9
Textiles in other forms of transportation

9.1 Introduction

In a similar way to the automotive industry, textiles provide a means of decoration and a warm soft touch to interior surfaces in all road vehicles, trains, aircraft and marine vessels, but are also used extensively in more functional roles. Also in common with the automotive industry, the comfort, safety and weight-saving factors are the driving force behind many developments. Weight saving is of especial importance in the aircraft and freight transport industries where any weight saved means increased payload and hence increased profits. In any situation where the general public is involved, safety is of the highest importance, and reduced flammability of textiles to very high standards are necessary, especially in aircraft. Furthermore public safety standards are usually requirements of government legislation.

The whole area of transportation is growing with increasing trade between the nations of the world which is generating higher volumes of both freight and passenger travel. Tourism is increasing as people have larger disposable incomes, increased leisure and become more interested in foreign cultures. The largest growth is expected in air travel and already intensive competition is bringing airfares down. More pleasing and relaxing travel conditions are necessary to attract fare-paying passengers who now have a wide choice of different travel companies and indeed the travel modes of rail, road and air now compete with each other. Another recurring factor in textiles in transportation applications is ease of cleanability because expensive vehicles such as jumbo jets or high-speed trains must earn their living by being in service and on the move as much as possible. Lengthy periods between journeys or being out of service for overhauls is wasted time and time is money. However, cleaning is important because dirty and untidy interiors would deter passengers.

Weight saving is important in all forms of commercial transport because it can make all the difference between profit and loss and in common with private cars, weight saving now has environmental implications; less weight means less depletion of natural energy resources and less pollution from exhaust fumes. Composites are playing an important role in this area and are certain to make an even larger contribution in the future. The use of composites in Europe is growing at a rate of 10% every year and by 2001 the market value will be almost 50% more than the 1997 level – a significant proportion will be in transportation applications.[1]

It is unfortunate that it has taken headline news disasters such as the Salt Lake City air disaster of 1965 and the Manchester airport fire of 1985 to drive up FR standards in public safety situations. Seating fire barriers, first developed for aircraft, are also becoming increasingly required in trains and road passenger vehicles.

Aesthetics and interior design of aircraft, trains and all other forms of transport are becoming increasingly important with rising living standards and increased expectations from the general public. However decor of trains and aircraft cannot be changed frequently and so pleasing but generally neutral designs are used free from transient fads or fashions.[2]

This chapter is preceded by three introductory sections on three subjects, which characterize transportation textiles, i.e. composites to save weight, increased safety by reduced flammability, and coated fabrics, the basis of much safety and survival apparatus and also the means of protection of both man and materials from the elements. A summary of the properties of the main fibres used in transportation applications appears in Tables 9.1 and 9.2.

9.2 Composite materials

Composites straddle the textile and plastic industries and can be regarded as a macroscopic combination of two or more materials to produce special properties, which are not present in the separate components, (an alloy is a combination on the microscopic scale). How composites work, can be illustrated by the analogy of the use of straw in clay bricks by the ancient Egyptians. It was possible to produce a strong brick because the straw reduced and controlled the occurrence of cracks in the hard but brittle clay. Glass fibres, used very extensively in modern composites, have a very high tensile strength, but are very brittle because of their extreme sensitivity to cracks and surface defects. However when incorporated into a composite, the plastic matrix protects their surface and prevents crack formation. Thus the high tensile properties of the fibre are protected and the two materials between them produce a strong composite. In general terms, the chemical properties are determined by the plastic component, and the physical properties determined by the fibre. Introductory accounts of composites are available in the technical literature,[3–6] including uses in transportation applications.[7–11]

Table 9.1 Properties of fibres used in transportation

	Density (g/cm^3)	Melting point (°C) *	Tenacity (g/den) **	Stiffness (flexural rigidity (g/den)	Limiting oxygen index % Oxygen	Abrasion resistance	Resistance to sunlight
Acrylic	1.12–1.19	150d	2.0–5.0 (HT)	5.0–8.0	18	Moderate	Excellent
Modacrylic	1.37	150d	2.0–3.5	3.8	27	Moderate	Excellent
Nylon 6	1.13	215	4.3–8.8 (HT)	17–48	20	Very good	Poor – good when stabilized
Nylon 66	1.14	260	4.3–8.8 (HT)	5.0–57	20	Very good	Poor – good when stabilized
Polyester	1.40	260	4.2–7.5 (HT)	10–30	21	Very good	Good – excellent when stabilized
Polypropylene	0.90	165	4.0–8.5 (HT)	20–30	18	Good	Poor – good when stabilized
Wool	1.15–1.30	132d	1.0–1.7	4.5	25	Moderate	Moderate
Cotton	1.51	150d	3.2	60–70	18	Moderate	Moderate

Table 9.1 (cont.)

	Density (g/cm^3)	Melting point (°C) *	Tenacity (g/den) **	Stiffness (flexural rigidity (g/den)	Limiting oxygen index % oxygen	Abrasion resistance	Resistance to sunlight
Ultra high modulus polyethylene	0.97	144	30	1400–2000	19		
Aramid	1.38–1.45	427–482d	5.3–22	500–1000	29–33		
Carbon	1.79–1.86	3500d	9.8–19.1+	350–1500	64+		
Glass	2.5–2.7	700	6.3–11.7	310–380	—		
Polybenzimidazole	1.30	450d	—	9–12	41		
Inidex (Acordis)	1.50	—	1.2	—	40		
Panox (LUCF)	1.40	200–900d	—	—	55		
Steel	7.90	1500	2.5–3.2	167–213	—	—	—
Aluminium	2.70	660	—	—	—	—	—

1. * d = does not melt but starts to degrade
2. ** HT = High tenacity
3. Thermoplastics begin to *soften* at temperatures below their melting point and thermoplastic fibres can deform or be damaged by the action of temperature well below their melting point. This is more likely if the heat is combined with pressure as for example in a lamination or a moulding operation.

NB: Data compiled from several sources and intended only as a guide.

Table 9.2 Additional values of limiting oxygen index (% oxygen)

Zirpro Wool	30
Cotton (Pyrovatex finish)	28–30
Cotton (Proban finish)	28–30
Viscose	18
Viscose FR	28
Polyester FR	28–30
Visil (modified viscose)	26–33
Basofil (BASF)	33
Chlorofibre	35–48
PTFE	80–90

The oxygen content of air is 21%, an L0I above this figure is an improvement in FR properties.
NB: Data compiled from several sources and intended only as a guide.

9.2.1 Fibres used in composites

Glass reinforced plastics (GRP) date from the 1920s and combine high strength with light-weight properties. Several different glass compositions and their variants have been formulated to produce specific properties. The original, referred to as A-glass, used in windows is now not used for fibres. E-glass which has special electrical properties necessary for radomes, (radar covers), is now the type produced on the largest scale followed by C-glass which was developed for its chemical resistance and D-glass, which is an improved form of E-glass.

During the 1960s more advanced fibres became available, carbon and aramid fibres and others which are all many times stiffer than glass but, with the exception of aramids, are brittle and must be used in combination with other materials. Each fibre has its own merits and disadvantages and no single fibre can be regarded as overall superior to the others. Carbon fibres were first produced at the Royal Aircraft Research Establishment during 1963 in England. There are a number of different varieties and their properties vary significantly depending on the conditions of manufacture. The stages in the process are spinning, stabilization, carbonization and graphitization. Most carbon fibres nowadays are made from an acrylic fibre precursor.

Aramid fibres date from the early 1960s with the introduction by DuPont of Nomex, aromatic polyamide (hence the name 'aramid').[12] This fibre has very high strength with excellent temperature resistance with 60% strength and modulus retention at 260 °C. It does not melt but chars to a black, crust-like material, which acts as a barrier at about 317 °C without giving off toxic fumes. Kevlar, a variant of Nomex introduced by DuPont about 10 years later, is weight-for-weight five times stronger than steel wire, has a modulus twice that of glass but a density of only 1.45 g/m^3 compared with 2.5 g/m^3 for glass and 7.8 g/m^3 for steel. Aramids are resistant to many solvents, have low water absorbency but they are sensitive to UV light and are not easily dyed. Several different variants of Kevlar have been introduced over the years, each for a particular specialized application.

In addition to the main three fibres, more specialist types have been produced including, ceramic, boron, metallic, quartz (pure silica), silicon carbide and the ultra high modulus polyethylene fibre which is finding many applications in transportation applications. In recent years the benefits and opportunities offered by natural fibres as composite reinforcement have been recognized and they have the advantage of being a replaceable resource.

9.2.2 Properties of composites

There are very many potential combinations of fibre and plastics, but in actual fact most composites are based on just three fibres: glass, carbon and aramid, or a combination of them, in a polyester, epoxy or phenolic resin. The density of these three resins, which are all thermosetting at about 1.2 g/m^3, is considerably less than even aluminium. Chemical properties are determined mainly by the fibre component, the chemical and thermal properties mainly by the polymer. Phenolic resins have the best heat resistance and fire-retardant properties of the three main resins. The fibre can be in the form of chopped lengths, short, long or continuous filament or in any fabric construction, woven, knitted or non-woven. The fibre length and orientation influence properties: the longer the fibre length the stronger the composite, with the strongest being obtained from composites made from actual fabrics or continuous filaments.

Carbon fibre composites, in general provide the highest stiffness and strength but they can be brittle and have low energy-absorbing properties. Aramid composites have lower strengths but can absorb energy without fracture. Glass-fibre composites fit in roughly somewhere below aramid fibres in terms of strength but they have some energy-absorbing properties and have the advantage of being less expensive.

9.2.3 Advantages of composites

At the present time the most significant advantage of composites is in the replacement of heavier metal with lighter components, which results in fuel savings throughout the life of the vehicle. Actual material cost of composites exceeds that of metal but there are several other significant benefits from their use. These include less bulk, and therefore more useful space, anti-corrosion, dent resistance, and high rigidity and strength. All of these properties make composites well suited to transportation applications. Composites also allow more design freedom, which means that complex shapes not easily produced in metal, can be more easily achieved. This is especially important in transportation applications where an aerodynamic shape is important. The various fibres, resins, additives and processing conditions available, enable properties to be tailored to suit the intended application. Integration of components is also more easily achieved when a single composite can replace several individual parts in metal which all have to be joined together. A good example is the 'stealth bus' prototype in California, in which 250 parts in a conventional bus, have been replaced by just three structural composites.[13] This bus, nicknamed after the stealth bomber, has an expected life of 25 years compared with 8–12 years for an ordinary bus and, being over 4000 kg lighter will save very large amounts of fuel during its lifetime.

With such significant fuel savings possible, some analysts believe it is only a matter of time before we see carbon fibres in large volume production cars but there are many technical and commercial problems to overcome first. Carbon fibres are not as easily processed as polyester or the more common fibres. For low volume production, such as specialist sports cars, goods vehicles, trains and aircraft, composites are feasible, but when large-scale mass production is considered, there are at present, prohibitive cost and technical difficulties. The production of carbon fibres is expected to grow by about 10% annually at least until the year 2001, although not all of it will be in transportation.[14] More advanced fabric structures and indeed more advanced fibres are being developed which are extending the scope of composites all the time.[15–17]

The absence of metal makes composites useful in items such as radomes. Composites may be more expensive than metal to initially produce but if a life-cycle analysis is carried out, the savings in fuel over the time in use far outweigh the extra costs of production. Composites are well suited to transportation applications in allowing savings both in weight and space. Disadvantages of composites include, susceptibility to impact damage, limited temperature and moisture resistance in some cases and at present limitations on repairability and joining techniques.

