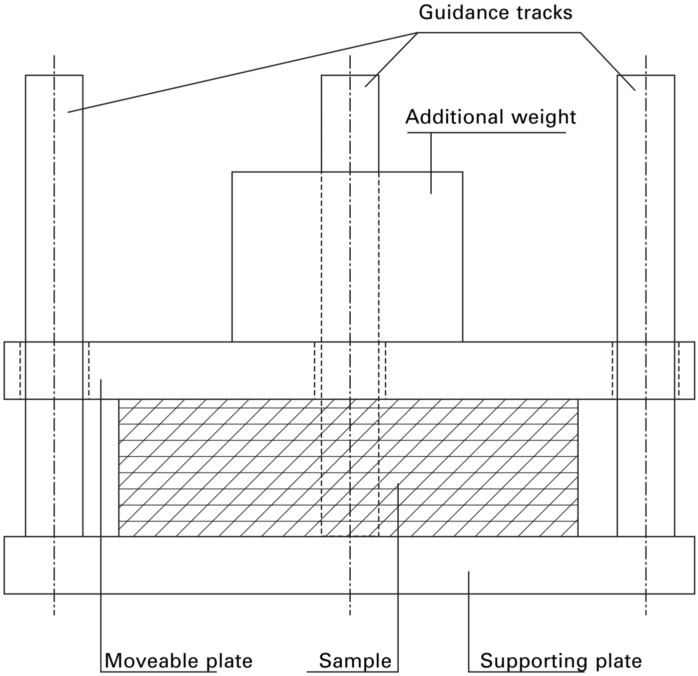
5.14 Measurement method lift test at 25% and 50%.



5.15 Results of lift test at 25% and 50%.

(grammage of 900 at 1200 g/m^2) have a residual compression deformation better than that of injected foam but worse than that of a thermoset felt of grammage 1300 g/m^2 (Fig. 5.17). The higher the fibre fineness the worse the deformation.

Passenger vehicle comfort is very important for the car manufacturers, particularly with regard to odour. Indeed, a norm exists. Samples are put in containers with water, then they are placed in a climatic chamber at 80°C for 2 h. When the containers are opened, the odour emission is classified (numbered



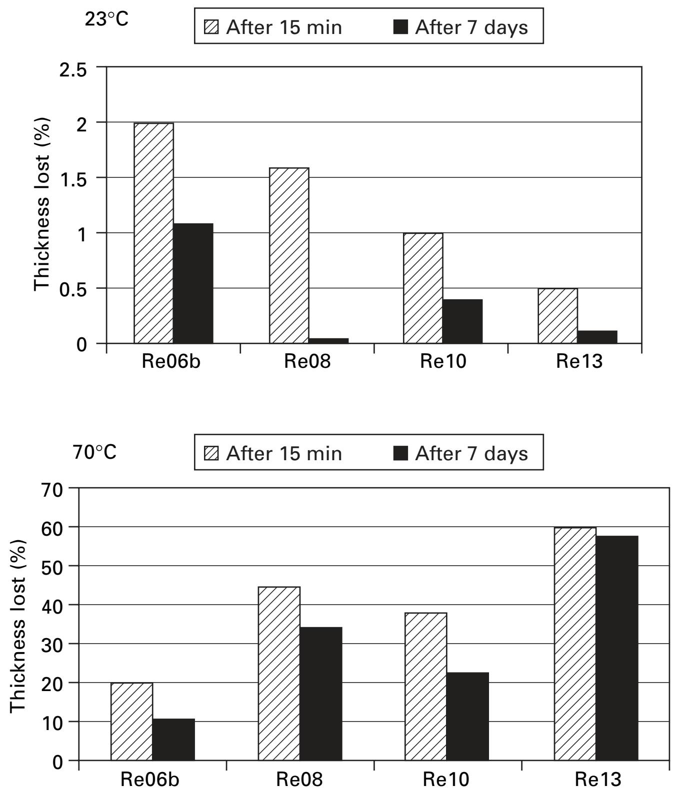
5.16 Measurement method.

from 1 to 7). The higher the number, the more unpleasant or even intolerable the odour emitted (1 for odourless, 7 for untenable).