Composites are enabling 'breakthroughs' in technology not thought possible several decades ago. The first man-powered aircraft, the Gossamer Albatros on 12th June 1979 flew across the English Channel in 2 h 49 min. The flight was sponsored by DuPont and would have been impossible without Kevlar as structural reinforcement. More recently the round-the-world hot air balloons all make use of Kevlar. Composite technology is still in its infancy, compared to metals and other materials, which have many decades and even centuries of accumulated knowledge. More significant advances can be expected in the future, with increased use of composites in all forms of transport.

Weight saving is especially important in aircraft because it significantly influences their commercial viability, and composites are playing a vital role in this area. The Airbus A-300 in 1980 was the first commercial aircraft to use significant amounts of composite material – about 6% of its body weight. This does not sound much, but on take-off the total weight of a plane, very roughly, comprises 50% aircraft structure, 25% fuel and 25% payload. Decreasing the body weight by 6% increases the payload's possible proportion to 28% of the whole plane weight. This increases the actual payload, i.e. the part that earns the money, by a very worthwhile 12%, which could make all the difference between profit or loss. These same considerations of course also apply to all other forms of freight commercial vehicles.

9.2.4 Fabrication of composites

Large components such as the hulls of yachts and small boats, are still frequently made by hand laying of non-woven glass fibre into a mould and applying polyester resin with a brush, building up layers as necessary and manually rolling to compact it into shape. Non-woven polyester fabrics are used as processing aids in this and other moulding operations to line the mould. They must be conformable to the shape and designed to equalize pressure in the mould and to allow the escape of gases and vapours during the curing process, an example is the Lantor Breatherfelt material. In specialist moulding operations, non-wovens can improve the surface appearance of components.

A layer of a novel non-woven honeycomb-structured polyester material, Firet Coremat developed by Lantor can be incorporated into the inner parts of the resin structure to produce significant weight savings. The non-woven fabric also contains microcapsules, which expand on the action of heat during the curing process and further contribute to the weight saving. This material also reduces vibrations, which is especially beneficial in transportation applications.

Most items relevant to passenger cars are produced by various moulding techniques. Moulding is a faster means of production than hand fabrication, but the cost of moulds and tools can be very expensive and in time, need replacing or renovation. Low production volumes may not recoup the cost. Short-length fibres, resin, catalyst, pigments (if necessary) and other additives are blended together and injected into the mould where heat is applied to cross-link the resin. Small external body parts and headlamp housings are made in this way. For larger components longer continuous filaments can be laid in to increase the strength in a linear direction. However, the manufacturing techniques required to produce large components in high volumes for regular production cars are not yet available for composite material and much research is working towards this end. The American 'big three', General Motors, Ford and Chrysler, together with the US government have pooled their resources in finding a solution to these problems.[18] Many other researchers around the world are also studying the problem but so far with only limited success.[10,11] However, the use of composites and plastics for small items in passenger cars continues to grow steadily. Large component composites are at present restricted to relatively small volume production such as in heavy goods vehicles, speciality cars, trains and aircraft.

Some composites are produced from fabrics pre-impregnated with resins, a 'pre-preg', which can be cross-linked in a later process. Layers of pre-pregs can be laminated and cross-linked together to form very strong materials. Continuous profile composite structures can be produced by a process termed pultrusion, which is low cost and involves drawing pre-treated fibres through a heated die. Circular or hollow structures can be produced by winding a continuous fibre filament on to a former. The filaments are immersed beforehand in a cross-linkable resin. When the required shape and thickness have been achieved, heat is applied and the filament layers are cross-linked together.

9.3 Flame retardancy

9.3.1 Basic mechanisms

Reduced flammability is a general safety requirement of virtually all textiles in the passenger transportation area. This section attempts to explain the main principles governing flammability and its control. Many articles have been published on these aspects and also the relevant test methods.[19–25] Burning depends on three factors, a source of ignition to provide the initial heat energy, fuel or materials capable of burning and a supply of air which contains oxygen (or an oxidizing agent), the gas on which combustion depends. Anything, which reduces these factors reduces combustion, which is essentially a chemical oxidation process. Heat energy first causes molecules of the fuel to break down into smaller parts called 'free radicals' which are unstable and therefore highly reactive. Burning proceeds by the formation of these free radicals and their subsequent reaction with oxygen. Certain flame retardancy (FR) agents under the action of heat, break down producing their own free radicals. The fuel free radicals then react preferentially with the flame-retardant free radicals instead of with oxygen, thus inhibiting combustion. An uncontrolled fire with a supply of fuel is self propagating in that heat from the burning material heats up the surrounding air and the material not yet burning.

9.3.2 Mechanisms of flame retardant chemicals

Hydrated chemicals contain significant amounts of water and when heated, this water is released, cools the flame and the water vapour formed dilutes the oxygen in the air. An example is aluminium trihydrate, which contains 35% of its weight of water. Chemicals such as aluminium hydrates and some boron compounds take in energy (endothermic) on decomposition, and the flame is cooled by this process. Materials, which decompose to release non-flammable gases such as carbonates, have some flame-retarding properties. Some chemicals will function by more than one mechanism.

The most effective mechanisms however are by inhibition of the free radicals and by reducing the availability of fuel by formation of a barrier of protective char. Chlorine and bromine (halogen) compounds have been found to have good FR properties especially in combination with antimony trioxide and the 'antimony/halogen synergy' is the basis of many FR formulations; antimony trioxide alone has no FR properties. The halogen compound releases free radicals, which react in the gaseous phase with the free radicals produced by the burning polymer. Thus reaction with oxygen is inhibited and burning retarded. This method is very effective and is widely used in plastics but it has the disadvantage of producing potentially toxic fumes.

Some chemicals or combination of chemicals prevent afterglow and re-ignition, others on combustion, form a char or barrier which effectively reduces air reaching the burning material. An example is zinc borate, which forms a glass-like coating and is claimed to significantly suppress smoke. Chemists have developed this concept and produced 'intumescent' coatings which form at relatively low temperatures, i.e. at an early stage of combustion, to produce a voluminous insulating char. This barrier inhibits flame spread by restraining the escape of gas formed by burning and also the access of oxygen to the flame. Intumescent coatings can be effective at low concentrations – intumescent paints are available – and continue to be developed. They contain a source of carbon, a 'blowing agent' to increase the volume, and fillers and other chemicals. Ceepree, invented in the laboratories of ICI is an FR system which works on the barrier principle.

Phosphorus FR chemicals work by encouraging the formation of char and are reported to suppress glowing which produces carbon monoxide and carbon dioxide and also carries the risk of re-ignition. Phosphorus FR agents in combination with certain nitrogen compounds produce an FR synergy for cellulosic materials. Certain polymers such as PVC and especially PVDC (polyvinylidene chloride) already contain high levels of FR chemical species such as chlorine and have inherent FR properties. These polymers have been used as FR compounds themselves, for example, the use of PVDC in styrene butadiene rubber to back coat automotive carpets.

9.3.3 Disadvantage of FR chemicals and recent developments

The main disadvantages of FR compounds are cost, problems associated with compounding, toxicity of fumes from burning and more recently environmental considerations. The most efficient FR chemical synergy for plastics, antimony trioxide and organic bromine compounds are not cheap and they have to be compounded into a polymer system or coating recipe. When compounding and coating automotive fabric with water-based systems, care is needed because the FR chemicals are solids and need surfactants and thickening agents to produce a uniform compound with reasonable shelf life. There is the danger of the solids separating out during storage or transportation or during the actual coating process giving rise to an unsightly appearance and irregular test results.

Many chlorine and bromine chemicals are believed to be potentially toxic and are subject to control or prohibition. Both antimony trioxide and bromine FR chemicals have been under environmental scrutiny for several years, and this seems to have intensified recently. The search has been on for alternative chemical systems with only limited success so far. Not everyone is convinced that the materials are hazardous; the bromine industry is calling for independent reports. Others believe there is greater risk from being burned in an accident, than the risk from bromine as an environmental pollutant. This has been discussed above in Chapter 8.

Among the alternative chemicals put forward are zinc hydroxystannate, zinc stannate, and systems based on zinc borate. However there is a quite widely held view, that a higher concentration of the alternative materials is required to produce the performance obtained with a lower level of an antimony/bromine system. In certain applications, it is possible to simply increase the loading of FR filler and chemicals but this is not easy with fabric coatings, where increased amounts of additives and add-on cause fabric stiffening. Also, there is a limit to the amount of FR chemical, which can be mixed into water or solvent-based resins for fabric coating.

9.3.4 The burning process

The stages of combustion are ignition, growth, propagation and finally decay, but all fires in real-life situations are unique in that the circumstances and conditions are never exactly the same. The way fabrics burn depends upon a variety of factors and combination of factors including fabric stiffness, drape, contact with or proximity to other materials, supply of air, draughts, etc. Fire is not only a hazard because of the danger of contact with flames, but also because of suffocation by toxic fumes, injury from heat levels and heat stress, all the dangers associated with panic and the inability to escape due to routes being obscured by dense smoke. Individual test methods have been devised to take all these factors into consideration, some of them after lessons learnt in actual transportation disasters.

9.3.5 Fireblocker materials

These fabric fire barriers were originally developed for aircraft seating but are now becoming required for passenger trains, buses, coaches and other road vehicles. There is now a whole variety of different fabrics being used for this component to combine FR performance with comfort, light-weight properties and minimal cost.[26–29] However some seats are made from foams with very high standards of FR properties, such as 'graphite' foam and in these cases fireblockers may not be needed.[30,31] This subject is discussed below in aircraft furnishings.

9.3.6 Fire safety in transportation

Standards for public safety are invariably controlled or influenced directly or indirectly by government departments, for example, the Civil Aviation Authority in the UK or the Federal Aviation Authority in the USA for safety in aircraft. The International Maritime Organization is responsible for safety at sea. The FR standards, although aimed at reducing ignition, propagation speed, heat and smoke are also intended to allow sufficient time to safely evacuate the aircraft or marine vessel and it is difficult to test for this overall factor. All textiles on passenger aircraft, marine vessels, trains and road vehicles throughout the developed world are subject to FR testing. Fibres with inherent FR properties, which are not removed by washing or dry cleaning are now available for furnishings such as curtaining, upholstery, bed linen. These include polyesters, Trevira FR and CS (comfort and safety), Fidion FR from Montefibre, Viscose FR from Lenzing and the more specialist fibres, modified acrylic and aramids. In addition the durable FR treatments, Proban (Albright and Wilson) and Pyrovatex (Ciba) are available for cellulosic fibres. Zirpro treatments are available for wool. As usual, cost and performance need to be balanced and the specialist fibres are frequently blended with regular fibres.

9.4 Fabric coating

Coated fabrics are engineered materials produced by a combination of a textile fabric and a polymer covering which is applied to the surface.[32–41]

Fabric coating confers new properties to the fabric such as impermeabilty to dust particles, liquids and gases and it is also possible to improve existing ones such as abrasion as has been seen with car seat fabric in Chapter 4. The most familiar coated fabrics are tarpaulins and waterproof protective clothing material. The fabric component determines the tear and tensile strength, elongation and dimensional stability, the polymer mainly controls the chemical properties, abrasion and resistance to penetration by liquids and gases. Many properties are determined by a combination of both components together and both base fabric and polymer must be carefully selected by thorough consideration of the properties required in the finished article. Other coated fabrics in the transportation area include materials for life jackets, life rafts, safety chutes, hovercraft skirts, protective coverings, awnings, aircraft fuel tanks, flexible containers and airbags. Aesthetic effects can also be achieved by fabric and polymer combinations; man-made leathers used for seat covers and apparel are essentially coated fabrics.

9.4.1 Base fabrics used

For quality coated fabrics, quality base fabrics are essential. This point is made because newcomers to the industry sometimes believe that the coating can cover fabric defects, when in fact the defect is frequently made more prominent. The cost of rejected coated fabric, with the added value of coating is higher than that of base fabric alone! Polyester and nylon are the main fibres used because of their strength and general resistance to moisture, oils, micro-organisms and many common chemicals.[36,37]. Generally polyester is more resistant to light and UV degradation than nylon, although nylon is more resistant to hydrolysis. The use of polyester, however, has grown at the expense of nylon because of its better dimensional stability and shrink resistance and lower extensibility. High tenacity yarns are used in many coated articles for extra strength and aramid fibres used, where more specialist properties are required. Acrylic fibres are used for some applications where very high UV resistance is necessary, such as car roofs. Cotton is still widely used and has certain advantages over synthetic fibres such as polymer adhesion, the cotton being rougher and of short fibre length, provides more opportunity for mechanical anchoring. The smoother synthetic fibres frequently require some means of promoting fibre–polymer adhesion especially with PVC plastisols and rubber coatings. A fabric coating is essentially a joining operation and the principles of adhesion apply, i.e. the fabric must be clean and free of dirt, dust, oils and any fabric finish to obtain the best results of coating adhesion. Fabrics are therefore preferably scoured (and rinsed thoroughly), and heat set to stabilize the fabric before coating.

In some cases, the fabric is pre-treated with an adhesion promoter. Much research work has been carried out to improve polymer fabric adhesion, especially for rubber and for composites. Research work has been directed at polyester and aramids using corona discharge and plasma treatments.[42–45]

Only a very small number of fabric constructions are used for polymer coating for transportation and industrial uses, i.e. plain weave, twill and basket constructions. To combine weight with high tear strength, rip-stop constructions are sometimes used; a stronger yarn is inserted every 5 mm or so. Knitted fabrics are used for apparel and are transfer coated to obtain soft handle. Fabrics are sometimes slightly raised or napped to improve coating adhesion.

9.4.2 Polymers and compounds used

The physical and chemical properties required largely determine which polymer type to coat on to fabrics, although cost and ease of processing are also important factors. Few polymers are used entirely on their own, but are mixed with other chemicals to improve a particular property or to assist with processing.

Coating mixes or compounds (sometimes referred to as 'cocktails'), can contain up to six or more different ingredients, each one having a role to play. PVC plastisols, used to produce tarpaulins, generally consist of the PVC, which could itself be a mixture of two or more different grades, a plasticizer which generally determines flexibility and other properties, stabilizers against light and heat degradation, pigment for colour, and possibly filler for economy. Sometimes secondary plasticizers are also included to help 'tailor' the properties to the particular application and flame-retardant chemicals, although PVC itself is quite inherently flame retardant.

Rubber compounds will generally contain at least a similar number of ingredients together with vulcanizing (this essentially means the same as cross-linking or curing) chemicals. Each ingredient must be chosen carefully for compatibility with the others and for minimization of side effects. With so many components, formulation and mixing of the compound are skilled operations – the importance of which is sometimes not appreciated. Many problems arising in production and during use by the customer, have their origins in the compounding stage and frequently, coating factories buy in ready-compounded mixtures and masterbatches, especially when pigments are involved.

In addition to the main ingredients, processing aids are frequently needed to control the viscosity of the mixture, which may change during the coating process. The flow properties are referred to as the rheology of the compound. Under the shearing action of the coating blade, the viscosity of the resin may become thinner, causing penetration through the base fabric – this is termed thixotropic behaviour. The converse is called rheopectic behaviour, whereas resins with constant viscosity are said to have Newtonian properties. Viscosity must be monitored frequently with a suitable instrument such as the Brookfield viscometer, (using the appropriate spindle) or Ford cup.

Most fabric coating comprises more than one layer and it is quite common for each layer to be different, requiring separate compound recipes. In general the first or base layer is soft and flexible and in the case of both PVC and rubber compounds it contains special chemicals to cross-link with the base fabric for good adhesion. Rubber technology is a whole science in its own right with many different types of rubber and their variants plus the art and technology of compounding. Table 9.3 shows the main products used in transportation together with the polymers used.

9.4.3 Direct coating

Coating is essentially spreading a polymer in the form of a thickened aqueous dispersion or an aqueous or solvent solution on to a fabric to form a continuous layer. It is necessary to thicken the liquid so that it does not sink into or through the fabric. The simplest method is the so called 'floating knife' or 'knife over air' technique where the fabric is stretched flat to form an even uniform surface and moves under a doctor blade. As the fabric moves forward, the knife scrapes the fabric surface and the polymer resin or compound is spread evenly over the fabric surface. This method is also referred to as the 'direct method'. The amount of polymer applied, the 'add-on', depends on the concentration of the dispersion or solution – this is the so called 'solids content'. The add-on is also influenced by the knife profile and angle and also fabric tension which determines the intimacy of contact with the fabric. A thick profile produces a higher add-on than a thin, sharp one; a blade angled forwards will tend to increase add-on compared to a perpendicular blade. A thick or angled blade however will tend to drive polymer into and possibly through the fabric which will cause stiffening and possibly loss of tear strength.

The knife on air method is important because the first layer of many coated products, is applied in this way. A quality base layer is especially important because it determines polymer–fabric adhesion and has a significant effect on coated fabric handle if this is important. Higher levels of application are then possible in second or third coats by supporting the fabric either by a table (knife over table) or by a roller (knife over roller). In these cases the knife does not actually touch the moving fabric, but is separated from it by a small gap set by use of a feeler gauge. The limiting factor governing the amount of compound that can be applied in one layer

Table 9.3 Summary of polymers used for fabric coating in transportation

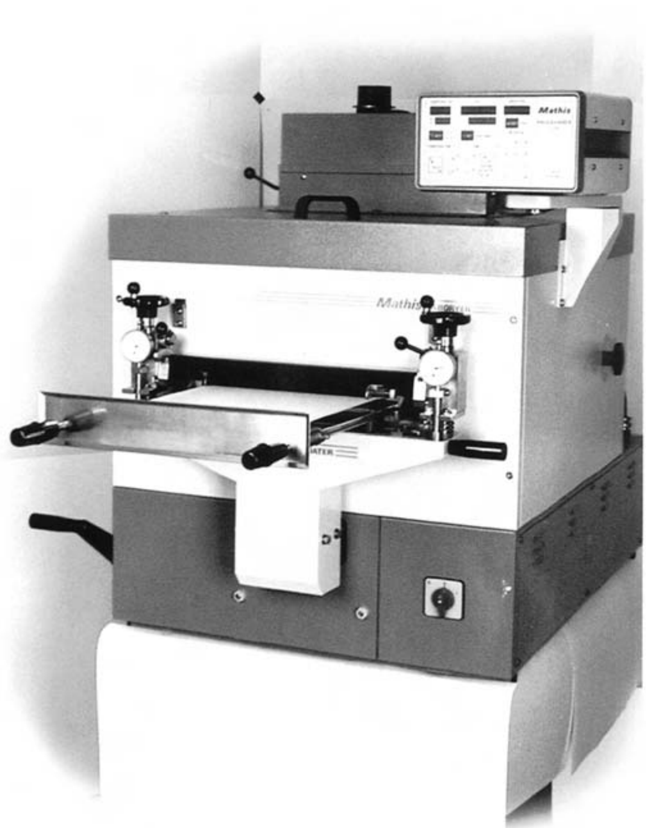
	Properties/advantages	Disadvantages	Typical products
PVC	Inexpensive, versatile – can be compounded to give wide range of properties, good FR properties; good oil, solvent, and abrasion resistance; weldable for water-tight seams. Plastisols and water-based available	Cracks when cold, plasticiser migration	Tarpaulins, coverings Seat coverings Protective clothing
Polyurethane	Tough, good extensibility, good weatherability, very good abrasion resistance. Solvent and water-based types available. Also thermoplastic grades	Some grades discolour, FR is only moderate. Some grades expensive	Aircraft life jackets Protective clothing Life rafts Lacquers for tarpaulins
Acrylic	Versatile, blendable with other polymers. Good clarity, inexpensive, good UV resistance. Solvent-based and water-based available	FR is moderate to poor unless compounded with FR chemicals	Back coating for seat coverings Lacquers for tarpaulins
Natural rubber	Good stretch and flexibility. General purpose material. Working temperatures up to 70°C. Fillers improve mechanical properties. Many grades available by compounding	Moderate sunlight and oxidative resistance. Moderate solvent resistance, and oil resistance. Flammable, needs FR fillers. Tendency to biodegrade.	Backing for carpets Escape chutes Liferafts Tyres
SBR	Similar to natural rubber but somewhat better abrasion and flexing resistance. Better resistance to micro-organisms		As natural rubber
Nitrile (acrylonitrile/butadiene)	Very good oil resistance which increases with acrylonitrile content. Better resistance to heat and sunlight than natural rubber		Oil seals

Butyl	Very low permeability to gases, better resistance to heat oxidation and chemicals than natural rubber	Seaming difficult	Lightweight life jackets Life rafts Chemical resistant clothing and coverings
Polychloroprene e.g. Neoprene (DuPont)	Excellent resistance to oxidation, oils, solvents and chemicals. Working temperatures up to 120 °C. Good FR properties, versatile material	Coloration is difficult therefore usually black only.	Life rafts Life jackets Airbags Aircraft slide/rafts Aircraft carpet backing Hovercraft skirts Radome covers Flexible gangway bellow between train carriages V-belts
Chlorosulphonated e.g. Hypalon (DuPont)	Excellent oxidation, oil, solvent and chemical resistance. Generally similar to neoprene but higher temperature resistance to 135 °C. Some grades, to 170 °C, can be coloured		Properties generally similar to polychloroprene, used where coloration and higher temperature resistance is required
Silicone	Odourless, inert, good resistance to many chemicals and micro-organisms. Wide temperature service range –60 to 200 °C	Expensive. Seaming difficult	Airbags
Fluoropolymer Viton (DuPont)	Very high temperature resistance to over 250 °C. Excellent resistance to solvents, oils, oxidation and ozone	Very expensive	Oil seals Hoses, gaskets

is usually the drying off process in the coating machine oven. This is an important process, especially in the case of inflatables where a continuous, pin-hole-free and surface-defect-free coating is essential for impermeability and waterproofness. The first layer is generally applied at a low processing temperature, without curing or only partially curing it, so that the next coating layer will adhere well to it. Full cross-linking of all layers is only carried out after the top layer has been applied, so all layers are cross-linked together. The top layer must have good abrasion properties and a smooth non-'blocking' (i.e. non-tacky) surface. Figure 9.1 shows a sample laboratory coating machine and Fig. 9.2 shows actual fabric production.

The length and design of the drying oven are important because they determine coating speed and quality. The best results are generally obtained when the evaporating process achieved by heating is gradual, i.e. setting the first chamber of a multi-chamber oven at a low temperature, well below the boiling point of the carrier liquid, and the others at gradually higher temperatures. Too rapid drying can cause an irregular appearance, bubble holes and a generally poor result. Fabric coating has been compared to painting – the best results are obtained by several layers of low add-on rather than one or two thick layers. However, machine and operator time is expensive so a compromise is reached depending on the level of performance and quality required. Usually the first or base coat is applied by knife on air and subsequent layers by knife over table or roller if the polymer type allows. Generally only fairly tightly woven fabrics capable of being pulled flat and uniform can be coated by the direct method. Automotive car seat fabrics, tarpaulins and light-weight material for inflatables are produced in this way. Some inflatables are produced by applying many layers – sometimes as many as 20 layers – of specialist rubber polymers by the direct method. With all polymer coatings, sufficient heat is essential to fully cross-link the polymer for optimum performance. PVC does not strictly speaking, cross-link, but sufficient heat is necessary to gell the material properly, otherwise poor results will be obtained such as poor abrasion.