The technologies in current use for the floor carpet application are injected foam PUR (polyurethane resin) and thermoset felt (cotton waste with a percentage of phenolic resin). The thermoset felt products emit a very disagreeable odour, caused by the presence of phenolic resin. The PUR foam products emit an odour that is strong but bearable. The products developed in this study (felt 100% PES) are almost odourless.

5.5.3 Headliner: recycling and use of recycled and shredded fibres

The acoustic study presented above was carried out solely using virgin polyester fibres. For the headliner application, the use of virgin fibres increases the cost of the part, making our offering uncompetitive. So to reduce costs, a search for suppliers of cheaper fibres was performed. This search allowed us to take delivery of a cheaper fibre set in order to create some prototypes and to test them according to the automotive manufacturers' specifications. The fibres tested were mainly recycled and shredded fibres.



Re06b: thermoset felt 1300 g/m^2
Re08: felt 100% PES 1200 g/m^2
Re10: felt 100% PES 900 g/m^2
Re13: injected foam 50 kg/m^2

5.17 Residual compression deformation at 23°C and 70°C.

Determination of fibre supply sources

A search of polyester fibre suppliers was performed for various fibres:

- Virgin: all densities are available, whatever the quantities. These fibres are mainly used for technical products and for exteriors.
- Recycled: these fibres are created mainly from PET bottles. The density varies between 6.7 dtex and 5 dtex, whatever the quantities. These fibres are mainly used for undercoats.
- Of transition: these fibres are created from coloured transition bales (fibres manufactured between two stages of production of two colours). The density varies between 6.7 dtex and 17 dtex, whatever the quantities. The downside is that sales of these are 'spot' sales, according to the stocks available. These fibres are mainly used for undercoats.
- Substandard: these fibres are fibre blends of different densities and lengths.

The downside is that sales of these are 'spot' sales, according to the stocks available. These fibres are mainly used for undercoats.

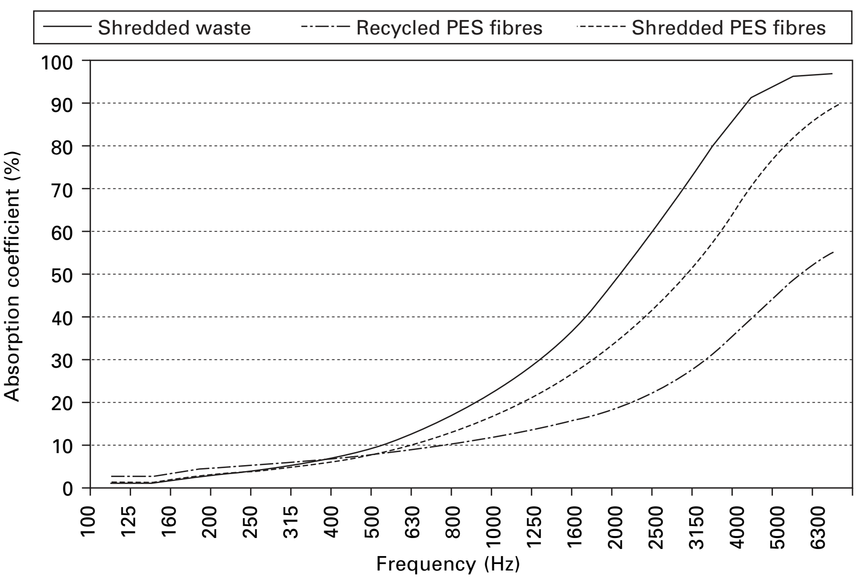
- Shredded: these fibres are created from the shredding of polyester wastes. The density is around 6.7 dtex and the length varies. These fibres are mainly used for undercoats.

Acoustic performance

Some measurements of absorption coefficients have been carried out by Mécaplast (Fig. 5.18). In the majority, the presence of high quantities of shredded fibres in the structure contributes towards an improved acoustic performance of the product.

Recycling of automotive products at the end of vehicle life

Some recycling trials for headliner applications have been carried out in-house on some 100% PES fibrous webs composed of thermobonding fibres and virgin fibres. The treatment envisaged for this complex is divided into four stages: washing (automotive products in the end of vehicle life cleaning, presence of chemical agents in the under-bonnet application, for example), crushing, densification (micronisation, manufacture of compounds, etc.) and drying.