In recent years, solvent-based resins have been used less frequently, but certain high performance properties are still not obtainable using the alternative water-based or higher solids varieties and development by the chemical companies continues. Standard tests for all coated fabrics include polymer adhesion (peel bond), tear strength, blocking (tackiness of the top layer), resistance to delamination by flexing and where applicable waterproofness. Figure 9.3 shows a Schildnecht flexing test apparatus used to test coated fabrics for delamination. Waterproofness and other tests are sometimes carried out on material first flexed on the Schildnecht or the Crumple-Flex machine. This last-mentioned machine twists the fabric slightly at the

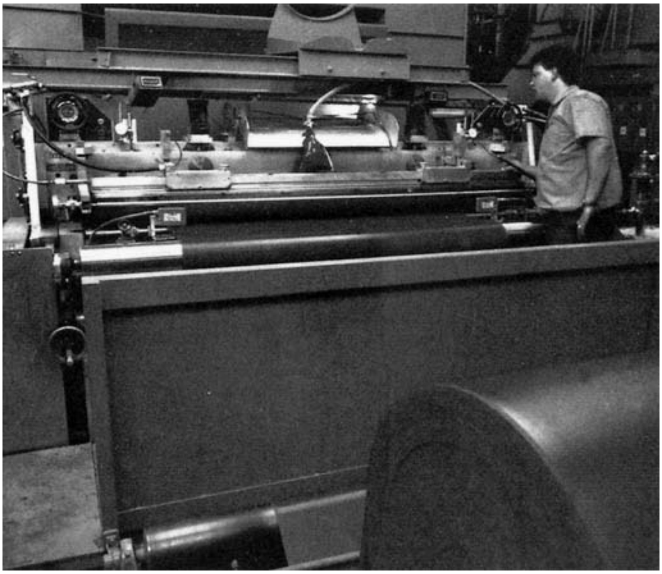


9.1 Mathis Type LTE-S laboratory development coating machine with knife on air, knife over roller and precision gap setting facilities. The oven has controls above and below air flow which can be set to any required temperature up to 200 °C. Reproduced with kind permission of Werner Mathis AG.

same time as flexing and also provides a larger fabric sample for further testing.

9.4.4 Transfer coating

Knitted fabrics can be coated by transfer coating which is used extensively for apparel where a good, soft handle and drape are important. Some PVC upholstery materials, especially expanded or ‘blown’ varieties, which have a soft touch are also produced in this way, which entails spreading the polymer first on to release paper. The top layer is applied first and then dried – but not cross-linked – followed by the middle layer, in a three-coat



9.2 Coated fabric bulk production. Reproduced with kind permission of Reeves Brothers, Inc.

9.3 Schildnecht Flextester. Flexing is an important test for coated fabrics to assess polymer adhesion. Each fabric sample is clamped around two cylindrical holders, one above the gap and one below. The rails move rapidly up and down to flex the fabric sample. Reproduced with kind permission of SDL International Ltd.

system or the base adhesive layer, in the case of a two-layer system. The coating is dried and then the fabric is laid on top of the adhesive layer to which it sticks, and after a final cross-linking heating treatment, the coated fabric is peeled off the release paper. Decorative or embossed designs can be obtained using embossed paper or by further processing. PVC uphostery is waterproof, cleanable and flame retardant.

9.4.5 Calender coating

Calender coating is used for thermoplastic polymers, which are applied by heating granules of the actual polymer. Friction of the moving rollers generates more heat, and the material is fabricated into a continuous sheet. There is no solvent or water to dry off and so high add-ons are possible. It is usual however to apply the first base layer by the direct method to obtain the best adhesion and subsequent layers by calendering. Polyurethane, PVC and certain rubbers are applied using this method.

9.4.6 Calender film lamination

Certain coverings are produced by the double-sided lamination of a very open-woven material with pre-manufactured thermoplastic films of polyurethane, polypropylene or PVC. The three materials are pressed together by a hot mangle, the two films melt and join together through the open weave of the fabric. Sometimes the fabric, more accurately referred to as a net, is not actually woven but comprises lengthways and widthways threads (or very narrow tape) locked in place by an adhesive. This material is sometimes referred to as 'weave lock' and provides the tear resistance of the material.

9.4.7 Other coating methods – rotary screen

Coating of lacquers and low-viscosity resins can also be carried out using rollers in various configurations to control the add-on accurately. These include direct methods and back-licking methods. The rotary screen technique used mainly for textile printing can also be used for coating. An array of dots are pushed through the perforated screen by a squeegee bar inside the screen and centrifugal force on to the surface of the fabric, which moves at the same speed as the rotation of the rotary screen. The resin in the dots flow and merge together to form a continuous coating. This technique allows some stretchy fabrics to be coated because the resin is *placed* on to the fabric, instead of being scraped on. The rotary screen method therefore requires less fabric tension for uniform application. This method is generally restricted to water-based resins because of the problems presented by the provision of solvent wash-off facilities.

9.5 Textiles in other road vehicles

9.5.1 Commercial and goods vehicles

Commercial vehicles can be roughly grouped into four or five classes depending on weight-carrying capacity. At the lower end are estate cars and small vans which have requirements similar to passenger cars but there may only be two seats in some vans and decor may not be as elaborate as cars. Middle-sized vans such as the Ford Transit generally have only two seats but there are many variants built to order with many more seats such as those vehicles used by the police, schools and local authorities, etc. Mini-coaches have in fact been a growth area in recent years with more schools and community organizations owning their own vehicle. Table 9.4 shows volumes of vehicles weighing more than 6 tonnes gross vehicle weight (GVW) and buses. Taking 1997 as the baseline, a 38% increase is forecast by 2004.

Table 9.4 World heavy commercial vehicle sales ('000 units)

	1996	1997	1998	1999	2000	2001	2002	2003	2004
North America									
USA	359	376	424	403	370	347	365	382	398
Canada	28	34	38	37	38	39	40	41	44
Mexico	9	18	19	22	22	23	26	28	30
Total	396	428	481	462	429	410	431	451	472
Latin America	71	87	90	70	74	81	89	98	108
Western Europe	287	279	330	333	321	321	321	313	299
Germany	76	77	86	92	89	87	88	88	84
Italy	29	24	29	29	23	26	32	33	29
France	47	43	52	56	55	53	51	46	45
UK	50	46	54	51	45	48	48	51	52
Spain	22	27	30	30	31	31	29	25	21
Eastern Europe	112	127	126	126	146	182	218	240	252
Japan	89	84	66	63	67	71	75	75	75
Asia/Pacific	620	583	553	605	684	754	821	904	987
Other	37	36	40	40	43	45	46	47	47
World	1617	1631	1693	1706	1772	1871	2010	2137	2251

Source: SMMT, National Sources, J.D. Power-LMC.
Note: Heavy Commercial Vehicles include trucks of more than 6t GVW, and buses.
Reproduced with kind permission of LMC Automotive Services (Oxford) UK.

Seat fabric wear patterns can be different because with small delivery vehicles, the driver is likely to be continually stopping, getting out to make a delivery and then getting in again many times during the working day. With longer distance vehicles the driver may get out and in again only four or five times during the day. Repair engineers may be wearing oil-stained overalls and may place tools and other items on the seats.

Larger commercial vehicles and even heavy goods vehicles (HGVs) generally have only two seats and the market for seat fabric is therefore considerably less than for passenger cars. However HGVs built for long-distance haulage where the driver is away for days at a time, require higher standards of comfort and décor. They are frequently built with sleeping accommodation, curtains, carpets and textile wall coverings. The need for comfortable interiors is growing in these vehicles and more attractive, livelier colours, softer surfaces and more rounded shapes are appearing.[46] In the USA there is a reported shortage of drivers and comfort and pleasant cab interiors are factors in attracting and retaining drivers. Owner-operators personalize their vehicle and may install more luxury items. In addition there is a growing number of husband and wife teams requiring the comforts of home in the cab. All textiles must satisfy flammability tests set by government regulations.

Weight saving is an important consideration because an already heavy, unloaded vehicle will have less capacity available for the payload because the overall vehicle weight is limited by government regulations. Composites made using low-pressure moulding techniques are being used for exterior body panels. Composites are also being used internally as space dividers and doors, replacing more bulky and heavier material and releasing more useful storage space. Cab seat coverings are generally similar to those of car seats but sometimes tend to be made of the heavier fabrics, sometimes about 430 g/m^2 using yarns up to 3000 dtex with higher performance requirements of FMVSS 302 flammability.

9.5.2 Tarpaulins

HGVs use large amounts of tarpaulins, PVC plastisol-coated high-tenacity woven nylon and polyester fabric. Tarpaulin weights vary quite considerably from lightweight coverings weighing a little over 100 g/m^2 to over 1000 g/m^2 produced from base fabrics weighing less than 100 g/m^2 to over 300 g/m^2 with the PVC being built up in several layers usually on both sides of the base fabric. In Europe some of the highest quality tarpaulin manufacturers are members of the Complan 'club' – a quality assurance body established by the manufacturers of Trevira polyester.[47] The equivalent body in the USA is Isoplan-Trevira. Top quality tarpaulins are lacquered with a polyurethane or acrylic resin to improve UV degradation resistance, improve abrasion resistance and soil-release properties and to prevent PVC plastisol migration.

Quality tests on tarpaulins include PVC peel-bond adhesion, flexing resistance, cold cracking, reduced flammability, waterproofness, tear and tensile strength, and dimensional stability over a range of temperatures and relative humidity. In addition they should be resistant to oils, engine fuels and common chemicals. Two special polyesters, Trevira HT Type 711 (Hoechst) and Diolen 174 SLC (AKZO), which are resistant to micro-organisms have been developed for tarpaulins. These are intended to overcome the problem of migration of micro-organisms into the tarpaulins via small cracks in the PVC coating. Tarpaulins must have especially good tear and flexing resistance and preferably be repairable in the field. Research continues to improve tarpaulin durability, to study mechanisms of degradation and to develop accelerated tests which reproduce conditions of wear in actual use.[48,49] Some non-PVC tarpaulins such as polyethylene have appeared because some pressure groups, notably Greenpeace believe PVC is harmful to the environment, especially during manufacture and disposal. Used in conjunction with tarpaulins are narrow fabric fastenings, which also need to be able to withstand UV degradation and weathering. Tarpaulins can reduce the air drag on goods vehicles, by producing smoother surfaces and fuel consumption improvements of up to 7% have been reported. More colourful tarpaulins with advertisements have appeared in the USA recently. Some analysts believe the sides of trucks on the move are areas for exploitation by the advertising industry. These have been printed and make use of up to date developments in digital printing.

9.5.3 Other textile uses

Flexible intermediate bulk containers (FIBCs) used for transporting powder-type materials are woven from polypropylene tape yarn and coated with a specially formulated coating. They need protection against static explosions when being filled or emptied and also require earthing with metal wire in the fabric. Recent developments have allowed the metal wire to be replaced with Negastat (DuPont), a polyester yarn which has permanent anti-static properties. Sacks produced from fabric woven from polypropylene tape yarn have significantly replaced the sisal and jute fibre sack market. This fabric is generally consolidated by curtain or extruder coating with melt polypropylene and is lighter, more chemical resistant and more durable to micro-organisms than natural fibres. This fabric – more resembling a plastic – is also used in bags and inexpensive coverings. The international sack market is estimated at about 23 billion units, 20 billion of which are made from polypropylene.

Another interesting textile application is spray guards for HGVs made from polyester monofilament yarn knitted in a spacer fabric construction about 12 mm thick. They are lighter than plastic equivalents and about six are required for each vehicle. The EC have issued a directive for reduction of road spray.

Road transporters have been constructed from composites produced from Twaron (AKZO) aramid fibres by filament winding in the circumferential direction. Weight savings of 25–30% compared with aluminium have been reported.[50]

9.5.4 Buses and coaches

Bus interiors are also becoming more attractive, welcoming and comfortable.[51] Wool or wool/nylon moquette fabric in generally conservative designs, seems to be the rule for many coaches and buses throughout the world. Wool is soft and warm and absorbs body perspiration without feeling damp, even in hot humid climates. Fabric weight is typically 780 g/m^2 after coating with acrylic latex and abrasion standards of about 80 000 Martindale rubs and lightfastness to wool Blue Scale 6 are normally minimum requirements. Tear strength, dye fastness to both acid and alkali perspiration, water spotting, crocking plus soil resistance and cleanability by shampooing are other quality tests carried out. Cleaning of seat fabric is done by vacuuming and shampooing using a mild soap. The life of seating fabrics in use vaies considerably depending on the volume of passenger traffic – it could be less than 6 months on busy commuter routes to over 10 years on luxury coaches. In some cities of the world vandalism and graffiti are problems and some 'vandal-proof' fabrics have been developed to minimize the effects – some have a pile that stands up so that if slashed with a knife the cut is not easily visible.[52]

Reduced flammability standards are becoming tighter, BS 5852 ignition source 5 and ignition source 7 are indicative of the standard sometimes necessary and the use of fireblockers similar to those used on aircraft (see below), are being specified more often. Similar to aircraft, the toxicity, opacity and heat flux of the burning materials are subject to examination. Tests are carried out both on the fabric alone and also on the actual seat assemblies. The new machine-washable Zirpro-treated wool developed for aircraft, see below, should find applications in buses and other forms of transport.

Composites are being used increasingly on bus and coach construction to reduce weight and thus conserve fuel. The slim-line profile of components in composites, also increase the useful carrying capacity. The benefits of the 'stealth bus' in California have already been mentioned.

9.5.5 Mobile homes

In the USA, mobile homes are a growing market especially with the affluent middle-aged groups of consumers. These vehicles are governed by safety standards and they generally need a high standard of comfort and décor.[53–55] Mobile homes generally have a longer service life than cars but probably less intensive use. In the UK and Europe, the caravan, which is a separate towed vehicle is preferred.

9.6 Railway applications

An integrated rail system is being planned for Europe and primary routes are being developed – the Channel Tunnel forms part of one. A plan comprising 30000km of new and improved lines was presented to the EU in 1989.[56] Rail is probably the most environmentally friendly mode of travel both for the commuter and the long-distance traveller. Increasing road congestion and traffic fumes strengthen the case for the railways and high-speed trains now compete with air for short- and medium-distance travel. Attractive decor (see Fig. 9.4) and high standards of comfort are key factors in winning passengers away from road and air travel. Details of coaching stock plus some estimate of volumes can be derived from Fox's book.[57] The main technical issues are reduced flammability, durability and cleanability.

9.4 Standard Class MK III, Midland Mainline coach (UK) refurbished by ADtraz (DaimlerChrysler Rail Systems). Reproduced with kind permission.

Seat upholstery, loose coverings, carpets, curtains and bedding in sleeper compartments must all satisfy stringent FR tests.[58–61]

Since privatization of the railways in the UK, Railtrack, the company that own the track and many stations, has prescribed performance standards, generally referred to as Railway Group Standards, with which any operators' rolling stock must comply as a condition of their use of the rail infrastructure. Textile properties including flammability standards form part of the Railway Group Standards.

9.6.1 Seat materials

Woven moquette fabric containing 15% nylon/85% wool weighing about 800 g/m^2 has come to be regarded as the standard fabric.[58,59] This material is tested for bursting strength, tear strength, abrasion resistance by Martindale to 80 000 rubs, lightfastness to wool Blue Scale standard 6, dimensional stability and for no significant change in appearance after shampooing. In Europe, some polyester is used, especially inherently FR varieties such as Trevira CS and FR. Design patterns are usually conservative and in dark colours to mask soiling. More varied designs may be expected as the different rail companies introduce their own corporate colours.

BS 6853 1987 'Code of Practice for Fire Precautions in Design and Construction of Railway Passenger and Rolling Stock' is the guiding standard for FR properties, which also include requirements for smoke and toxic fumes assessment. Fabrics are tested singly and also in the made-up seat form using BS 5852 crib 7 and fireblockers are being increasingly required.[59,60] The control of smoke and toxic fumes is especially important in trains which pass through tunnels, especially single track tunnels similar to the Heathrow link. Materials, which release toxic fumes on combustion such as modified acrylic fibres and PVC are not used in passenger rail coaches.

All international passenger trains must comply with the International Union of Railways specification UIC 574-2 DR. The building of the Channel Tunnel means that certain British trains must comply with Continental regulations such as the French standard NF F 16-101 which contains detailed procedures for the testing of individual materials for FR properties including smoke opacity and toxicity. There are many different standards across Europe which are now being standardized.

Train interiors suffer from graffiti and vandals and some fabric designs are intended to minimize the visual effect of graffiti. In some Continental cities metal wire is used beneath fabrics to reduce damage by knife slashing. Some fabrics have been specially developed to minimize the visual effect of slashing with a knife. A new cut-resistant polyester fibre (CRF), developed by Hoechst Celanese, but now sold by AlliedSignal, should find applications in public transport. CRF is a bicomponent polyester fibre embedded with ceramic platelets to deflect cutting edges.

9.6.2 Other rail uses of textiles

Rail carpets are important items of comfort and decor but must be extremely hard wearing and capable of withstanding high volumes of foot traffic of up to 20h every day.[62] Wool and nylon are the two fibres most used, but they must be treated to pass FR tests for spread of flame, (BS 476 Part 7), for smoke emission, toxicity of fumes and heat release (ASTM E 648). Wool has the better FR properties but nylon is better for soil release and cleanabilty. Durable antistatic properties are a requirement and this is sometimes obtained using small amounts of conductive fibres in the carpet such as Resistat (BASF) and Antron P140 (DuPont). Rail curtains and sleeping compartment textiles all need to have FR properties. The concertina or bellows-like material, which covers the space between carriages is coated nylon or polyester coated with neoprene, which remains flexible during the coldest winters.

The use of composite material both in interiors and exteriors is increasing to reduce weight in long-distance high-speed trains, which now compete with aircraft. The French advanced train TGV capable of speeds of 300km/h contains very significant amounts of carbon fibre/epoxy composite. Nomex is used as insulation in some high-speed trains' transformers resulting in weight savings of half a tonne. Light-weight ceiling panels, satisfying the German FR standard DIN 5510, made from Nomex and glass/phenolic composites are used in some continental city trams, Cologne for example. Nomex honeycomb composites are extensively used in the interiors of trains including 'Le Shuttle'.[63,64] The use of composites in place of metals in European passenger trains is expected to grow by 45% in the period 1997 to 2002 according to a study by EuroTrends Research. The EC have funded research work on composites for rail applications.[65]

9.7 Marine applications

In ships and boats, textiles are again used as a means of decor and comfort. There is also a growth in composites being used in the structure of vessels especially in sports and smaller vessels including pleasure craft. Fibres are used in sailcloth, ropes, boat coverings, awnings, flags and bunting and safety equipment including life jackets and inflatable life rafts. Reduced flammability is again of paramount importance because of the restrictions on escape routes at sea and also because it is believed low ceilings and narrow corridors in vessels, increase the tendency for people to panic in the event of a fire. The 'marine area' is growing with increased affluence in countries of the developed world – already a high proportion of families own pleasure craft in Scandinavian countries. In addition holidays on cruise ships is already a growth area in the leisure industry with several luxury cruise ships larger than the *Queen Elizabeth II* in service and several more under construction or being planned that are larger than 100 000 tons and capable of accommodating over 3000 passengers. Safety procedures and standards are being reviewed following a recent incident, which required evacuation of a new large cruise liner. Although everyone was safely taken off, the time taken to achieve this, was twice as long as the 30 min required by safety regulations, even though the ship was not full to capacity. This highlights the fact that the very large modern passenger ships are presenting new challenges and situations of which there is no previous experience.

9.7.1 Furnishing fabrics

The International Maritime Organization has set international standards for safety such as the IMO Resolution A471 (XII) for fire resistance. Cruise ships are really floating hotels and all furnishing fabrics must be of 'contract standard' generally with increased FR standards.[66–70] Pyrovatex-treated cotton is used and more use is being made of special grades of textiles such as Trevira CS and Fidion polyesters which have permanent FR properties that are not reduced by multiple washings. FR tests required include DIN 4102 class B and BS 476 paragraph 6. Carpets have a special function on passenger ships because of their noise and vibration absorbing properties which produces a much more pleasant and comfortable atmosphere at sea. The carpet dyes must be of the highest standard of durability because areas of the ship are in use 24 h each day and cleaning must be done to tight schedules. Ferry vessels can have over 1 million passengers a year and carpets are expected to last several years. Wool carpets are Zirpro-treated for the highest FR standard and durable anti-static properties are also required.[70] Sometimes this is achieved by the use of conductive fibres such as Resistat (BASF) which provides permanent anti-static properties which will not wear off in a similar way to anti-static finishes.

9.7.2 Marine functional applications

The advantages of composites over more traditional materials are easy handling, corrosion resistance and lower maintenance charges.[8,9,71] In some cases metal cannot be used, for example, in minesweepers, sonar domes and in cargo ships carrying certain corrosive materials. In addition composites are being increasingly used for navigational aids such as buoys. An advantage here is that no damage is caused in the event of a collision. Many small craft such as patrol and pleasure boats are made from glass-reinforced plastic but some polyester fibre is now being used in place of the more costly glass fibre. At the other end of the cost scale Kevlar is also used in combination with glass fibre in small vessels. Recently a new generation hovercraft has been designed making use of Kevlar 49 composites in place of aluminium. Advantages include lighter weight, corrosion resistance, less noise in operation, better shock absorbency and higher abrasion resistance to rocks and sand surfaces.

Coated woven nylon is used for life rafts, buoyancy tubes, canopies and life jackets. Polymer coatings are butyl rubber, natural rubber, polyurethane and polychloroprene and total weights of the coated fabric are between 230 g/m^2 up to 690 g/m^2. Quality tests include hydrostatic head to ensure waterproofness carried out after ageing and after flexing, coating adhesion, breaking load and tearing strength tests. Life jackets are generally woven nylon coated with butyl or polychloroprene rubber to give total coated-fabric weights of between 230 and 290 g/m^2. Tests for these items include assessment after immersion in water for 24 h. The specifications and performance standards for life jackets and life rafts are subject to government regulations. The Underwriters Laboratory (USA), issue specifications e.g. UL 1123, Marine Buoyant Devices and UL 1180, Recreational Inflatables, which are available for purchase, and specifications are also issued by the military in various countries. Finally all marine vessels use large amounts of material such as fibreglass, for vibration, thermal and noise insulation, especially in and around turbines and engine rooms.

9.7.3 Sails and ropes

Sail design is quite a complex subject; the main requirements are high strength, UV resistance, resistance to water and micro-organisms, light-weight properties, low creep and minimum distortion. Natural fibres, such as sisal were first replaced with nylon and polyester, which were both lighter and stronger and had better resistance to rotting. In addition polyester especially has better light and UV resistance than nylon and because of this has become more often used. The woven polyester sail fabric needs to be wet processed and if necessary, dyed using pressurized jig-dyeing machine to prevent formation of creases. Relaxation during wet processing and stentering reduces porosity by closing up the fabric structure. Modern sails, especially in racing yachts now use aramid and carbon fibres strands to combine lightness with strength.[72] Aramids however, are not especially UV resistant and the ultra high modulus (UHM) polyethylene yarns Spectra (AlliedSignal) and Dyneema (DSM) are now also used. Many light-weight sails are laminated materials where film is bonded to the fabric.