5.18 Acoustic measurements.

To show whether the under-bonnet products developed in this study can be recycled by shredding, some trials have been carried out with different prototype products dirtied with different liquids to discover the behaviour of chemical agents present under the bonnet. Some products have been dirtied so as to be similar to what their state would be at the end of vehicle life. These shredding trials have been conclusive; the odour of engine liquids persists.

The apparatus performing the shredding and cutting of the headliner operates as follows. The raw material is fed in by a conveyor, then pinched at the entry between the feed cylinder rotating at low speed and the static part (metallic static part taking on the exact shape of the feed cylinder) and shredded by an opener cylinder rotating at high speed. On exit from this machine, the raw material enters a cyclone to separate the fibrous material and the heavy pollutants such as wood or metallic materials.

5.6 Future trends

The two studies with Mécaplast were carried out as a result of the European Directive which increased the rate of reuse and recovery to 85% by average weight per vehicle and year by 2006, and to 95% by 2015, and increased the rate of reuse and recycling over the same period to at least 80% and 85% respectively by average weight per vehicle and year. Since the textile materials used in a typical mid-size car represent only 2% of the raw materials used to manufacture the car (from less than 21 kg in 2005), more and more car manufacturers are asking their suppliers, such as Mécaplast, to supply them with easily removable and easily recyclable textile products. They are also asking suppliers to take back their textile products and to recycle them.

Nowadays, automotive textile products are made from several raw materials, making them partially recyclable. The main objective of these studies was to produce some 100% recyclable automotive products having the same characteristics as the existing products currently on the automotive market.

Different methods (measurement, calculation and bibliography) have demonstrated and evaluated the influence of raw material parameters (fineness, shape, rugosity of fibres, etc.) on their acoustic and filtration performances.

For the acoustic structures, the lower the fibre density, and the more the shape and the fibre surface are complex, the better is the acoustic performance. Some headliners based on recycled or shredded fibres have been designed and validated according to the automotive manufacturers' requirements. The presence of a lot of shredded fibres in the structure notably improves the acoustic performance of the product.

The key advantages which manufacturers agree unquestionably that these synthetic media have are their increased capacity and their recyclability. However, they will also be studying the new requirements such as their fire behaviour, resistance to humidity, behaviour with soot types, etc. In these areas the synthetic media offer certain advantages (integration potential into the under-the-bonnet architectural constraints, cost gains in the air filtration function and so on).

As for recycling, which is the major advantage of these synthetic media and acoustic structures, the crushing and shredding tests carried out on industrial units allow us to conclude that they are industrially recyclable with such technologies. The recycling methods for products at the end of their life, and for production waste, are numerous, while the interest of the recycling professionals (recyclers or users of recycled materials) has been demonstrated.

Following the good results of the two studies, Mécaplast must manufacture synthetic engine air filters and recyclable acoustic insulation structures. This society must put forward these recyclable textile products to car manufacturers.

Owing to the European Directive on used vehicles, the results of these studies are duplicated for other products (textiles or not) used to manufacture automotives. This eco-friendly idea is being used more and more in the manufacture of cars.

5.7 References

1. Study with IFTH and Mécaplast financed by ADEME: To replace the classical engine air filter manufactured from several raw materials, which are difficult to separate and partially recyclable, with a filter composed of a thermoplastic (recyclable or not) mono material. The recycling of this mono material was studied for automotive applications or for other fields.
2. Study with IFTH and Mécaplast financed by ADEME: To replace classical acoustic insulation products manufactured from several raw materials, which are difficult to separate and partially recyclable, by textiles structures (nonwovens) composed of a thermoplastic (recyclable or not) mono material. The recycling of this mono material was studied for automotive applications or for other fields.
3. European Parliament Directive 75/442/EEC.
4. Study by the Saxony Textile Research Institute in Germany: ‘Verband der Automobilindustrie (VDA) Jahresbericht 2005’.
5. Market study: ‘Marktstudie Technische Textilien 2003, DRA’.
6. Market study of David Rigby: The technical textiles 2005.