The new UHM polyethylene yarns have found applications as extremely strong marine ropes, which are lightweight, and have the useful ability to float in water. One method of expressing the strength of ropes is the 'free breaking length', which is the theoretical length at which a rope breaks under its own weight. For steel rope the length is 25 km, for polyester and nylon, the length is 85 km, for carbon fibre it is 195 km and for aramids it is 235 km. The figure for Dyneema is quoted as 330 km.[73] The material is also claimed to have very good resistance to UV light and is also resistant to acids, alkalis and solvents.

Marine vessels, especially those with sails, use considerable amounts of rope and weight saving by taking advantage of lightweight materials is a considerable advantage. Other important requirements of rope material are excellent abrasion, UV and light-degradation resistance, low moisture absorbency and of course high strength.

9.8 Textiles in aircraft

Interior design in aircraft is assuming more importance to make them more welcoming and passenger friendly, see Fig. 9.5. Competition with an increasing number of airlines, and with other forms of transport, make this now more essential. This will not only mean more pleasing fabric patterns but also more head room and rounder and softer surfaces to give the impression of increased spaciousness.[74–76] To increase safety, research is being conducted to make seats stronger, but with thinner profiles for increased space, and bulk-head airbags may be introduced. However, the main impetus for textile development is safety through more satisfactory flame retardancy and weight saving. Statistics also show that 25% of all deaths in aircraft disasters are associated with fire.

The number of planes built in a year is tiny compared with the automotive industry – very many more cars are built in the world in a single day than all the aircraft built in a year. About 500–600 large civil aircraft are constructed in a year, 75% of them in the USA and 25% in Europe. About 250 smaller planes, 1300 light aircraft and 1500 helicopters, all for civil use are also made every year.[52] The average life of an aircraft is 30 years and so the numbers are increasing steadily. Furnishings are replaced on a regular basis or when there is sign of wear. Aircraft production is believed to have peaked during 1999 with about 620 made in the USA and 300 in Europe.[77] There are an estimated 12 000 civil aircraft, capable of carrying at least 60 passengers, in the world at present.[78]

9.8.1 Furnishing fabrics

Collins and Aikman in the USA together with the Douglas Aircraft Company are credited by some writers with producing in 1941 the first fabrics specifically designed for use in aircraft.[79] Previously ordinary

9.5 Upper class aircraft seating. Reproduced with kind permission of Virgin Atlantic Airways Ltd.

fabrics and carpets were used, but the aircraft company realised the wisdom of lighter materials and Collins and Aikman achieved significant weight reductions without loss of durability or performance. Seating fabric was reduced in weight by 41% and carpets by 31%. The new fabric, a worsted Bedford cord was soon adopted by all three armed services and contributed to the war effort. After the war, the fabric was adopted by the American civil aircraft companies.

Modern furnishing fabrics include, not only seat covers and carpets but also curtaining, headcloths and on long-distance flights, blankets and pillows. Each airline has its own livery colours, sometimes with logos. A vital factor associated with aircraft is reduced flammability of textiles and in fact of everything else on the plane. Aircraft carry huge amounts of highly flammable liquid fuel and also in the event of any incident involving fire, there is very limited means of escape – especially in the air! Seat covers need to be flame retardant but a fire barrier, made from material with very high inherent flame-retardant properties, over the seat foam is also sometimes necessary to prevent the foam catching fire and the seat as a whole has to pass very stringent tests. All materials must be flame retardant to high standards but in addition to ignition tests, the products of combustion, smoke and toxic fumes are also assessed. Research shows that many casualties in aircraft fires did not actually come into contact with flame but were overcome by fumes. In addition smoke reduces visibility and causes disorientation reducing the ability to escape. Safety standards such as the Airbus Industrie ATS 1000.001 controls smoke opacity and the concentration of toxic gases such as CO, HCl and HCN. Modified acrylic fibres and PVC have high levels of potentially toxic fumes, see Table 9.5, whilst wool and aramids have especially low levels. The physiological effects of the main products of combustion are shown in Table 9.6.

More recent work has identified the issue of heat release and Ohio State University have developed the OSU 65/65 test which requires that interior components larger than 10 inches square (25.4 cm) on aircraft built after 1990 must not release more than 65 kW/m^2/min during 5 min of flame exposure and the heat issued must not peak at more than 65 kW/m^2 at any time during the test.[80] Table 9.7 shows data on some fabrics. All the tests combined are expected to give passengers one-and-a-half minutes to evacuate the aircraft.

Table 9.5 Composition of off-gases of Kevlar and other fibres under poor combustion conditions*

	Combustion products in mg/g of sample									
	CO_2	CO	C_2H_4	C_2H_2	CH_4	N_2O	HCN	NH_3	HCl	SO_2
Kevlar	1850	50	—	1	—	10	14	0.5	—	—
Acrylic	1300	170	5	2	17	45	40	3	—	—
Acrylic/ Modacrylic (70/30)	1100	110	10	1	18	17	50	5	20	—
Nylon 66	1200	250	50	5	25	20	30	—	—	—
Wool	1100	120	7	1	10	30	17	—	—	3
Polyester	1000	300	6	5	10	—	—	—	—	—

*The sample is placed in a quartz tube through which air is drawn at a controlled flow and heated externally with a hand-held gas–oxygen torch. Air flow and heating are varied to give a condition of poor combustion (i.e. deficiency of oxygen). Combustion products are collected in an evacuated tube and analysed by infrared.
Source: Kevlar Technical Guide (H-46267) 12/92 Table II-8.
Reproduced with kind permission of DuPont.

Table 9.6 Combustion products and their physiological effects

Product	Sources	Physiological effects	
Oxygen depletion	All fires	21% 12–15% <–6%	= Normal concentration = Headache, dizziness, fatigue, loss of co-ordination = Death in 6–8 min
Carbon monoxide	All fires (incomplete combustion)	1000 p.p.m. 5000 p.p.m.	= Death after 2 h = Death within 5 min
Carbon dioxide	All fires	250 p.p.m. 5% 12%	= Normal concentration = Headache dizziness, nausea, sweating = Death within 5 min
Hydrogen cyanide	Nitrogen containing polymers (nylon, wool, modacrylics etc.)	50 p.p.m. 180 p.p.m.	= OK for 1 h = Death after 10 min
Hydroden chloride	PVC, PVDC fibres, neoprene coatings	10 p.p.m. 100 p.p.m.	= Irritation = Death within 5 min
Oxy-fluoro compounds	PTFE membranes	50 p.p.m. 100 p.p.m.	= Irritation = Death within 1 h
Acrolein	Polyolefins, Cellulosics (cotton)	1 p.p.m. 150 p.p.m.	= Severe irritation = Death in 10 min
Antimony compounds	Some modacrylics some rubber coatings, tentage	>0.5 gm/m^2	= Pulmonary and gastro-intestinal problems

Source: See foot of Table 9.7.

Table 9.7 Heat release rate (HRR), total heat release rate (THRR) and time to peak of heat release (T_p) for a variety of fabrics

Fabric	HRR (kW/m^2)	THRR (kW min/m^2)	T_p (s)
Cotton/polyester	170	53	33
Wool	117	39	24
Modacrylic	83	28	27
Zirpro Wool	64	24	25
Panox	27	15	30
Meta/aramid	13	6	40

Source: Tables 9.6 and 9.7 from Masri, M 'Survival under extreme conditions' in *Technical Textiles International* June 1992. Reproduced with kind permission.

The item requiring most attention inside the plane interior is the seat or more correctly the seat assembly, which is tested as a whole by tests such as the FAR 25.853c procedure in which a paraffin burner delivering flame at 1038 °C is applied for 2 min. The average weight of the covered seat cushion must not exceed 10% and the char length must not exceed 17 inches (43 cm). All seats in every passenger aircraft had to pass this test from 1 July 1987,[81] and this led to the use of 'fireblockers' under the face fabric to surround the polyurethane foam cushion and shield it from flame. There are various types of fireblocker in use, depending on the degree of protection to the particular foam grade necessary to pass the test and also on weight restrictions and cost.[26–29] Among the heaviest is a 60% wool/40% Panox (Lantor-UCF), material, the lightest but most expensive is 100% aramid. Many other materials and combination of materials are in use and under development including, Inidex (Acordis), Polybenzimidazole (PBI-Hoechst-Celanese), and Visil (Sateri Oy, Finland), a silica-modified cellulosic. In some cases the foam is sufficiently FR so that the seat assembly passes the tests without a fireblocker, but some of the higher FR grades of foam have the tendency to crumble. Seat comfort and other physical properties may also be compromised with these high FR foams. Tables 9.1 and 9.2 show values of limiting oxygen index (LOI) test results for materials used for their FR properties. LOI provides a numerical way of rating FR properties; materials with an LOI rating of more than 21% has some FR properties because 21% is the oxygen content of normal air.

All textiles used in aircraft interiors must pass stringent vertical burn tests such as BS 3119 or DIN 53906. American federal tests are influential and an internationally accepted test is the FAR 25.853b procedure which limits burning time to 15 s after removal of the ignition source and char length must not be greater than 20 cm. The seat cover however is also tested in combination with the cushion over which it is placed as described above. The seat cover fabric of aircraft seats is generally woven wool or wool/nylon blends, nylon in the warp, in the weight range of 350–450 g/m^2. Some reduced flammability polyester and blends are believed to be under test or in use with the objective of saving weight and improving easy-care properties. Hook and loop fasteners are used extensively to securely fasten fabric to aircraft seats and to allow easy removal for cleaning and changing.

Quality tests include colour fastness, crocking, pilling, snagging, dimensional stability and cleanability. Wool is invariably Zirpro-treated (IWS) for the highest FR properties, which are retained after dry cleaning. Until recently Zirpro-treated wool fabric could not be washed in water which was a disadvantage because most stains are in fact water-based.[82] A disadvantage of dry-cleaning, is the retention of trace amounts of dry cleaning fluid in the seat fabric. Recent work has been successful in overcoming this difficulty by the development of FR treatments for wool, which can be washed in water.[82] After dry cleaning (and now presumably after washing), a representative proportion of the cleaned seat covers, are tested for retention of FR properties. In-situ cleaning of seats must be done during the short time in between flights and soil release properties are important to make this as easy and effective as possible. The airlines evaluate this property by test staining with materials such as lipstick, coffee, ball point pen ink, mayonnaise and other oils. Residual stains or colour change after cleaning are assessed with Grey Scales. Antistatic properties of seat covers have been examined both for comfort but now increasingly for non-interference with electronic equipment. Anti-static finishes are used and there are some reports of conducting fibres in some aircraft seats.

Aircraft carpets, typically under 2000 g/m^2 (62 oz/yd^2) in total weight, are generally woven loop pile wool sometimes with a polypropylene backing for economy and to save weight. The pile is locked in with FR neoprene foam or a similar FR compound.[83] Appearance is important and aisle carpets which are subject to the highest wear including the effects of food and drinks trolleys need to be replaced as soon as wear is evident, sometimes after 6 weeks. Other areas such as under seats, need changing much less frequently, perhaps after a year or more. The carpet is tested for flammability using tests such as FAR 25 853(b) and also for smoke and toxic gas emissions and heat release. They must be easily cleaned and contain conductive fibres together with an antistatic coating on the back for permanent antistatic properties. Some airlines require a maximum of 1000 volts in a static body voltage generation test. The carpet or indeed any other article on the aircraft must not contain any substance, which could give rise to corrosive chemicals that could cause deterioration of the aircraft's metal structure.

9.8.2 Fibre re-inforced composites

The importance of composite materials in the commercial viability of aircraft has already been mentioned. Composites are used in many parts of the aircraft interior and structure resulting in significant savings in weight and space. Internal space dividers are usually made from glass fibre in phenolic resin and they must also pass all the flammability tests. Phenolic resin is used because of its FR properties and low smoke and low toxicity of the products of combustion. Composite development continues apace and further weight savings and other benefits can be expected. It has been estimated that even 1 kg saving in weight in an aircraft reduces fuel costs by £150 a year. Analysts predicted that by the year 2000 civil aircraft would be built with up to 30% of their total weight in composite material – some believe it could be as high as 65%.[84] Already many military aircraft are produced from over 50% composite material and in helicopters the figure could be as high as 70%. The increased use of carbon fibre, in some cases replacing glass fibre is expected to continue as carbon fibres become more available and processing efficiencies increase. Recently, researchers believe they have developed a means of containing terrorist bombs using 20 layers of AlliedSignal Spectra fibre.[85]

9.8.3 Other textiles uses in aircraft

Coated textiles are used in many safety items including escape chutes slide/rafts, inflatable life rafts and life jackets, see Figs. 9.6, 9.7 and 9.8. These items are generally produced from polyurethane or synthetic rubber coatings on woven nylon fabric. PVC coatings are generally avoided because of emission of toxic gases if they catch fire. Life rafts generally comprise buoyancy tubes, so that if one is punctured, the raft stays afloat. They can hold up to 30 or more persons and are covered with fabric to increase survival prospects in Arctic conditions. Life jackets are generally about 250 g/m^2 total weight, the polyurethane being applied by hot-melt coating over a first base layer of either water-based or solvent-based material applied by a doctor knife. They are made to the highest standards and are periodically individually checked for serviceability. Coated fabrics are used for fuel tanks in some aircraft, especially military, because they are flexible and can make use of awkward shaped spaces on the plane.

Seat belts are usually woven polyester at present lap only, but there has been some discussion regarding making them more like car seat belts with three anchoring points. This would more than double the amount of material required. Airbags for head protection have also been discussed but so far have not appeared in civil aircraft. Finally there are quite sizeable

9.6 Aircraft evacuation slide. Reproduced with kind permission of Reeves Brothers, Inc.

9.7 Defence Aviation Liferaft MS.33 for 33 persons produced from butyl rubber sandwiched between two layers of heavy duty nylon fabric. Reproduced by kind permission of Beaufort Air-Sea Equipment Ltd.

9.8 Beaufort Lifejackets are light and compact in storage. In use, they are designed to turn the wearer whether conscious, or unconscious to the correct angle of flotation with the nose and mouth held clear of the water. Courtesy of Beaufort Air-Sea Equipment Ltd and reproduced with kind permission.

volumes of non-woven fabric being used as disposable head cloths on seat backs.

Mention must also be made of the use of fabric in hot-air balloons and airships, which some writers believe could play a significant part in cargo transport in the future. The German government is supporting construction of freight airships and a German firm is reported to be building airships for the tourist industry. Strength-to-weight ratio, UV degradation and hydrolysis resistance are amongst the important requirements. Coated fabric and fibre composites are likely to be extensively used.

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10
Future development and outlook

10.1 General survey

The two main factors likely to continue to influence research and development in the automobile industry for the foreseeable future are, the environment and the control of cost. The textile industry can contribute to the environment by introducing lighter weight fabrics and devising ways of facilitating recycling of car components. Textile recycling poses a challenge because the textile face fabric is usually inseparably joined to another material, which is generally chemically dissimilar. The use of a textile to replace this other material to help reduce the number of chemical types and hence facilitate recycling, presents opportunities. However the most significant way in which textiles are likely to contribute to a better environment is via composite materials which replace heavier metals and significantly reduce the weight of road vehicles. Cost is being driven down by commercial factors, such as company mergers, joint ventures and the economies of large-scale production and purchasing. Technology is contributing by development of novel production methods, which combine two or more processes into one. These new techniques, which increase efficiency also reduce human error and provide more consistent quality, will continue to be developed and improved. New high-performance materials being developed by fibre and chemical companies, such as the ultra-high-strength polyethylene fibre and the thermoplastic polyolefin foils, present further opportunities to innovate in both products and production techniques. Advances in information technology and communications are also contributing to reduced costs and better efficiency.

A third factor driving development in the automobile industry at present is safety. Safety features represent the biggest single growth area in technical textiles at the present time but they add to the cost of the car. However OEMs in the USA in particular have no choice, because they are a requirement of federal law. Developments in the USA influence practice in the rest of the world, especially in the global automotive industry and airbags are becoming standard features in European cars, even though at the moment, legislation does not make them compulsory. There is opportunity for substantial growth in side-impact safety devices world-wide. Side-impact devices are already in new cars in the USA but protection for the 'full continuum of passengers' is likely to become a further requirement of US federal law. This means effective protection for a whole family of two adults and three children.

Road safety is becoming an important issue all over the world and we can expect more concerted efforts to improve the present situation. As previously mentioned, over half a million persons are killed on roads worldwide and a further 15 million injured and a significant increase in these figures is anticipated as developing and emerging nations use more cars and the young populations of the world grow to adulthood. We can expect more legislation and the development of more advanced safety features.

Product innovation will continue to play a very important role as OEMs compete to provide better value for money and gain sales advantage by offering something different and more advanced than their competitors. This is no easy task because of the extremely high requirements of product durability not to mention the ever present restrictions of tight cost control, which make the acceptance of additional products or features by the OEMs very difficult. However technical advancement is inevitable not only in the automobile industry but in every department of human activity. Technical advances in other industries will influence developments in the automobile sector, for example the development of synthetic fibres and advanced composites, while product development specifically tailored for the motor car will continue, because of the high volumes and potential reward.

Mobility is essential for all human activity, in both work and play, and cars embody personal freedom and individuality. Despite rising costs and increased road congestion it is unlikely that in the developed world people will be willing to give up their cars. In the developing countries people who can afford cars, own cars and most persons who cannot afford them at present, will almost certainly buy when their financial resources allow. Motor cycles crowd the streets of developing nations in South-east Asia and in the not too distant future these will be replaced with cars. The industry is set to continue to grow for the foreseeable future. This will happen despite a huge manufacturing overcapacity in the world – although some analysts take the view that there is a shortage of efficient manufacturing plant.

Car ownership is approaching saturation in the developed world but there are at present opportunities in South America, Eastern Europe and South-east Asia. There are even greater opportunities in the more distant future in China, India, Africa and Central Asia. All of these developing and new markets with their own cultures, historical backgrounds and heritage will come with their own particular technical requirements and especially interior design preferences. An example is the Ford Ikon specially, designed for the Indian market, which has extra leg room in the back because many Indian car owners employ chauffeurs and also extra powerful air-conditioning for the hot weather. One report claimed that head-space in the back was checked to ensure that a person wearing a turban could be comfortably accommodated.[1]

10.2 Manufacturing

New products and new manufacturing techniques lead to new test methods, and many demand higher standards of acceptance in existing tests. New materials although well suited to a particular application, may face unnecessary delays in acceptance because the product specifications are written around existing materials or processes. Some of the specification requirements may be too severe and some, not entirely necessary. Innovators must therefore have the determination to convince potential customers of the benefits of a new product or process. Anything new, must justify the sometimes lengthy task of rewriting standard operating procedures and other quality documents. Newer and more efficient production methods can take a considerable length of time before acceptance on a wide scale.

The industry is understandably cautious, because despite intensive testing and product evaluation, new products can still give problems or break down prematurely when used by the consumer. This can be extremely damaging to sales of an otherwise excellent vehicle and to the reputation of the OEM. In addition a new process or product may require new tools, new apparatus and new procedures using innovative but still to be proven technology. New tools or plant can be expensive and always presents a certain amount of risk. New products have a much better chance of acceptance if they can be produced on existing equipment or presented when existing plant is nearing the end of its life and will have to be replaced in any case. Cost reduction is the main driving force at the present time and innovative features with real benefits may not be considered purely because it will add to the overall cost. Other developments may not be given the opportunity of even being presented, because the decision-makers are too busy with the pressures of day-to-day tasks. These factors, although understandable, can be discouraging to research and development workers in university and company laboratories. Some ideas may never be given an opportunity because innovative research and development staff in a supplier company may have no access to their counterparts in a customer company who may be receptive to new thinking.

Nevertheless the industry leaders call for more creativity, imagination and new thinking but changes still take place slowly because of the reasons mentioned. In addition some analysts maintain that there is some unreasonable reluctance to change and believe that the most innovative changes could well first appear in a developing country where there is no existing plant to replace and there are no rigid thought patterns to overcome. Some very novel labour- and material-saving processes such as 3-D knitting of car seats still await large-scale adoption.

Fabric production, dyeing, finishing and lamination have become substantially more efficient over the last 20 years or so. The concept of 'blind dyeing' would have been thought impossible and quite reckless in the 1970s but the introduction of the computer and better and more precise control of parameters influencing dye uptake has made this quite normal procedure. One task still carried out very much the same as 20 years ago is final fabric inspection. Inspection table design has improved but operatives capable of human error and with human limitations still perform this important but relatively tedious and repetitive job. Technology does exist, in theory at least, to automate this process and reduce the number of defects being passed to the customer, but the breakthrough of making it affordable is still to be made. However, final inspection, no matter how efficient or automated, cannot correct faults once they have been introduced. The concept of zero defects continues to be the ultimate goal and is encouraged as a target for all the individual processes along the production chain.

10.3 Fabric performance

Automotive textiles are still in their infancy compared to clothing and there are many developments which could be applied to car interior trim but which the limitations of durability and cost at present rule out. The surface touch of car seats is generally rough and even abrasive compared to the latest 'peach skin' tactile properties of clothing. However fabrics with softer touches made from cellulosic materials such as Tencel would fail abrasion tests by very large margins. The use of cellulosic fibres in polyester blends, in optimized constructions with engineered yarns might lead to abrasion properties approaching automotive standard. If this became possible, the benefits could include improved thermal comfort as well as softer handles.

The garment industry is exploring ways of offering more 'customization', i.e. allowing the customer to choose garments made to exactly the correct size, and produced in his or her own design and colour in any fabric construction. Some analysts believe the success of this is necessary for survival of the garment industry in developed countries. The customers' own designs could be communicated directly to fabric production plants (3-D knitting would be ideal for this concept) or printing plants via the internet. Could this degree of individuality ever become viable in the automotive industry? We have perhaps seen the beginning of this new concept with the launching of a car which has changeable exterior panels – the Swatch/

Mercedes mini car. Also some vehicles such as the multi-purpose vehicle (MPV) now offer the facility of altering the seat layout and even removing seats altogether. This could eventually lead to a replacement seat market which might tolerate slightly lower standards of performance. This would make possible many fabric developments, at present not viable because of the very high standards of durability demanded by the OEMs for car seat fabric, which is fixed in place for the life of the car.

The general feeling, however, is that fabric performance requirements are likely to be raised even higher, especially in the USA. Recent analyses showed that the average car being made now will still be on the road in 17 years' time. Having said this, certain researchers hold the view that some durability requirements are not entirely realistic. For example the abrasion properties required for door casing fabric is frequently the same as the high standard specified for seating. Areas close to door handles certainly need good durability, but some other areas of the door casing are rarely touched.

Throughout the developed world, population patterns are changing and the next century will see significantly higher numbers of retired people who are living longer. Will they want to hold on to their cars for longer – or will some want to change even more frequently because they still have more money to spend? In the USA more pick-up trucks than cars were sold during some years of the late 1990s. These are advertised as robust vehicles and are likely to be treated as such. In addition, in the USA more and more cars are being leased and so the car's private life does not begin until it is sold after perhaps 2 or 3 years. An interior in excellent condition is essential for a good resale value because most people are not mechanically minded. If the interior appears worn and badly maintained they will assume the rest of the car is the same. Changing attitudes, lifestyles and social patterns need to be monitored and studied for possible effects on car interior requirements.

10.4 New developments and opportunities

Increased living standards, larger disposable incomes and higher 'quality of life factors', are likely to create higher expectations of quality and of comfort in all its forms. Softer handle, more thermal comfort – less sweating in hot weather, more effective soil resistance and better cleanability are all opportunities for fabric technologists. Increased hygiene awareness and attitudes could make the last-mentioned factor more of a requirement. Car seat fabric is fixed in place and not thoroughly cleaned during the life of the car; one researcher compared this to not changing our clothes for 40 consecutive days! The problem of odours and air pollution from external sources is being addressed with increased installation of cabin filters using activated carbon. However the public is now also more aware of odours from inside the car, especially in new cars and this is leading to revised manufacturing procedures. The Ford requirement for suppliers to be equipped with an electronic nose could spread to other OEMs. Associated with odour is the possible use of anti-microbial finishes or fibres with permanent built in anti-microbial properties, such as Amicor (Acordis) and Bactekiller (Kanebo). These materials could be especially useful for the car seat fabric and the carpet. More food and drink is being consumed inside cars, especially the MPV – certainly more cup holders are appearing in vehicles – and spillage is likely to become more common. One novel invention which does not appear to have been widely adopted is the odour-absorbing back-coating on car seat fabric – possibly further development is required.[2]

Textiles are already in most areas of the car, but it has been suggested that opportunities still exist for further usage in dashboards, door and seat pockets, seat backs and sunvisors. A new generation of fibres by biological synthesis is likely to appear in the new millennium, which could provide the world with 'super-fibres' with virtually any property or combination of properties required.[3,4] The new methods of polymer synthesis could combine at present seemingly paradoxical properties e.g. softness with high abrasion resistance and significant moisture absorbency, of fibres with improved thermal comfort allied to the durability of polyester. Use could be made of the phase-change temperature-regulating materials to further enhance thermal comfort.

Possibilities do exist for innovation and to offer something new or different – or simply to keep up with the competition. In addition to up-to-date, attractive, novel and imaginative fabric designs are the following desirable properties: higher standards of cleanability; 'lint' resistance; anti-microbial finishes/anti-microbial fibres; better thermal comfort; anti-static properties; softer 'touch' fabrics; easily replaced seat covers; and fewer odours.

10.5 Environmental issues

Public opinion and attitudes have gradually changed over the last decade or so and the effect of human activity on the environment is now taken very seriously. A new generation has grown up educated in environmental issues, the Green Party are in office in the European Parliament and every country has a senior minister responsible for the environment. Companies want to be recognized as environmentally responsible organizations and many are already registered with ISO 14001. Regular world summits are held on the environment and countries are expected to contribute to conservation of world resources and to protect the planet from ecological disasters such as global warming. In Kyoto 1997, the European Union representatives undertook to reduce carbon dioxide emissions over Europe and in turn the EU requested the European automobile industry to play its part. Furthermore, legislation has been passed which will have wide-ranging and significant impact on the automobile industry. Thus the industry is under pressure from all sides, the general public, local, national and EU government to protect the environment. The car however is here to stay but its use could well be restricted by governments of the world in sustainable transport systems.[5] Air pollution apart, there simply will not be enough road to accommodate all future cars.

European OEMs have voluntarily agreed a 25% reduction in car exhaust emissions in new cars by 2008, taking 1995 as the baseline.[6] This will mean an average of 140 g of carbon dioxide emitted per kilometre. Some cars achieving 120 g/km will be available by 2000 and the position will be reviewed to take plans beyond 2008.[7] Zero emissions is the ultimate target for OEMs and very soon Japanese made 'hybrid vehicles', partly electric and partly petrol driven, will appear on the roads in Europe. For some time now, alcohol-powered vehicles and cars running off propane have been used in some countries of the world.

Emission reduction will be achieved by cleaner engines but OEMs are also striving to make cars as light as possible to obtain more mileage per unit of fuel. Fibre composites, competing with aluminium are likely to play a major role here and it is only a matter of time before the problems associated with high volume production of large car panels in composites are resolved. Carbon fibres may even eventually appear in the bodywork and structure of regular production cars, probably first in up-market models. A South African company, Aerotek has developed a racing motorcycle wheel using carbon fabric prepregs, which is about half the weight of a conventional cast wheel.[8] Specially designed composites are contributing to safety by dissipating crash energy more effectively to protect the car occupants. The science of composites is still in its infancy compared with metal processing with over a century of accumulated know-how. Already all-plastic concept car bodies have appeared composed of only several pieces of plastic compared to innumerable pieces of metal.

The EU Directorate making OEMs responsible for the disposal of ELVs, which has just been approved by the European Parliament, will have wide-ranging effects. It will certainly hasten changes in the design of cars specially for recycling because the cost of scrapping an ELV is estimated at about $200 per car.[9] In the UK alone this will amount to £300 million every year.[10] As far as fabric producers are concerned, the landfill restriction aspects loom in the distance and there may not be too much pressure for maybe 2 or more years. Even by 2015, 50 kg of an average car weighing one tonne, can go to landfill, and so in theory all the textile material could be disposed of in this way. However textiles in the car are joined inseparably, to other materials and the whole component, e.g. a headliner weighs much more than the fibre alone. OEMs and the auto industry will expect everyone to contribute and the 5% landfill allowance is likely to be needed for other items which are impossible to dispose of in any other way. Incineration with energy recovery is a possibility but any combustion process inevitably produces carbon dioxide, a global-warming gas.

Ford in 1993 stated that for a part to be considered recycled, it must contain at least 25% recycled material.[11] In the UK, the British Plastics Federation and the Consortium for Automotive Recycling (CARE), have very recently introduced the first generic recyclate standard.[12] The objective is to encourage and promote the use of recycled material in automotives. This first particular standard, relates to a mineral-filled polypropylene, which must contain a minimum of 25% post-consumer-sourced recyclate. Three car makers, Ford, Nissan and BMW have already endorsed it. More recyclate standards are to follow and eventually it is hoped that all car makers will adopt them. There could conceivably be, at some time in the future, a similar standard for recycled textiles. Efforts will continue to find ways of recycling automotive textiles and also to use recycled textiles in the car. In addition, thought will continue to be given to use as few polymers as possible to facilitate dismantling.

More consideration needs to be given to the concept of temporarily joining materials together via some mechanical means, or using a measured amount of adhesion, sufficient to hold components together for the life of the car, but allowing relatively easy separation at the end of the car's life, e.g. the Crea Tech Process. Recently, industry in the USA organized a competition for young designers to produce a car seat which could be easily disassembled for recycling.[13] Meanwhile development continues apace to find more environmentally friendly materials and methods. Biodegradable composites, using natural fibres to replace fibreglass in plastic moulding processes are being researched and these are finding applications in cars.[14] Much positive, useful publicity and public respectability could be gained by the OEM and anyone else associated with a 'green' car.

10.6 Visions of the future – fabric design aspects

The one requirement which can be confidently predicted to continue, will be that of design and styling, particularly of the car interior, to keep pace with the development of trends and exterior body shapes. The contribution which textile products can make to this is considerable as has been demonstrated forcibly over the past decade or so. The question is not whether this will continue but rather what textile technology will be found to be the most suitable and efficient at providing the flexibility, scope, quick response and high performance, etc. over a range of substrates to support future development requirements.

The answer to this question is not clear yet, but there are obvious advantages to be gained by having large stocks of standard fabrics which can be converted into a figured product on a short time scale once the requirement is known. Today, we consider this to be the realm of the jacquard, whether woven or knitted. Printed fabric however, can perform the task better, but until recently all printing was a contact process, which in some way altered, usually for the worse, the fabric aesthetic characteristics and it also required very large throughput to become a competitively viable process. The development of the non-contact ink-jet printing process is changing the whole concept of how printed fabrics can be viewed and for the automotive producer solve many of the previous problems. A study of the process and the advantages it offers are contained in Section 4.3. At least one producer world-wide is making great progress in developing this specifically for automotive applications. All those involved in the business of producing interior trim fabrics should be looking very hard at this as a vision of the future and an opportunity which needs exploiting and refining to better service the OEMs.

10.7 Further visions of the future

Production costs are likely to be driven down even further not only by commercial and technological innovation but also by advancements in communications via the Internet. There is already some purchasing activity using this facility, but the major OEMs are to develop integrated on-line purchasing networks which will create a virtual marketplace for parts, goods and services. Expected purchasing cost savings to the OEM are believed to be up to 20% and suppliers using similar systems could also cut their procurement costs by the same amount.[15]

The car of the future will contain large amounts of composites, possibly carbon fibres, have no heavy glass in it and will be virtually non-polluting. It could be driven by electricity, fuel cell, cleaner petrol or some other fuel, or a combination of these technologies – a 'hybrid'. Electric vehicles may increase the amount of fabric needed for battery separators. A smoother, quieter vehicle is likely to require less vibration- and noise-control material, which could harm the polyurethane industry but could also affect textiles. In the USA, the federal government and the main auto-makers, have formed a Partnership for a New Generation of Vehicles (PNGV). The objective is to redesign the car so it will be three times more economical than the present average medium size car but at the same time have the same performance, same safety features and same ownership costs.[16] The new generation vehicle will be easier to recycle and will weigh substantially less than present cars. This will be made possible by an integrated approach to the redesign of the vehicle, by making use of polymer composites. In the UK there is similar activity via the Foresight Vehicle Programme.

The trend of fewer suppliers will continue and indeed there is likely to be significantly fewer OEMs. Some analysts predict that only six major producers will be operating in the year 2020 compared to the present 20. There could be as few Tier-1 (or 'Tier-0.5) suppliers, and some analysts believe Tier-2 suppliers may disappear altogether – having been bought up by the Tier-1s! Analysts warn however, that this general loss of contact between the OEMs and the smaller companies may be detrimental to innovation.

Production runs will be very large, but at the same time there will be greater choice for the buying public, partly by the use of fewer platforms and even OEMs sharing each others' platforms. There will also be a greater choice of interior trim, maybe by the increased use of printing on to standard base fabrics or by the use of computer-controlled knitting – perhaps involving 3-D knitting. The possibility of customers communicating their own designs via the Internet has already been mentioned.

The plastic manufacturers have joined forces to produce an alternative for glass, which will reduce further the weight of cars. Glass replacement with polycarbonate plastic is likely to alter the spectral distribution of sunlight entering the car and if this is significant it could well modify fibre and material type and dye and pigment choice for the car interior. In addition it may be possible with the use of additives to the polycarbonate to filter out more of the damaging UV rays which would further extend design possibilities. Car interiors are likely to become cooler in any case – at least while occupied – by the widespread use of air-conditioning, which could open further opportunities for the use of different kinds of fabric.

All cars in the not too distant future are likely to have items such as air conditioning, refrigerators and satellite navigation systems fitted as standard. Textile development must keep pace with these levels of luxury and in general match advancements in the quality of life provided by other sectors of industry. It may be possible to automatically provide ideal seat thermal comfort by controlling conditions within the human skin–car seat cover micro-climate as well as providing other aspects of comfort within the car.[17] Already heating can be provided by a textile fibre which is capable of evenly distributing warmth throughout the car.[18]

There are more scientists and technologists alive and working than any other time in the history of the world and they have the benefit of the latest computers and equipment. They can converse with fellow researchers all over the world instantly via the telephone, the fax machine and e-mail. They have access to a wealth of information in all the libraries, databases and via the Internet. As one writer put it 'technology is never going to be as slow as it is today'.

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